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Packaged Reciprocating Compressors

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Introduction

It is necessary that users of this standard be aware that further or differing requirements can be necessary for individual applications. This standard is not intended to inhibit a vendor from offering, or the purchaser from accepting, alternative equipment or engineering solutions for the individual application. This can be particularly appropriate where there is innovative or developing technology. Where an alternative is offered, it is necessary that the vendor identify any variations from this standard and provide details.

Unlike previous editions, which used a bullet (•) at the beginning of a clause or sub-clause to indicate that either a decision is required, or the purchaser is required to provide further information, bullets are not included in this 3rd Edition. Instead, the comprehensive data sheets include provisions for all optional or purchaser specified choices to be indicated.

This standard uses SI units as primary and includes US Customary units in parenthesis.

This document includes significant content originally published in the *GMRC Guideline for High-Speed Reciprocating Compressor Packages for Natural Gas Transmission & Storage Applications*[40] under permission granted by the Gas Machinery Research Council (GMRC).

This specification includes a set of data sheets. However, these data sheets vary considerably from the prior edition. Prior data sheets were used by the purchaser to specify site conditions and required performance and by the packager to communicate the performance details of the offered equipment. They were also capable of being used as a permanent record of the package details. In the decades since the 2nd Edition, much of the numerical information previously filled in manually is now included on outputs from computer applications. These 3rd Edition data sheets make no attempt to duplicate the details available in equipment performance program outputs. In this era of 3-D models and digital twins, there is also no intent for these data sheets to be used as a permanent record. These data sheets are intended to support clear communication of what the purchaser desires and what the packager proposes. The specification sets out minimum standards for scope and calls on the purchaser to specify upgrades or additional scope. At each location in the specification where a purchaser needs to supply information or make a scope decision, that language is extracted and duplicated on the data sheet with the paragraph reference. Space is provided for the purchaser to supply the information or describe the scope preference. Separate space is provided for the packager to confirm compliance, comment or take exception.

This document includes INFORMATIVE Annexes that provide tutorial information, guidelines and best practices for reference in the selection, project management, design, fabrication, site preparation and placement, handling and operation of reciprocating compressor packages.

Annex A contains information on typical project management responsibilities.
Annex B contains information on project sequence and schedule considerations.
Annex C contains guidelines for bid evaluation.
Annex D contains recommended vendor drawing and data.
Annex E contains guidelines for torsional vibration analysis data and testing.
Annex F contains guidelines for preliminary pulsation suppression bottle sizing.
Annex G contains guidelines for compressor package vibration screening and baseline testing.
Annex H contains guidelines for sour and corrosive gases.
Annex I contains guidelines and best practices for enclosed cold weather packages.
Annex J contains best practices for distance piece vents and drains.
Annex K contains guidelines for compressor safety, accessibility and maintainability.
Annex L contains guidelines and best practices for compressor package design and fabrication.
Annex M contains information on compressor package noise avoidance and control.
Annex N contains information on package physical location considerations.
Annex O contains information on package loading, shipping and unloading considerations.

Annex P includes information on package installation and connection considerations.
Annex Q includes information on package start-up and commissioning considerations.
Annex R includes information on compressor capacity control and automation design.
Annex S includes guidelines and best practices for air-cooled heat exchangers.

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To be populated prior to publication.

1 Scope

This standard covers the minimum requirements for packaged reciprocating compressors for oil and gas production services. Compressors covered by this standard are horizontal separable balanced opposed reciprocating compressors suitable for direct coupling to a prime mover. These compressors have pressurized crankcase lubrication, crossheads and double acting, steeple, or tandem cylinders with injected lubrication.

Packages covered by this standard include the compressor, coupling, spark ignited natural gas fueled internal combustion engine or two bearing electric motor prime mover, process and auxiliary coolers, process piping, pressure vessels and auxiliary systems mounted on a fabricated steel base. Packages may also include control panels, isolation valves and capacity control systems.

The standard defines responsibilities for manufacturers of compressors, prime movers, and other components; packagers who select components, design and fabricate packages; and purchasers who define site and operational requirements as well as applicability of other specifications.

It is not the intent of the standard writers to exclude other types of compressors or prime movers, additions or deletions of scope, additional parties or different assignments of responsibilities. The intent is to cover the largest part of the industry. Where other compressor types, prime mover types, different allocations of responsibility or different scopes of supply are considered, it behooves the parties to communicate between themselves what parts of this standard apply, what parts will not apply and what other standards, specifications or mutual agreement will supplement this standard.

Alternative types of compressors that are not addressed in this standard include:

a) Screw or scroll compressors
b) Labyrinth compressors
c) Diaphragm compressors
d) Vertical, “Y” or “W” cylinder arrangements
e) Single acting cylinders with combined pistons and crossheads
f) Pressurized crankcases
g) Splash lubricated crankcases
h) Non-lubricated cylinders

Alternate types of drivers that are not addressed in this standard include:

a) Integral engines – combined prime mover and compressor frame
b) Gas turbines, steam turbines, speed reducing or increasing gears, clutches
c) Diesel engines, dual fuel engines
d) Dual drive with both an engine and an electric motor

While Oil and Gas Production Services is a broad category, it does not encompass specialty services such as:

a) Downstream refinery and petrochemical services – see API 618
b) Any application containing more than 20% hydrogen by volume
c) Food grade gas or air compression
d) Utility air compression

Packaged high speed balanced opposed reciprocating compressors can be successfully applied outside of oil and gas production but these services require additional review not covered in this specification. They also require additional oversight on installation, commissioning and operator training as the familiarity and knowledge base existing in the oil and gas industry should not be assumed for other services.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Recommended Practice RP 686, *Machinery Installation and Installation Design*

API Standard 688, 2nd Edition, *Pulsation and Vibration Control for Positive Displacement Machinery Systems for Petroleum, Chemical, and Natural Gas Industry Services*

ASME Standard B1.1, *Unified Inch Screw Threads (UN, UNR and UNJ Thread Forms)*

ASME Standard B1.20.1, *Pipe Threads, General Purpose, Inch*

ASME Standard B16.5, *Pipe Flanges and Flanged Fittings*

ASME Standard B16.11, *Forged Fittings, Socket-Welding and Threaded*

ASME Standard B16.20, *Metallic Gaskets for Pipe Flanges*

ASME Standard B31.3, *Process Piping*

ASME *Boiler and Pressure Vessel Code (BPVC)*, *Section II, Part D, Appendix A - Metallurgical Phenomena*

ASME *Boiler and Pressure Vessel Code (BPVC)*, *Section VIII: Rules for Construction of Pressure Vessels; Division 1: Rules for Construction of Pressure Vessels*

ASME *Boiler and Pressure Vessel Code (BPVC)*, *Section IX: Welding and Brazing Qualifications*

ASTM Standard A53/A53M, *Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless*

ASTM Standard A193/193M, *Standard Specification for Alloy-Steel and Stainless Steel Bolting for High-Temperature or High Pressure Service and Other Special Purpose Applications*

ASTM Standard A216/216M, *Standard Specification for Steel Castings, Carbon, Suitable for Fusion Welding, for High-Temperature Service*

ASTM Standard A278/278M, *Standard Specification for Gray Iron Castings for Pressure-Containing Parts for Temperatures up to 650°F (350°C)*

ASTM Standard A395/395M, *Standard Specification for Ferritic Ductile Iron Pressure-Retaining Castings for Use at Elevated Temperatures*

ASTM Standard A487/487M, *Standard Specifications for Steel Castings Suitable for Pressure Service*

ASTM Standard A503/503M, *Standard Specification for Ultrasonic Examination of Forged Crankshafts*

ASTM Standard A536, *Standard Specification for Ductile Iron Castings*

ASTM Standard A615/A615M, *Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement*

ASTM Standard A668/668M, Standard Specification for Steel Forgings, Carbon and Alloy, for General Industrial Use

ASTM Standard A703/703M, Standard Specification for Steel Castings, General requirements, for Pressure-Containing Parts

ASTM Standard A781/A781M, *Standard Specification for Castings, Steel and Alloy, Common Requirements, for General Industrial Use*

ISO Standard 8501, *Preparation of Steel Substrates Before Application of Paints and Related Products – Visual Assessment of Surface Cleanliness*

MSS Standard SP6, *Pipe Flanges, Standard Finishes for Contact Faces*

MSS Standard SP 95, *Swage(d) Nipples and Bull Plugs*

MSS Standard SP 97, *Integrally Reinforced Branch Outlet Fittings: Socket Welding, Threaded, and Buttwelding Ends*

NEMA Standard MG 1, *Motor and Generators*

NFPA Standard 70, *National Electrical Code (NEC) Handbook*

3 Terms, Definitions, Acronyms and Abbreviations

3.1 Definitions

3.1.1
aftercooler
AC
Process gas cooler or cooler section after the final stage of compression.

NOTE Also known as discharge cooler.

3.1.2
anchor bolt
A stud, cap screw or other threaded rod used to attach the compressor or prime mover to the skid or to attach the skid to the foundation.

3.1.3
area classification
A designation under any one of several systems, rating the hazard of dust or various gases being present in the atmosphere at a specific location.

3.1.4
blow down valve
BDV
A valve connecting the process gas system, typically after the final stage or aftercooler, to a vent header, flare header or an atmospheric vent.

NOTE The blow down valve can be actuated. It may be part of the emergency shut down system when the package is blocked in with suction and discharge isolation valves and the pressure is bled or vented through the blow down valve.

3.1.5
break out flanges
An additional set of flanges to facilitate fabrication, inspection, assembly or maintenance.

3.1.6
Cat 5e / Cat 6
A performance specification for twisted pair ethernet cables.

3.1.7
choke tube
A pipe of specified inside diameter and length between volumes which reduces the peak-to-peak gas pulsation pressure.

NOTE A choke tube may be internal to a multi chamber pulsation bottle, or it may be in the piping between a suction scrubber and a suction pulsation bottle.

3.1.8
contractor
A general term for any entity supplying primarily services such as engineering services, installation services or compression services.

3.1.9
demister
Inside a scrubber, the component intended to separate fine liquid particles from the flowing gas.

NOTE The most common devices are mesh pads made-up of finely woven stainless steel wire that provide a surface where the liquid particles agglomerate, or vane packs which force the flowing gas to make direction changes separating the liquid particles by inertia.

3.1.10
design pressure
The highest pressure that a component is intended to be exposed.

NOTE Must be lower than the maximum allowable working pressure.

3.1.11
DIN rail
As used in compressor package control and protection panels, a standard mounting system for terminal strips, relays, circuit breakers, fuses, barriers and other components.

3.1.12
downcomer
Inside a demister vessel, a vertical pipe or tube to carry liquid from the liquid collection area in the upper part of the vessel downward to an area below the gas inlet nozzle, ending either above or below the normal liquid level.

3.1.13
electric heat tracing
Electric resistance wire which generates heat preventing liquid freezing or keeping fluids warm inside enclosed tanks and/or piping systems.

3.1.14
emergency shutdown
ESD
A sequence of stopping the compressor under urgent circumstances.

NOTE An emergency shutdown may be triggered by a critical parameter exceeding a preset value, or by a remote signal, or manually with a special switch. An emergency shut down may omit cool down steps such as post lube and it may include activating isolation valves and a blow down valve.

3.1.15
end user
The entity responsible for the operation of the package.

NOTE The end user can be the owner or a contract operator.

3.1.16
flange projection

On a pressure vessel nozzle, the radial distance from the nominal vessel outside diameter to the gasket surface of the flange.

3.1.17
full load amps (or full load current)
FLA
The current draw of an electric motor at the nameplate power, voltage, frequency and power factor.

3.1.18
heat flux density
A measure of the flow of energy per unit area, per unit time.

NOTE Its SI units are Watts per square meter (W/m2). The unit value has both a direction and a magnitude, and so it is a vector quantity. A maximum heat flux density limit generally defines the amount of electric heat energy an immersion heating element can apply to a fluid where it is immersed, without overheating.

3.1.19
immersion heater
An electric resistance element that is immersed below the liquid level of the fluid being heated.

3.1.20
Interlock
A method of preventing an automated function from proceeding without having first satisfied certain conditions.

NOTE This can be accomplished with software logic steps or physical switches or barriers.

3.1.21
interstage cooler
IC or I/C
Process gas cooler section after each stage of compression except the last (see aftercooler).

3.1.22
Lucent connector
LC
A miniaturized fiber-optic plug or receptacle.

3.1.23
maximum allowable working pressure
MAWP
The highest pressure to which a component is allowed to be exposed.

3.1.24
nondestructive examination (or nondestructive testing)
NDE (or NDT)
Any of several methods used to validate a physical parameter of material or a component without causing damage. Examples are radiography, ultrasonic, hydro, dye penetrant, magnetic particle and X-ray fluorescence.

3.1.25

OM1 / OM3
Multimode fiber optic cable specifications.

3.1.26
original equipment manufacturer
OEM
The manufacturer of any discrete component purchased by the packager to be included in the package.

3.1.27
owner
The entity that will hold title to the package.

NOTE The purchaser can be the owner or the purchaser can convey title to the package as part of a complete site installation.

3.1.28
packager
The entity responsible for the design, component purchasing, fabrication and assembly of the compressor package.

NOTE Purchaser documents can refer to this entity as vendor or supplier, but these terms are not used in this context in this document.

3.1.29
paddle type orifice
A plate with a round section sandwiched between flanges and having a handle that extends out past the flanges.

NOTE The plate may have a hole matching the adjoining pipe inside diameter, referred to as “full bore”. It may have a smaller bore selected to create a localized pressure drop for flow measurement or to reduce pressure pulsations while minimizing permanent pressure loss. The bore information and any orientation requirements should be stamped on the handle.

3.1.30
post weld heat treat
PWHT
A process of thermally treating pressure vessels or cooler header boxes after completion of welding to relieve stress induced by welding or otherwise change the properties of the base metal and weld deposits.

NOTE This is typically not applied to cooler tube to tube sheet welds.

3.1.31
provider
An entity providing services or non-OEM goods to the packager.

3.1.32
pulsation bottle
bottle
A pressure vessel designed to reduce the peak-to-peak pressure pulsations.

NOTE May also be referred to as a volume bottle or dampener. Typically mounted on the compressor cylinder inlet and outlet.

3.1.33
purchaser
The entity that issues the order to the packager. The purchaser may be the owner of the equipment or the owner's appointed agent.

3.1.34
reinforcing pad
On a pressure vessel nozzle, an additional circumferential layer welded to both the vessel shell and the nozzle pipe. Often referred to as a re-pad.

3.1.35
self-framing
A common design for small steel buildings where pre-formed exterior wall panels include ribs and do not require an independent framing structure.

3.1.36
settle out pressure
The resulting pressure of the process gas system when the recycle valve is opened without depressurizing the system. In a multistage system, the settle out pressure can be higher than the suction pressure safety valve setting.

NOTE Also referred to as equalization pressure.

3.1.37
single step threaded reducing bushing
A short fitting with a female NPT thread on the inside and an overlapping male NPT thread one size larger on the outside. Typically avoided in pressure service because the overlapping threads create a section of unknown wall thickness.

3.1.38
taper plug
A cooler tube access plug which is tapered.

3.1.39
vendor
Supplier, manufacturer or manufacturer's agent supplying equipment and is normally responsible for service support.

3.2 Acronyms and Abbreviations

ACI	American Concrete Institute
AISI	American Iron and Steel Institute
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASSP	American Society of Safety Professionals
ASTM	American Society for Testing Materials International
AWG	American wire gauge
BMEP	brake mean effective pressure
COG	center of gravity
EFRC	European Forum for Reciprocating Compressors
EPDM	ethylene propylene diene monomer
ESD	emergency shut down
FEA	finite element analysis
ff	filter frequency
GMRC	Gas Machinery Research Council
HAZOP	hazard and operability analysis or study
HRB	Rockwell hardness B
ISA	International Society of Automation
ISO	International Standards Organization
ITP	inspection and test plan
MAWP	maximum allowable working pressure
MDMT	minimum design metal temperature
MSS	Manufacturers Standardization Society
NACE	National Association of **Corrosion** Engineers
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NPS	nominal pipe size
OD	outside diameter

OSHA	U.S. Occupational Safety and Health Administration
PLC	programmable logic controller
P-P	peak-to-peak
pPk OA	pseudo peak overall = RMS OA x √2
PRCI	Pipeline Research Council International
PSV	pressure safety valve
PTFE	polytetrafluoroethylene
PVC	polyvinyl chloride
RFQ	request for quotation
RMS	root-mean-squared at individual frequencies
RMS OA	root-mean-squared overall
RPM	revolutions per minute
RTFE	reinforced polytetrafluoroethylene
SPT	soil penetration test
tPk OA	true peak overall = RMS x crest factor
tP-P OA	true peak-to-peak from a waveform
USCS	Unified Soil Classification System
UPS	uninterruptible power supply
VDDR	vendor drawing and data requirements
VFD	variable frequency drive

4 General

4.1 Units of Measure

The purchaser shall specify whether data, drawings, and dimensions shall be in the U.S. customary (USC) or SI system of measurements.

4.2 Language

The purchaser shall specify any language requirements other than English.

4.3 Emissions

New package installations shall comply with all applicable regulations. Ultimately the responsibility for compliance rests with the site operator. The purchaser shall specify any package content needed to facilitate compliance. Emissions sources during various operating modes to be considered may include:

a) Engine exhaust
b) Engine crankcase vent
c) Engine starter exhaust
d) Compressor packing vents and drains
e) Compressor crankcase vent
f) Blowdown valve
g) Valve actuator vents
h) Controller vents
i) Scrubber drains
j) Blowcase vents
k) Leaks

4.4 Project Management and Scheduling

There are many challenges involved in the specification, design, construction and application of a reciprocating gas compressor package. Good management is fundamental to any successful project, and this is especially true for complex and/or versatile compression applications. In field gas applications, compressor packages may be owned or leased by end users. The Informative project management recommendations or best practices outlined in Annex A and Annex B can be useful for purchases made by either an end user directly or by a rental fleet operator. Careful and objective evaluation of package bids is an important project management step. Since the scope, compliance with specifications, price and lead time of competitive bids generally vary, Annex C discusses a process and bid-evaluation method that may be used for objective review and comparison of bids for reciprocating gas compressor packages.

5 Requirements

5.1 Operating and Site Conditions

The purchaser shall specify the following:

a) Required compressor capacity (operating point and range)
b) Process gas analysis
c) Souders-Brown constant (K) (reference 13.4.14 and Annex L.7)
d) Suction pressure (operating point and range)
e) Suction temperature (operating point and range)
f) Discharge pressure (operating point and range)
g) Process gas aftercooler discharge temperature (minimum and maximum)
h) Driver type
i) Available fuel gas composition, pressure, temperature, and flow rates
j) Available start gas composition, pressure, temperature, and flow rates
k) Preferred cooler type and approach temperature (reference 10.1 and 10.2)
l) Installation site location
m) Installation site elevation
n) Installation site ambient temperature, min and max
o) Minimum design metal temperature (MDMT)
p) Corrosion Allowance
q) Any wind, seismic or snow load requirements
r) Available installation site utilities
s) Electric power available, including source, voltage, phase, frequency, and short circuit current.
t) Media available for starting, instruments and controls; air, process gas or other
u) Available media pressure and flowrate for instruments and controls
v) Desired or preferred capacity control method(s)

w) Package installed in a building?

NOTE The Souders-Brown constant can have a significant impact on the diameter of the scrubber.

5.2 Prime Mover Selection

The type of prime mover (gas engine or electric motor) shall be specified by the purchaser. The prime mover shall be sized to meet the maximum compressor specified operating conditions and shall be in accordance with applicable specifications as stated in the inquiry.

6 Compressor

6.1 Quoted Capacity

The compressor shall be designed to flow the quoted capacity with the stated purchaser defined gas analysis, suction pressures, suction temperatures, discharge pressures and site conditions.

The number of stages of compression shall accommodate pressure limitations and gas additions or withdrawals as set forth by the purchaser. The package design shall also allow for all pressure drops through the scrubbers, pulsation bottles (if any), coolers and piping from the inlet flange to the outlet flange on the skid.

6.2 Performance Calculations

The compressor packager shall use the gas analysis, suction pressures, suction temperature, discharge pressures and site conditions as specified by the purchaser to calculate the compressed gas thermodynamic properties.

6.3 Induction Motor Slip

Compressors driven by induction motors shall be sized at the actual motor operating speed (accounting for slip).

NOTE The difference between the synchronous speed of the electric motor magnetic field, and the shaft rotating speed is “slip”.

6.4 Forces and Couples

The compressor manufacturer shall furnish values for the unbalance primary and secondary forces and couples in the horizontal and vertical planes for the quoted compressor.

6.5 Maximum Allowable Cylinder Discharge Temperature

The compressor manufacturer shall state the maximum allowable discharge temperature. The manufacturer’s maximum allowable discharge temperature shall not be exceeded at any specified operating condition.

The manufacturer shall state the predicted operating discharge temperatures for each specified operating condition.

6.6 Rod Load

6.6.1 Maximum Allowable Rod Load

The maximum operating rod load (gas or combined) over the range of specified operating conditions shall not exceed the compressor manufacturer’s maximum allowable rod load.

The purchaser shall specify any additional limits on the rod load.

6.6.2 Crosshead Pin Load Reversal

The compressor manufacturer shall state the allowable reversing load criteria and limits. The load reversal over the range of specified operating conditions shall be greater than the compressor manufacturer's minimum allowable reversal limit.

6.7 Compressor Frame Nameplate

The frame nameplate shall contain compressor manufacturer's name, serial number, date of manufacture, model, stroke, minimum and maximum rotating speed and maximum allowable rod load.

6.8 Compressor Cylinders

6.8.1 General

Compressor cylinders, including bolting, are pressure retaining parts that should not be altered or modified without the manufacturer's approval.

6.8.2 Compressor Cylinder Nameplate

Nameplates on each compressor cylinder shall include bore diameter, stroke, MAWP, serial number, class/type, and minimum clearances for each end as a percent of the displacement of that end.

6.8.3 Compressor Cylinder Unloader Nameplate

Nameplates on each compressor cylinder unloader shall include the part or model number, serial number, maximum allowable working pressure, pocket volume (for volume pockets), actuator cylinder volume, and the minimum required and maximum allowable actuation pressures.

6.8.4 Cylinder Maximum Allowable Working Pressure

The maximum allowable working pressure of the cylinder shall be higher than the rated discharge pressure by at least 10 percent or 172 kPa (25 psig), whichever is greater.

6.8.5 Cylinder Hydrotest

Each compressor cylinder shall be hydrotested separately with water or solvent by the manufacture at 150% of the maximum allowable working pressure, but not less than 689 kPa (100 psig). The compressor cylinder cooling jackets, if any, shall be hydrotested separately with water or solvent by the manufacturer to at least 517 kPa (75 psig).

6.8.6 Cylinder Orientation

Horizontal cylinders shall have the discharge gas connections on the bottom. Any alternative arrangement shall be approved by the manufacturer.

6.8.7 Cylinder Maintenance

Cylinders shall be spaced and arranged to permit access and removal for normal maintenance of all components (including covers, packing, valves, or unloaders mounted on the cylinder) without removing the cylinder, major piping or pulsation bottles.

6.8.8 Crosshead Guide and Cylinder Supports

6.8.8.1

Crosshead guide supports shall be adjustable and designed to avoid distorting the cylinder, distance piece and frame assemblies or creating excessive rod runout during warm-up and at actual operating temperature.

6.8.8.2

Cylinder supports shall be constructed to allow normal maintenance including cylinder head removal. Cylinder supports shall only be attached to the cylinder as designated by the compressor manufacturer.

6.8.9 Cylinder Bolting

Studded connections shall be furnished with studs installed. Valve cover fasteners shall be long enough to retain the cover until the pressure seal is released.

Bolting shall be furnished as follows:

a) Details of threading shall conform to ASME B1.1.
b) Capscrew or stud material shall be the compressor manufacturer's standard for the specified operating conditions.
c) Adequate clearance should be provided at bolting locations to permit the use of socket or box type wrenches.

6.8.10 Cylinder Gas Connections

Main compressor cylinder inlet and outlet gas connections shall be suitable for the working pressure of the cylinder. Where a cylinder is designed using a non-ASME flange, the manufacturer shall furnish the special (non-ASME B16.5) mating flanges and gaskets. When non-ASME B16.5 flanges are used for the cylinder connection, the manufacturer shall supply a mating blind flange for packager's hydrotest.

NOTE Some low-pressure cylinders require the use of mating flat face flanges with full face gaskets.

6.8.11 Indicator Connections

Each cylinder end shall be provided with a 12 mm (½in.) National Pipe Tapered threads (NPT) threaded and plugged indicator tap connection.

NOTE An indicator tap connection is a hole drilled through the cylinder body into the compression chamber allowing measurement of the pressure in the chamber.

6.8.12 Compressor Valve Selection

The compressor valves shall be selected for operation with the specified gas analysis and operating conditions.

NOTE There can be challenges with selecting valves to cover a wide operating range. This is a topic that requires discussion with the packager and compressor manufacturer.

6.8.13 No Reversible or Interchangeable Compressor Valves

The compressor valves shall be designed such that valve assemblies cannot be inadvertently interchanged or reversed. For example, it shall not be possible to fit a suction valve assembly into a discharge port, nor a discharge valve assembly into a suction port; nor shall it be possible to insert a valve assembly upside down.

6.8.14 Valve Installation

The cylinders shall be tagged to indicate suction and discharge for installation of the valves in the correct locations.

6.8.15 Hollow Pistons

Hollow pistons (single or multi-piece) shall be self-venting.

6.8.16 Piston Wear Bands

Non-metallic wear bands, if required by the manufacturer or specified by the purchaser, shall not overrun valve ports or counter-bores by more than one-half the axial width of the wear band.

6.8.17 Piston Rod Hardness

A surface hardness of Rockwell C50 minimum is required on piston rods in the area that passes through the packing. For piston rods in corrosive gas service, see Section 18.

6.8.18 Piston Rod Threads

Piston rods shall be furnished with rolled threads.

6.8.19 Coated Piston Rods

Unless otherwise specified, coated piston rods are not required . When coated piston rods are furnished, the base and coating materials and application method shall be noted in the proposal.

6.8.20 Crankshafts, Connecting Rods, Bearings, and Crossheads

Crankshafts, bearings, connecting rods and crossheads shall be of the compressor manufacturer's standard material and design.

The crankshaft drive stub should be keyless.

6.9 Distance Pieces

6.9.1

The purchaser shall specify the distance piece type. Distance pieces shall conform to types '0', '1', '2', or '3' (Figures below). Non-conforming arrangements shall be noted in the proposal.

6.9.2

Distance pieces may be single or two compartment, long or short. Two compartment distance pieces are generally used where an additional layer of protection is desired to limit process gas passing into the compressor crankcase. An oil slinger may be provided on long distance pieces to prevent packing lubricants from contaminating the crankcase oil, or to prevent crankcase oil from contaminating non-lubricated cylinders.

NOTE Process gases can contain compounds that are corrosive, toxic, or otherwise incompatible with crankcase lubricants or bearing materials, and the crankcase is generally vented to the atmosphere where it is unsafe to expel those gases. The purpose of the compressor distance piece is to provide an isolated cavity or space in which to collect leaked process gases and injected lubricant from the pressure packings, and prevent these from entering the compressor crankcase.

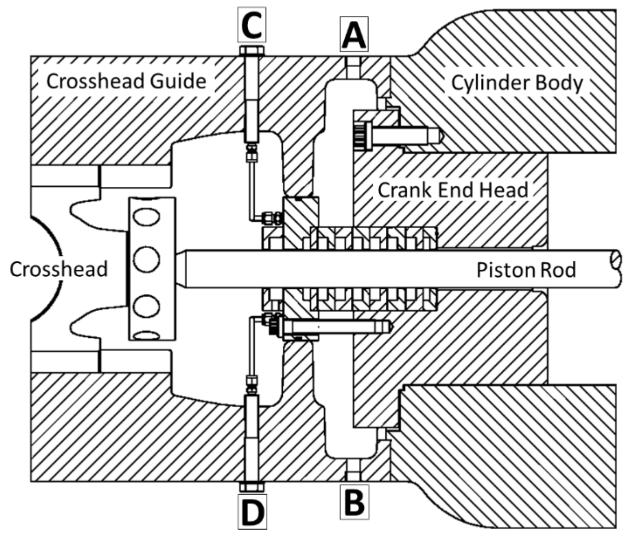


Figure 1 - Type Ø Distance Piece

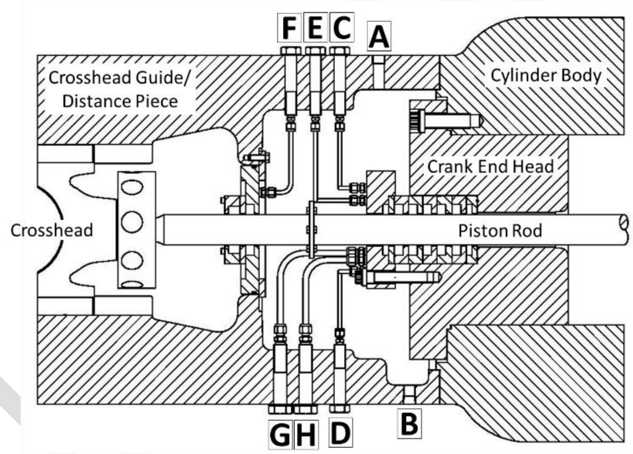


Figure 2 - Type 1 Distance Piece

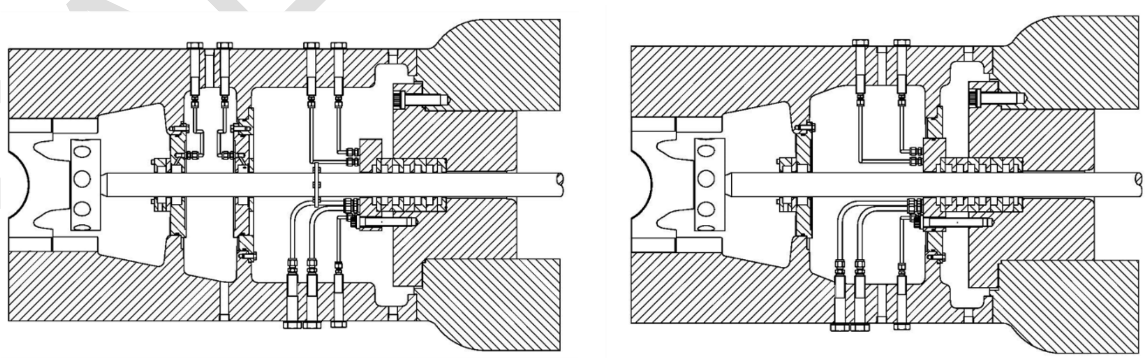


Figure 3 - Type 2 Distance Piece

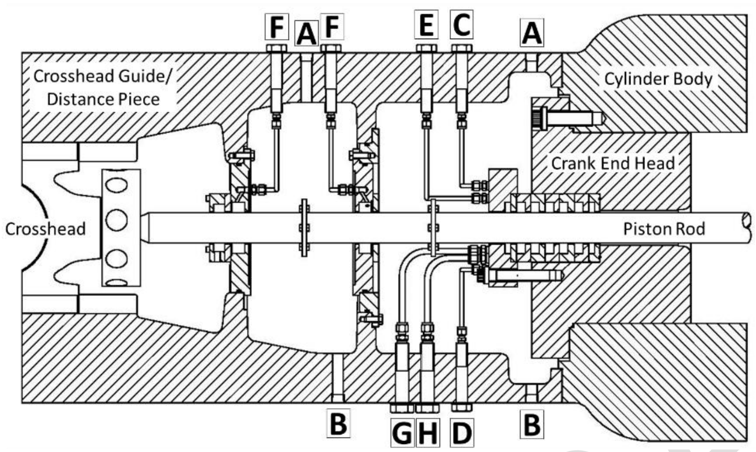


Figure 4 - Type 3 Distance Piece

Table 1 - Distance Piece Connection Legend

Connection	Description
A	Distance piece vent
B	Distance piece drain
C	Piston rod packing lube
D	Packing vent/drain
E	Piston rod packing purge
F	Partition purge
G	Piston rod packing coolant in
H	Piston rod packing coolant out

6.10 Over-Pressure Relief Device

Unless otherwise specified, crankcase over-pressure relief devices are not required.

6.11 Piston Rod Packing and Packing Case

6.11.1 Estimated Pressure Packing Leakage

The compressor manufacturer shall specify estimated gas leakage rates for new and worn pressure packing.

NOTE Actual leakage rates will vary depending on the application, operating conditions and maintenance practices.

6.11.2 Pressure Packing Vent/Drain

Pressure packing cases shall be provided with a common vent and drain below the piston rod tubed to the outside of the distance piece.

6.11.3 Crankcase Oil Wiper Packing

Crankcase oil wiper packing shall be provided to minimize oil leakage from the crankcase.

6.12 Compressor Frame Lubrication System

6.12.1 General

The compressor frame lubrication system shall be pressurized and shall provide adequate lubrication at all rated speeds.

The system shall contain a suction strainer, positive displacement pump, pressure safety valve, full-flow replaceable element filter(s) and inlet and outlet oil pressure gages.

The main oil pump may be driven by the compressor shaft or by an electric motor.

NOTE: Compressors with a maximum speed no higher than 600 rpm may use anti-friction bearings with splash lubrication.

6.12.2 Gauges and Connections

The frame shall have a sight oil level gauge and an oil filling connection.

6.12.3 Filtration

Full-flow filters with replaceable elements shall be furnished consistent with the compressor manufacturer's requirements. Filters shall be located downstream of coolers. Filters shall not be equipped with internal pressure safety valves or bypasses.

6.12.4 Oil System Pressure Regulation

The oil system shall be protected from over pressure with a pressure regulating valve and/or a pressure safety valve integral with or downstream of each positive displacement pump. All components in the system shall have working pressure ratings higher than the regulating valve and/or pressure safety valve set point(s).

6.12.5 Pre-Lube Pump

A pre-lube pump shall be furnished by the packager. The packager shall specify the power source of the pump.

The pre-lube pump shall return upstream of the compressor oil filter and any compressor oil temperature sensors.

Unless otherwise specified, a strainer upstream of the pre-lube pump is not required

The packager shall ensure that the pre-lube pump circuit cannot have reverse flow.

6.12.6 Oil Cooler

An oil cooler is required unless specified otherwise by the compressor manufacturer. The oil cooler shall be upstream of the filter(s).

6.12.7 Thermostats

A thermostat shall be furnished to regulate the compressor oil temperature.

6.12.8 Oil Piping Materials

Piping between the oil filter and the frame shall be stainless steel.

6.12.9 Oil Makeup and Level Control

The packager shall specify the oil type, maximum consumption rate, and minimum and maximum supply pressure and temperature for the compressor frame oil makeup system.

A compressor frame oil level control device shall be furnished by the packager.

If the level controller requires a vent or balance line, that line should be connected to the crankcase vapor space.

Unless otherwise specified, a lubricant storage tank with level gage is not required.

Unless otherwise specified, the storage tank shall have a minimum 30-day capacity.

When a suitable common lubricant is used for compressor, cylinders, and/or driver, a common storage tank may be used. On-skid oil storage tanks shall be mounted high enough to create sufficient head pressure for adequate supply of level controls. Elevated oil storage tanks shall have provisions for filling from ground level.

6.12.10 Fire Safety Valves

Unless otherwise specified by the purchaser, the packager shall provide fire safety valves designed to fail closed and shut off the oil supply from the storage tank and crankcase inlet.

Fire safety valves shall be arranged to prevent loss of containment from the compressor crankcase (below the bullseye level gauge) or from the oil storage tank. Fire safety valve quantity and placement should consider hoses, bullseyes and level gage tubes as potential leak points.

6.12.11 Lube Oil Heater

Unless otherwise specified, a lube oil heater is not required.

Electric oil heaters shall be interlocked with the low oil level switch.

Where used, direct static electric immersion heater elements shall be appropriately sized for the maximum energy density limited by the element size and consistent with the compressor manufacturer's specifications for pre-heating and they shall be protected from overheating by a low-level cut-out switch that interrupts the electrical supply to the element if exposed to air.

6.13 Compressor Cylinder Lubrication

6.13.1 Cylinder Lubrication

A divider block or pump-to-point lubricator system shall be provided for lubrication of compressor cylinder bores and piston rod packing.

The lubricator pump(s) may be crankshaft driven either directly, or via chain or gear, or by an electric motor. Lubricator flow shall be adjustable.

The lubricator system shall be supplied from a filtered source, either gravity feed, pressurized, or from the compressor frame oil system.

The lubricator system may be frame or console mounted.

Individual lubrication points shall be fed with steel tubing and shall be equipped with check valves.

The lubricator pump housing shall be equipped with a level indicator.

When dissimilar oils are used for the crankcase and cylinder lubricator box, the lubricator box overflow shall not be piped to the compressor crankcase to avoid contamination of the frame oil.

The lubricator system shall include a provision for a low flow shutdown.

Divider block systems shall include rupture relief discs or pressure safety valves and visual cycle indicators.

Pump-to-point systems shall include sight indicators for each point.

The lubricator system shall include a line filter

Unless otherwise specified, a lubricant consumption meter is not required

6.13.2 Oil Supply & Oil Level Control

The packager shall specify the oil type, maximum consumption rate, and minimum and maximum supply pressure and temperature for the compressor cylinders.

Lubricator housing oil level control shall be furnished when the pump(s) take supply from the housing.

Unless otherwise specified, a lubricant storage tank with level gauge is not required

Unless otherwise specified, the storage tank shall have a minimum 30-day capacity.

NOTE: When a suitable common lubricant is used for the frame, cylinders, and/or driver, a common storage tank can be used.

On-skid oil storage tanks shall be mounted high enough to create sufficient head pressure for adequate supply of level controls.

Elevated oil storage tanks shall have provisions for filling from ground level.

6.14 Materials

6.14.1 Materials of Construction

Unless otherwise specified, materials of construction shall be the compressor manufacturer's standard for the specified process conditions and shall be stated in the proposal.

6.14.2 Casting and Forging Quality

Castings shall meet ASTM (specifics below) or other applicable quality specifications for the material used. Grade/class shall be specified by the compressor manufacturer.

6.14.3 Casting Standard - Gray Iron

Gray iron castings shall be produced in accordance with ASTM A278.

6.14.4 Casting Standard - Ductile Iron

Ductile iron castings shall be produced in accordance with the ASTM A395 or A536.

7 Spark Ignited Gaseous Fuel Engines

7.1 Rated Brake Power

The gas engine shall be selected for the greatest power required for any of the compressor operating conditions plus accessory power without exceeding the engine manufacturer's site-specific rating criteria for continuous duty service. The engine manufacturer's continuous duty service is defined as the load and speed which can be applied without interruption after taking into consideration the engine performance impact of site conditions of altitude, ambient air temperature, exhaust emissions, and fuel gas composition.

The purchaser shall specify any excess power requirements.

7.2 Operating Speed

The packager shall not apply an engine at an operating speed either greater or less than the manufacturer's recommended continuous duty speed range. The packager shall specify undesirable operating speeds that result from adverse torsional or acoustic outcomes.

7.3 Starting Systems

Electric, air, gas or other starting systems for the engine driver shall be specified by the purchaser. Cranking torque requirements of the driven equipment shall be maintained to within the capabilities of the engine's starting system up to idle speed.

NOTE: Cranking torque reduction strategies might include the use of suction valve unloaders, recycle loop(s), blowdown, etc. Annex L.8 provides additional on compressor starting system guidelines.

7.4 Intake Air Filters

7.4.1 General

Unless otherwise specified, the engine manufacturer's standard intake air filter, suitable for outdoor service, shall be provided. See 14.22 for air intake piping requirements.

Other types of intake air filters shall conform to the following minimum criteria:

a) The micron particle rating and maximum allowable pressure drop shall be as recommended by the engine manufacturer.
b) Site environmental conditions (blowing sand, ice, snow, etc.) shall be taken into consideration.
c) The filter shall be located and oriented to allow maintenance.

7.5 Engine Shutdowns

See Section 16 Protection, Control and Instrumentation

7.6 Engine Ignition Systems

All components shall be of a weather-protected design. Unless otherwise specified, certification of compliance to applicable hazardous locations codes is not required.

7.7 Engine Lubrication System

7.7.1 General

Engines shall be equipped with the engine manufacturer's standard lube oil system unless otherwise specified. Alternative lubrication systems or components, when furnished, shall meet all of the engine manufacturer's requirements.

7.7.2 Pre and Post Lubrication

The engine manufacturer shall specify any pre or post lubrication requirements. The engine manufacturer's provided pre or post lubrication system should be used when available.

7.7.3 Oil Level Control

An engine oil level control device shall be furnished by the packager.

NOTE: If the level controller requires a vent or balance line, that line should be connected to the crankcase vapor space.

7.8 Crankcase Over-Pressure Relief Device

Unless otherwise specified, crankcase over-pressure relief devices are not required to be furnished on the engine crankcase.

8 Electric Motors for Compressor Drive

8.1 Motor Description

The purchaser shall specify the motor description including:

a) Available supply voltage and frequency
b) Starting conditions and method
c) Type of enclosure
d) Area classification including the temperature code rating and gas group
e) Type of insulation
f) Service factor
g) Required accessories such as temperature detectors, vibration sensors, heaters, and instrumentation.

8.2 Rated Brake Power

The motor shall be suitable for the large vibratory torque associated with reciprocating compressors. The motor nameplate power rating at the specified site conditions shall be a minimum of 110% of the power required for any of the specified compressor operating conditions. Unless otherwise specified by the purchaser, the design of the motor shall conform to the NFPA 70 and NEMA MG-1 specifications.

Heavy duty or severe duty motors should be specified for reciprocating compressor drives.

NOTE Motors selected solely based on the mean torque or power requirements will, in most cases, be inadequate as drivers for reciprocating compressors. Heavy duty or similar motors generally have larger shaft diameters, have more robustly designed cooling fans, bearing end bell supports, etc.

8.3 Motor Shaft

The motor shaft shall be keyless and have a minimum ultimate tensile strength of 621 Mpa (90 ksi). Unless approved by torsional analysis, the minimum diameter between the drive-end and the rotor core (including through the drive-end bearing) shall be the same or larger than the compressor crankshaft stub diameter.

8.4 Motor Shaft Grounding

For all medium voltage induction motors, the opposite-drive-end (ODE) bearing shall be insulated to eliminate shaft currents.

Unless otherwise specified, shaft grounding devices are not required.

8.5 Motor Current Variations

The inertia of the combined motor and compressor shall be sufficient to limit motor current variations to 66% of the full load current in accordance with NEMA MG-1.

8.6 Motor Insulation

The insulation shall be corrosion-resistant and non-hygroscopic (a material that does not readily take up moisture). When specified for tropical locations, the insulation material shall be given the following treatments:

a) All parts (such as coils and windings) shall be protected against fungus attack
b) Unpainted ferrous metal surfaces shall be protected against corrosion by plating or other suitable coating.

9 Main Drive Couplings and Guards

9.1 Main Drive Couplings

9.1.1

Unless otherwise specified, the coupling shall be a torsionally rigid, disc-pack type. When specified by the purchase or when required by the torsional vibration analysis and with approval of the purchaser, other coupling types may be used.

9.1.2

The coupling-to-shaft juncture shall be designed and manufactured to be capable of transmitting power at least equal to the power rating of the coupling.

NOTE The coupling flexible element is intended to be the weakest link in the drive system.

9.1.3

Flexible couplings with cylindrical bores shall be mounted with an interference fit or use a tapered clamp arrangement.

9.1.4

Coupling hubs shall be furnished with puller holes to facilitate removal.

9.1.5

The coupling shall be serviceable without moving the compressor or driver.

9.2 Main Drive Guards

9.2.1

Guards shall be provided by the packager and be removable without disturbing the coupled elements and shall meet the requirements of 9.2.2. through 9.2.6.

9.2.2

Coupling and flywheel guards shall enclose the coupling, flywheel, and the shafts to prevent personnel from contacting moving parts or accessing the space between the guard and such moving parts during operation.

9.2.3

Guards shall be constructed with sufficient rigidity to withstand a 900 N (200 lb_f) static point load in any direction without the guard contacting moving parts.

9.2.4 Coupling Guard Materials

Guards shall be constructed of steel, brass, aluminum, or non-metallic (polymer) materials. If specified, non-sparking guards of agreed material shall be supplied. Guards should be fabricated from solid sheet or plate. Guards using expanded metal or perforated sheets may be used if the size of the openings does not exceed 10 mm (0.375 in.).

9.2.5

Guards shall be removable without disassembly of the compressor, piping, instrumentation, or driver. Openings with removable covers shall be provided for a barring device, flywheel locking device, timing mark or magnetic center mark.

9.2.6

Coupling guards shall be designed to prevent excessive heat build-up. When elastomeric couplings are utilized, the coupling guard shall be designed to allow for proper ventilation to prevent excessive heat build-up.

10 Air-Cooled Heat Exchangers

10.1 Air-Cooled Heat Exchanger Configurations

An air-cooled heat exchanger may include multiple tube bundles for the following cooling services: engine cooling, process gas cooling and compressor cooling. Purchaser, packager and air-cooler manufacturer shall agree on the air-cooler configuration. See Table 2 for typical configurations.

Table 2 – Typical Air-Cooled Heat Exchanger Configurations

Config. Ref. No.	Fan Drive	Air Draft	Fan Orientation	Bundle Orientation	Air Intake	Air Discharge
ACHE-1	Engine/Motor	Forced	Vertical	Slanted	Horizontal	Vertical
ACHE-2	Engine/Motor	Induced	Vertical	Vertical	Horizontal	Vertical
ACHE-3	Engine/Motor	Forced	Vertical	Horizontal	Horizontal	Vertical
ACHE-4	Motor	Forced	Horizontal	Horizontal	Vertical	Vertical
ACHE-5	Motor	Induced	Horizontal	Horizontal	Vertical	Vertical
ACHE-6	Engine/Motor	Forced	Vertical	Vertical	Horizontal	Horizontal
ACHE-7	Engine/Motor	Induced	Vertical	Vertical	Horizontal	Horizontal

10.2 Air-cooler Design Parameters

The following air-cooler application design parameters shall be specified by the purchaser and/or packager as a minimum.

NOTE: Annex S provides typical default values that may be used where required design parameters have not been specified.

a) Compressor performance calculations at the specified design conditions - where varying conditions are specified, the extents of the operating range shall be provided, considering suction pressures, discharge pressures, inlet gas temperatures, and gas compositions.
b) Maximum design inlet air temperature at air-cooler

   NOTE Air-cooler air inlet temperatures may be elevated above the maximum ambient air temperature as a result of site conditions.

c) Minimum design inlet air temperature at air-cooler
d) Site altitude (also provided in 5.1 m)
e) Each gas interstage cooler (IC) tube bundle maximum design outlet temperature or maximum design approach temperature

   NOTE Approach temperature is the difference between the ambient temperature and the lowest outlet temperature required from the heat exchanger tube bundle.

f) Final stage gas aftercooler (AC) tube bundle maximum design outlet temperature or maximum design approach temperature
g) Minimum IC and/or AC gas tube bundle outlet temperatures
h) Gas outlet temperature control design (manually actuated louvers, automatic pneumatic or electric actuated louvers, warm air recirculation system, variable speed fan, etc.)
i) Maximum allowable working pressure (MAWP) for gas tube bundle(s)
j) Maximum allowable fan parasitic horsepower for engine-driven fans
k) Fan sound level limits, if specified
l) Fan tip speed limit, where applicable [tip speed is the distance that any selected point on the periphery of the fan travels in a set time in m/sec (ft/min)]
m) Fan air flow draft of forced-draft (fan on cold air-side of tube bundles) or induced-draft (fan on warm air-side of tube bundles)
n) Any specification for gas cooler tube bundle tube materials of construction, where applicable
o) Any specification for gas cooler tube bundle header materials of construction, where applicable
p) Any specification for gas cooler tube bundle header minimum corrosion allowance and/or non-destructive examination (NDE) above ASME Section VIII Division 1 requirements, where applicable
q) Engine and/or compressor coolant type and percentage composition
r) Packager shall specify the process gas tube bundle nozzle locations and/or orientations, when predetermined.
s) Any dimensional limits for transportation and/or installation, where applicable

10.3 Air-Cooler Tube Bundle Design

10.3.1 Performance Condition Range

The air-cooler supplier shall design the air-cooler for the full specified range of performance conditions as defined by purchaser or packager including maximum and minimum gas outlet temperatures for each compressor stage at the defined maximum and minimum inlet air temperatures and site altitude.

10.3.2 Pressure Drops for Gas Tube Bundles

Unless otherwise specified, maximum allowable pressure drops for gas cooler tube bundles shall be as specified in Table 3.

Table 3 – Pressure Drops for Gas Cooler Tube Bundles

Operating Pressure		Pressure Drop, greater of		Pressure Range	
psig	kPag	psi	kPa	psig	kPag
≤30	≤207	5%	5%	≤1.5	≤10
>30 and ≤250	>207 and ≤1724	3% or 1.5	3% or 10	1.5 to 7.5	10 to 52
>250 and ≤750	>1724 and ≤5171	2% or 7.5	2% or 49	7.5 to 15	52 to 103
>750 and ≤1500	>5171 and ≤10,342	1.5% or 15	1.5% or 108	15 to 22.5	103 to 155
>1500	>10,342	1% or 22.5	1% or 157	≥22.5	≥155

10.3.3 Governing Pressure Vessel Code

Governing pressure vessel code shall be the prevailing edition of ASME Boiler and Pressure Vessel Code, Section VIII, Div. 1.

10.3.4 Process Gas Tube Bundle Registration

Purchaser or packager to specify if gas cooler tube bundles shall be registered with the National Board of Boiler and Pressure Vessel Inspectors.

10.3.5 Process Gas Tube Bundle Pressure and Temperature Ratings

Maximum allowable working pressure (MAWP), maximum design metal temperature and minimum design metal temperature (MDMT) of each gas cooler bundle, shall be as follows, unless otherwise specified:

a) MAWP shall be the greater of 10% or 345 kPa (50 psi) above the maximum specified operating pressure
b) Maximum design metal temperature shall be 176.6 °C (350 °F)
c) MDMT shall be -28.8 °C (-20 °F)

10.3.6 Non-Code Tube Bundle Nameplate

Non-code air-cooler tube bundles shall have a nameplate stamped with design information that at minimum includes MAWP, hydrotest pressure, maximum design metal temperature, and MDMT.

10.3.7 Coolant Tube Bundle Thermal Design

Coolant tube bundles shall be thermally rated for engine and/or compressor manufacturer’s equipment design temperatures and at minimum 110% of the engine and/or compressor manufacturer's highest published duty rating for site design conditions, with the engine and/or compressor manufacturer's highest duty tolerance applied and within manufacturer’s allowable pressure drops. Near end header of each coolant tube bundle shall include a plugged high point coupling for vent connection by packager.

10.3.8 Compressor Oil Cooling Tube Bundle Thermal Design

When required, purchaser or packager shall specify if direct air to compressor oil cooling tube bundle is to be installed in the main air-cooler, or if a separate air-cooler for oil cooling service is required. Where direct air to oil cooling service is required, the packager shall specify the oil type and/or properties. Oil cooling tube bundle shall be thermally rated at or less than compressor manufacturer’s maximum design oil operating temperature and at minimum 110% of the compressor manufacturer's highest published duty rating for site design conditions, with the compressor manufacturer's highest duty tolerance applied and within manufacturer’s allowable pressure drops.

10.3.9 Process Gas Tube Bundle Thermal Design

Process gas tube bundles shall be designed for a minimum of 100% of the calculated maximum surface areas including design fouling factor (a thermal design safety factor which accounts for a reduction in heat transfer due to a decrease in cleanliness of the tubes), based on the thermal controlling conditions of the provided compressor operating cases. Calculated surface areas shall include any condensing heat loads, and all inlet gas streams shall be considered as water saturated.

10.3.10 Minimum Fouling Factors

Unless otherwise specified by the purchaser or packager, the minimum fouling factor on tube bundles shall be as specified in Table 4.

Table 4 - Minimum Fouling Factors

Service	Fouling Factor	
	°F·ft²·h/Btu	m²·°K/W
Engine Cooling – glycol mix or demineralized water with inhibitor	0.0005	0.00009
Compressor Lube Oil Cooling	0.001	0.00018
Process Gas Cooling – less than or equal to 0.8 SG with minimal oil particulates (e.g. lubricated reciprocating compressors)	0.001	0.00018
Process Gas Cooling – greater than 0.8 SG or with high oil particulates (e.g. oil-flooded screw compressors)	0.002	0.00035

10.3.11 Gas Tube Bundle Design for Draining of Liquids During Operation

Gas tube bundles should be free draining with outlet nozzles located at the lowest position on upright or horizontal gas tube bundle headers to minimize the accumulation of liquid. When nozzles cannot be located at the lowest position on gas headers, low point drain connections on gas headers may be specified.

10.3.12 Air-Cooler Tube Bundle Test Water Draining

Air-cooler manufacturer and packager shall ensure that air-cooler tube bundles are fully drained of water used for hydrotest and shop run test.

10.3.13 Air-Cooler Tube Bundle Header Access Plugs

Round fin air-cooler tube bundles shall have removable header access plugs at the end of each tube to facilitate tube cleanout and replacement. Gas tube bundles shall use National Pipe Straight (NPS) shoulder plugs with gaskets. Non-code tube bundles may use National Pipe Taper (NPT) plugs.

10.4 Air-Cooler Air Flow System Design

10.4.1 Fan Drive System Support

Fans, shaft bearings, sheaves, electric motors, and gear boxes shall be supported by the air-cooler structure. Belt drives shall be designed to facilitate tensioning adjustment and belt replacement, without removal of the motor or sheave assemblies.

10.4.2 Shaft Bearings

Anti-friction shaft bearings shall have a calculated rating life L_{10} of 50,000 hours at maximum load and speed.

10.4.3 Fan Drive System Safety Guards

Fan guards shall not exceed 51 mm (2 in.) nominal mesh size. The distance from the fan guard to the fan blade at its maximum operating pitch shall be at least 150 mm (6 in.) or six times the smaller of the opening dimensions, whichever is less. Other exterior exposed fan drive system moving parts that require safety guarding shall be by this API 11P standard or by prevailing regulatory requirements, e.g., Occupational Safety and Health Administration (OSHA) standards, unless otherwise specified by purchaser.

10.4.4 Louvers

Manually actuated independent air flow louvers (also known as shutters – a device designed to limit or restrict the air flow by opening or closing blades on the inlet or discharge of the cooler). shall be provided at minimum on the air discharge side of each process gas tube bundle. Purchaser or packager to specify if louvers are manually or automatically controlled with either air or electric actuators and if louvers on cold air-side of tube bundles are required. Purchaser or packager to specify any preference for the elevation of manual louver operators in relation to bottom of air-cooler. Purchaser or packager to specify any preference for auto louver air or electric actuator locations and accessibility requirements. Operating levers for manual louvers shall have blade position indicators for any louvers on which blade position cannot be seen from ground level.

10.4.5 Inlet Screens and Discharge Guards

Unless otherwise specified, inlet screens and/or discharge hail guards are not required. Minimum mesh size is #8 (8 openings per linear inch) for inlet screens, and maximum 19 mm (¾ in.) openings for discharge hail guards. Free open area of screens and guards and resulting increase in air static pressure loss shall be considered in the air-cooler design. Air-cooler manufacturer shall specify the inlet screen method of attachment which shall be readily removable for cleaning and storage.

10.4.6 Belt Drives

Belt drives shall be either conventional V-belts or high-torque type positive-drive belts. V-belt drive systems shall have a minimum service factor of 1.4 based on motor-driver rated power or based on maximum fan power for engine-driven fans for the application. High-torque type positive-drive belt systems shall have a minimum service factor of 1.8 based on motor-driver rated power for the application.

10.4.7 Remote Lubrication Supply Line Connections

Lubrication supply lines for the fan and idler shaft bearings shall be terminated to a location to permit lubrication without stopping the unit and without removing the guards.

10.4.8 Fan Vibration Device

Vibration sensing device shall be installed for each air-cooler fan by the Packager.

10.4.9 Fan Anti-Reverse Rotation Device

Unless otherwise specified, a self-actuating braking device is not required to prevent reverse rotation of an idle motor-driven fan.

10.4.10 Fan Rating Tolerance

Fan rating at design conditions shall ensure that at rated speed the fan can provide, by an increase in blade angle, a 10% increase in air flow with a corresponding air static pressure increase. Since this requirement is to prevent stall and inefficient operation of the fan, it is not necessary that the resulting increased power requirement govern the fan drive system.

10.4.11 Minimized Air Flow

The air-cooler manufacturer should consider the effect on air-cooler performance at the minimum air flow on air-coolers driven by variable speed fan drivers.

10.4.12 Cold Weather Fan Drive System Loading

Air-cooler fan and fan drive system shall be capable of operating within their respective mechanical limits, at the design blade pitch (angle of the fan blades) and speed setting, and at minimum/maximum inlet air temperatures. If a reduced fan blade pitch is required to operate at low inlet air temperatures within the fan drive system mechanical load limits, reduced blade pitch shall be specified, and any limitations clearly stated in the operating information.

10.5 Air-Cooler Electric Motors

10.5.1 Electric Motor Rating

Air-cooler fan drive electric motors shall be three-phase, totally enclosed fan-cooled motors, suitable for continuous duty and designed for a 80 °C (140 °F) temperature rise over 40 °C (104 °F) motor air inlet temperature and 1000 m (3280 ft) altitude at motor nameplate rating exclusive of service factor. For increased air temperature and/or altitude at site conditions, available motor horsepower shall be derated by the motor manufacturer’s guidelines. If the motor manufacturer’s guidelines are not available, see Annex S.5 for typical derate guidelines.

Purchaser or packager shall specify:

a) voltage and frequency
b) applicable motor specification
c) hazardous area classification
d) temperature classification
e) insulation class.

All electric motors for air-cooler fan drives shall be rated for inverter duty. All fan motors shall be suitable for horizontal and vertical operation, either shaft up or shaft down.

10.5.2 Motor Service Factor

Motor design loading at site conditions shall exclude the service factor allowance.

10.5.3 Motor Enclosures

NEMA motors shall be utilized with frames of cast steel or cast iron construction with integrally cast support feet, unless specified otherwise.

10.5.4 Motor Drains

Motors shall be designed to prevent water ingress and have unplugged drains at the lowest point of the motor frame as mounted on the air-cooler.

10.5.5 Motor Space Heaters

Unless otherwise specified, fan motor space heaters are not required. Fan motor space heaters may be wired directly into the main motor junction box.

10.5.6 Motor Bearings

Motors shall have bearings designed for an L_{10} life of at least 40,000 hours under continuous duty at rated load and speed. If the motor is mounted in the shaft-up position, an external conical slinger shall be fitted to the shaft to prevent water from entering the bearing housing along the shaft.

10.5.7 Motor Lift Points

Air-cooler structure shall include lift points above motors heavier than 23 kg (50 lb).

10.6 Air-Cooler General Design

10.6.1 Pipe Supports

Pipe supports shall be attached to the air-cooler structure members and not to sheet metal.

10.6.2 Silencer, Platform, and Surge Tank Mounting Elevation Above Air-Cooler

Placement and support of silencer/converter, platform, surge tank, and other top mounted components shall consider air flow, radiant/exhaust heat, and weight. Inlet and outlet air-cooler air flow shall not be restricted without consulting the air-cooler manufacturer. For engine silencer/converter mounted above air-cooler, radiant and exhaust heat from silencer/converter shall be restricted from warming air-cooler tube bundles and/or inlet air. Consideration shall be given for elevating and/or insulating silencer/converter and extending exhaust discharge pipe. See Annex S.3 for more information.

10.6.3 Site Layout

The purchaser shall consider the site layout of air-coolers basis the site factors that can affect cooler performance. These may include:

a) Prevailing summer wind directions
b) Proximity to enclosures, walls, sloped roof lines and other objects that may restrict or redirect air flow
c) Proximity to heat sources, including other existing or future air-coolers, which may reject heat and reduce the heat transfer performance of the air-cooler
d) Adequate accessibility and personal clearance for maintenance.

NOTE See Annexes N.1.3 and S.4 for more information on cooler orientation and site layout.

11 Skids

11.1 General

The skid (the structural steel base to which the motor or engine, compressor, scrubbers, etc., are bolted, welded, or otherwise secured) and compressor pedestal shall be designed to transmit shaking forces to the foundation and provide adequate structural support under piping and other critical components.

Unless otherwise specified, the skid shall be designed to accommodate the compressor, driver, vessels, piping, cooler, control panel and all other equipment included in a complete compressor package.

The packager's proposal shall specify the skid design and any equipment not mounted on the skid.

11.2 Foundation

The Purchaser shall specify the intended foundation type for the compressor package and any off-skid equipment. The skid and any off-skid equipment shall be designed for compatibility with the specified foundation type.

NOTE: It is important for the purchaser to provide a stable foundation for safe and reliable long term operation of the compressor, driver and other equipment on the package. The preferred type of foundation will vary with the environment and the geological properties of the soil under the foundation. The common types of foundations include compacted caliche or gravel pads, driven piles, reinforced concrete with or without driven piles, and screw piles. Since the foundation is outside the scope of the compressor package, the best practice is for the Purchaser to arrange for a complete dynamic analysis of the skid and foundation. Further guidance and best practices for skid and foundation design can be found in Annex N.2

11.3 Lifting & Transportation

The skid shall have provisions for winching and/or lifting. The package center of gravity shall be located within the lift point locations. During lifting the skid shall have a maximum vertical deflection as defined by Equation 1:

$$D = \frac{L}{360} \tag{1}$$

Where: D is the maximum vertical deflection
L is the distance between the lift points
D and L have the same units

Unless otherwise specified, the packager shall provide pad eyes (reinforced lugs or weldments on the skid where shackles or bolts are inserted to safely lift the package) or trunnions suitable to permit hoisting of the skid. The packager shall provide information such as lift weights, lift dimensions, lift center of gravity, as well as any specific instructions necessary to facilitate the safe handling, loading, off-loading and transport of the equipment. Unless otherwise specified, an engineered lift study and/or lift drawing is not required to be provided by the packager.

Further guidance and best practices for package loading and shipping can be found in Annex O.

11.4 Structural Members

The structural members of the skid shall have sufficient strength and stiffness to prevent permanent deformation and to prevent excess deflection that would damage installed equipment when the skid is moved or installed.

Unless otherwise specified, the skid shall have a minimum of two full-length main runner beams parallel to the crankshaft.

Design and fabrication of the skid shall not compromise the strength of the flanges of load bearing members.

11.5 Mechanical Equipment Mounting

11.5.1 General

Mounting shall conform with the compressor and driver manufacturers' guidelines.

The compressor and driver shall be mounted above full depth, longitudinal and transverse load bearing members. The mounting may be integral to the skid beams, or on a pedestal or pedestals that are welded to the skid beams. Mounting bolt holes shall have clearance to allow longitudinal and transverse adjustment.

Full-depth gussets shall be installed under the compressor and driver mounting points.

Equipment mounting shall provide for vertical adjustment to eliminate soft foot.

Mounting bolting shall be selected to provide sufficient preload to accommodate the dynamic loading. This may include high strength fasteners, hardened steel washers, spherical washers, spring washers or stretch length as a multiple of bolt diameter with through bolting to stirrup plates supported by gussets or through spacer tubes.

Further guidance and best practices for equipment mounting can be found in Annex L.9.

11.5.2 Shims

Shims shall be made of a corrosion resistant material such as stainless steel.

11.5.3 Levelling and Alignment,

11.5.3.1

Mounting plates shall have jackscrews conforming to the following:

a) The compressor parts (such as a crankcase or a crosshead frame) shall be equipped with vertical jackscrews.
b) The feet of the drive equipment shall be equipped with vertical jackscrews.
c) When the drive equipment mass exceeds 450 kg (1000 lb), the drive train mounting plates shall be furnished with horizontal jackscrews (axial and lateral) the same size as, or larger than, the vertical jackscrews. The lugs holding the jackscrews shall be attached to the mounting plates so that they do not interfere with the installation or removal of the drive equipment, jackscrews or shims.
d) Care shall be taken to prevent vertical jackscrews in the equipment feet from damaging the shimming surfaces.
e) Jackscrews shall be treated for rust resistance.
f) Jackscrews shall be supplied for leveling soleplates.
g) The vendor having unit responsibility shall supply all jackscrews.
h) Alternative methods of raising equipment for the removal or insertion of shims or for moving equipment horizontally, such as provision for the use of hydraulic jacks, may be proposed. Such arrangements shall be proposed for equipment that is too heavy to be raised or moved horizontally using jackscrews.

11.5.3.2

Anchor bolts shall not be used to fasten drive train equipment to mounting plates, or to fasten compressors through baseplates or skids.

11.5.3.3

Shim packs, where used, shall be removable. Tapered and step shims shall not be used unless allowed by the equipment manufacturer.

11.5.3.4

Fasteners for attaching the components to the mounting plates shall be supplied by the packager.

11.5.3.5

The drive equipment feet shall be drilled with pilot holes that are accessible for use in final doweling.

11.5.3.6

Unless otherwise specified, epoxy grout shall be used for machines mounted on concrete foundations. The packager shall blast-clean in accordance with ISO 8501, Grade SA2 or SSPC SP6, all grout contact surfaces of the mounting plates and paint those surfaces with inorganic zinc silicate primer in preparation for epoxy grout.

NOTE Inorganic zinc silicate is compatible with epoxy grout, does not exhibit limited life after application (unlike most epoxy primers).

11.5.3.7

Equipment shall be designed for installation in accordance with API 686.

11.6 Anchor Bolt Holes and Levelling Screws

11.6.1 General

Unless otherwise specified the package anchor bolts shall be provided by the purchaser. The packager shall specify the size and location of the anchor bolt holes.

For skids mounted on concrete foundations, leveling screw and anchor bolt holes shall be provided with a minimum of four per each of the four sides and at critical interior anchor locations as determined by the packager. Anchor bolt holes should be located at transverse member locations and accessible for inspection and tightening.

Interior skid anchor bolts, when required, shall be accessible for inspection and maintenance after installation is complete. When deck plate and a perimeter drip lip (an inverted channel around the perimeter of the skid or pedestal, positioned to collect fluid and direct it to a drain) are specified, any interior anchor bolts shall be boxed with a drip lip.

Leveling screws shall be provided in a sufficient number to support the total weight of the skid and installed equipment. Leveling screw hole locations shall be reinforced. Leveling screws shall be of sufficient length to accommodate grouting.

Grout alone shall not be used to anchor any portion of a skid as it cannot provide sufficient tensile strength.

11.6.2 Skid Levelling Plates

Unless otherwise specified, leveling plates are not required. Leveling plates shall be steel plates at least 19 mm (3/4 in.) thick.

NOTE: The GMRC *High-Speed Compressor Package Guideline For Field Gas Applications* provides additional guidance for foundation and package anchor bolt design.

11.7 Deck Plate

Open areas on skids shall be covered with removable grating or 5 mm (3/16 in.) minimum thickness solid raised-pattern deck plate welded in place. Deck plate shall be recessed to be flush with the top of all main beams to prevent a trip hazard. Provisions shall be made for facilitating grout placement, anchor bolts or welding to the foundation. Deck plate is not required for concrete filled compartments. Grating shall be of sufficient load-bearing strength to support personnel.

Where inspection and access ports are provided in the skid deck, covers shall be provided that can be removed and reinstalled as necessary. Skids shall have no open holes that pose a trip or fall hazard.

11.8 Construction

Skids shall be of welded construction. Abutting beams shall be welded on both sides. Flanges of load bearing members shall not be spliced. Contact between webs at perpendicular joints shall be a minimum of two-thirds of the depth of the smallest member. The full-depth beam flanges shall have full penetration welds and the beam webs shall have fillet welds all around.

If any section of the skid is designed to be removed, a bolted joint design with sufficient stiffness is required.

11.9 Skid Drip Edge and Drains

Unless otherwise specified, the skid shall be furnished with a drip-lip adequate for preventing leakage of fluid off the skid and shall be furnished with a 38 mm (1½ in.) NPT or larger drain connection in each corner.

When deck plate and a perimeter drip lip are provided, any penetration shall have a drip lip or be seal welded.

11.10 Grout Access Ports

Unless otherwise specified, grout access ports with covers are not required.

11.11 Crosshead Guide Support

Crosshead guide supports shall comply with the compressor manufacturer's guideline.

Crosshead guide supports shall be welded or bolted directly to full depth skid beams and have sufficient stiffness to prevent excessive vibration.

11.12 Cylinder Head-End Support

The skid and/or foundation shall be designed to accommodate the addition of cylinder head-end supports in the field.

11.13 Scrubber Support

Scrubbers, when skid mounted, shall be supported with full-depth structural members, boxed in and concrete filled. Scrubber supports shall be of adequate stiffness to prevent excessive vibration of the vessel and attached components. See Annex L.7 for scrubber support best practices.

11.14 Discharge Bottle Support

Unless otherwise agreed, skids shall have members located at discharge bottle support locations.

11.15 Pipe Supports

Pipe clamp stands shall be mounted directly on skid beams. Pipe clamp stands shall not be supported on deck plate. See Annex L1.5 and Annex P.10 for pipe support best practices.

11.16 Concrete Fill

Concrete may be added to skid compartments to provide additional mass and damping. Unless otherwise specified by the purchaser, concrete shall be poured into the skid in the packager’s shop. Concrete filled compartments shall have rebar or anchor studs welded to members to provide a mechanical connection to the skid members. If concrete is to be poured onsite, suitable access openings shall be provided. In all cases the skid shall be capable of being lifted with all the required concrete.

11.17 Foundation Design and Construction

The packager shall provide all the individual package weights, the unbalanced forces and moments for the compressor and driver, and the package anchor bolt locations to the purchaser or the foundation designer. The purchaser has the responsibility to ensure the foundation is designed to restrain the static and dynamic loads of the compressor package, while maintaining reasonable soil loading and/or low foundation stresses. Annex N.2 provides additional guidance for determining the foundation requirements and best practices for implementation.

NOTE ACI 351.3R is a useful reference for concrete foundation design.

12 Capacity Control

12.1 General

The packager shall provide a capacity control scheme that allows operation within the purchaser's specified operating range. The packager shall ensure the capacity control scheme does not exceed any manufacturer limit, such as rotating speed, rod load, pin reversal, oil pump capacity, valve events, or other constraint. Additional guidance on capacity control options is provided in Annex R.

12.2 Method of Capacity Control

12.2.1 General

The purchaser shall specify whether the capacity control system is to be manual or automated. The purchaser may specify a preferred capacity control method and control parameters.

NOTE Some manual methods can require unit shutdown and depressurization to effect a change.

12.2.2 Valve Clearance Spacers

Unless otherwise specified by the purchaser, valve clearance spacers are acceptable.

12.2.3 Suction Valve Unloaders

Finger type suction valve unloaders, when used, shall be installed on all suction valves of the cylinder end involved.

12.2.4 Plug-Type Suction Valve Unloader

Where plug-type suction valve unloaders are used, the number of unloaders shall be determined by the manufacturer.

12.2.5 Pneumatic Actuators

Pneumatic actuators shall be suitable for operation with sweet natural gas or air. If air actuated, they shall be designed so that the actuation air cannot be mixed with the gas being compressed even in the event of actuator failure. Sour gas shall not be used for actuation.

13 Pressure Vessels

NOTE The requirements of this Section do not apply to box style air-cooler headers.

13.1 Pressure Vessel Code

13.1.1

Pressure vessels shall be designed and fabricated in accordance with the specified pressure vessel code(s). Unless otherwise specified, the governing pressure vessel code shall be the ASME Boiler and Pressure Vessel Code (BPVC) Section VIII.

NOTE 1 Compressor cylinders are not covered by the ASME BPVC.

NOTE 2 Pulsation bottles constructed using pipe fittings can be considered code pressure vessels in some governing jurisdictions.

13.1.2 National Board Registration

Unless otherwise specified, pressure vessels are not required to be registered with the National Board of Boiler and Pressure Vessel Inspectors.

13.1.3 Wind Loads

Unless otherwise specified, vessels are not required to be designed to withstand a wind load in conformance with ASCE 07.

13.2 Design

13.2.1
The packager shall specify in the proposal, the size and maximum working pressure of all vessels. Unless otherwise specified, the following list provides the design pressure and temperatures of each vessel:

a) Maximum design temperature for discharge vessels shall be 177°C (350 °F)
b) Maximum design temperature for scrubbers and suction vessels shall be 93°C (200°F)
c) Minimum design temperature for all vessels shall be -29°C (-20°F)
d) MAWP for any vessel shall be at least the greater of 10% (gauge) or 345 kPa (50 psi) higher than the highest expected operating pressure for the particular vessel and the system settle out pressure where applicable.
e) All vessels shall be rated for full vacuum.

NOTE : "Full vacuum is a condition where the internal absolute pressure is 0 kPa (0 psi) and the external absolute pressure on the vessel is 103 kPa (15 psi) . If calculation of the vacuum loading case is required, the purchaser typically specifies a maximum allowable external pressure (MAEP) of 103 kPa (15psi).

13.2.2
Purchaser shall specify any requirements for a corrosion allowance (additional metal thickness applied to maintain allowable pressure while compensating for future corrosion) or corrosion-resistant material for pressure vessels.

13.2.3
Minimum wall thickness for vessel and appurtenances shall conform to the following:

a) Minimum shell and head thickness for pressure vessels, excluding corrosion allowance, shall be 13 mm (½ in.).
b) Internal rings, supports, vortex breakers, miscellaneous plates, piping supports, and any other structure internal to the vessel shall have a minimum thickness of 6.4 mm (1/4 in.) excluding the corrosion allowance, unless calculations that support a lesser thickness are approved by the purchaser.
c) Threaded connections inside vessel skirts are not permitted.
d) Couplings shall be attached to the shell by full penetration welds

13.2.4
One-piece, spherical, or 2:1 elliptical heads shall be used.

13.2.5
Vertical vessels shall be designed to avoid mechanical resonance. Unless otherwise specified:

a) Skirt wall thickness shall match the shell thickness unless calculations supporting a lesser thickness are approved by the purchaser.
b) Support legs shall not be used unless approved by the purchaser.
c) The skirt shall have an access opening to accommodate any service or maintenance.
d) When not welded to the skid a minimum of four anchor bolts shall be used.
e) Anchor bolts shall be a minimum 19 mm (3/4 in.) diameter.
f) Flanges and valves shall not be located inside the vessel skirt.

13.2.6
Unless otherwise specified, vessel openings shall conform to the following:

a) Slip-on flanges may only be used with purchaser approval.
b) If used, slip-on flanges shall have full internal and external fillet welds.
c) Blind flange manways shall be complete with bolting, gaskets, davits, or hinges.
d) Nozzle sizes NPS 1¼, 2½, 3½, and 5 shall not be used.

e) All connections larger than NPS 2, shall be of flanged and welded construction.
f) Cast fittings shall not be used for threaded connections.
g) Threaded connections NPS 1 and larger shall have a minimum Class 6000 rating and NPS ¾ and smaller shall have a Class 3000 minimum rating.
h) Flange projection shall be sufficient for maintenance and, where appropriate, insulation.
i) Reinforcing pads, where used, shall be a minimum of 51 mm (2 in.) wide, with a minimum thickness of 9.5 mm (3/8 in.).

Small bore piping connections shall be designed to minimize overhung weight and be adequately supported. See Annex G.3, Annex L1.3, and API 688, 2nd Edition Annex F for additional guidelines.

13.2.7
Piping bends shall not be provided in lieu of elbows or 180 degree return bend fittings.

13.3 Required Documentation
Packager shall supply in the package databook detailed dimensioned drawings and calculations for the pressure vessel design, including components and appurtenances (e.g., thickness of shell, head, skirt, nozzles, etc., reinforcement requirements for nozzles, handholes, manways, inspection openings, and supports).

13.4 Scrubbers

13.4.1
A scrubber shall be furnished immediately upstream of each stage of compression, designed to remove any condensed water or hydrocarbon liquids, or free liquids entrained in the gas stream.

Scrubber(s) may be vertical or horizontal, and unless otherwise specified shall be skid mounted. Scrubbers should be installed as close as practicable to the cylinders, and shall not have pockets or low points in the piping system between the scrubber and the cylinders where liquid can accumulate.

13.4.2
Scrubbers shall be designed for all specified pressure, temperature and flow conditions indicated on the compressor data sheets, including transient conditions such as startup and turndown.

13.4.3
Unless otherwise specified, scrubbers shall not be designed for upstream bulk liquid capacity. Where necessary, separator vessels or slug catchers should be installed upstream of the compressor package.

13.4.4
The design of the scrubber shall include connections for the following: manual drain on the bottom of the vessel, automatic drain, high liquid level sensing, level indication and level control.

13.4.5
The scrubber design shall have sufficient liquid capacity to permit operation for 5 minutes from the normal liquid level to the high level shutdown, based upon the maximum design flow plus the calculated maximum liquid slug volume taken from the compressor package piping system and coolers.

The scrubber drain valve control system should be considered so the drain valve cycle time is within the manufacturer's stated maximum number of cycles.

13.4.6
Scrubbers shall be furnished with internal demister elements, i.e. wire mesh pad, vane, coalescing filter media, cyclonic or combination elements. The Packager shall specify the demister type used for each scrubber.

13.4.7
Orientation of nozzles shall be arranged to ensure that the inlet stream is not deflected toward the outlet of the vessel or the liquid collection area. Outlet nozzles should have adequate disengagement distance from the demister surface (see Figure 5).

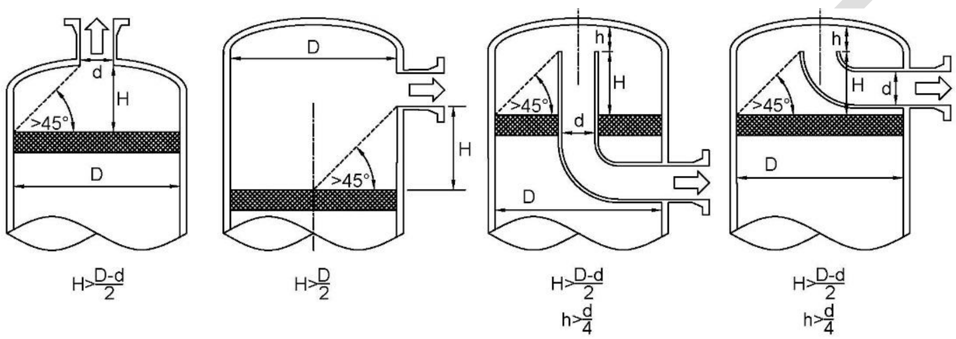


Figure 5 – Outlet Nozzle Disengagement Distance

13.4.8
Compressor scrubbers shall not have any direct path for accumulated bulk liquid to bypass the demister and re-enter the outlet section of the vessel. Where used, liquid downcomer pipes shall terminate above the high liquid level and be fitted with a liquid trap.

13.4.9
Provision shall be made to keep internal floats or displacers out of high gas velocity areas.

13.4.10
Mist extraction devices shall be stainless steel or other corrosion resistant material appropriate for the service.

13.4.11
Mesh type mist extractors, when furnished, shall be constrained on both the upstream and downstream sides of the mesh.

13.4.12
Mesh pads or demister devices shall be fixed (non-removable).

13.4.13
Unless otherwise specified, mesh pads shall have a minimum thickness of 102 mm (4 in.) and a minimum mesh density of 144 kg/m^3 (9 lb/ft^3).

13.4.14
The recommended minimum vertical scrubber internal diameter ($\boldsymbol{D}$) is calculated using the Souders-Brown constant ($\boldsymbol{K}$) as follows in Equation 2:

In SI units:

$$D = \sqrt{\frac{Q_a \times 10^4}{V_a \times 0.7854}} \qquad (2)$$

In USC units:

$$D = \sqrt{\frac{Q_a \times 144}{V_a \times 0.7854}} \qquad (2)$$

Where the maximum allowable gas velocity through scrubber (V_a) is calculated by Equation 3;

$$V_a = K\sqrt{\frac{d_l - d_g}{d_g}} \qquad (3)$$

Where:

- V_a = maximum allowable gas velocity through scrubber in m/sec (ft/sec)
- d_l = density of liquid at operating conditions kg/m^3 (lb/ft^3)
- d_g = density of gas at operating conditions kg/m^3 (lb/ft^3)
- K = Souders-Brown scrubber constant m/sec (ft/sec)
- Q_a = gas actual volume flow rate at operating conditions m^3/sec (ft^3/sec)
- D = minimum inside diameter of scrubber cm (in.)

The suggested K-values for vertical scrubbers with a horizontal mesh pad or horizontal vane demister are as follows:

a) K of 0.055 m/sec (0.18 ft/sec) results in a scrubber diameter that is typically used for inlet scrubbers or wet gas applications.
b) K of 0.076 m/sec (0.25 ft/sec) results in a scrubber diameter typically used only for interstage scrubbers without side streams.
c) K of 0.107 m/sec (0.35 ft/sec) results in a scrubber diameter typically used only for dry gas applications.

The suggested maximum K-value for a vertical scrubber diameter using a vertical vane demister is 0.213 m/sec (0.60 ft/sec).

13.4.15
The maximum pressure drop across each scrubber shall be considered in the compressor performance calculations. When specified the packager shall provide scrubber process design calculations for the purchaser's review and approval.

13.4.16
The pulsation analysis should consider all levels of liquid in the scrubber.

13.5 Pulsation Bottles

13.5.1
Unless otherwise specified, pulsation bottle cylinder connection nozzles are not required to be fabricated using long weld neck flanges.

13.5.2
Unless otherwise specified by a mechanical analysis or the purchaser, all weld neck or long weld neck bottle nozzles shall have reinforcing pads which shall extend a minimum of 51 mm (2 in.) radially beyond the nozzle.

13.5.3
Reinforcing pads shall be the same thickness as the shell up to 19 mm (¾ in.). Reinforcing pads shall be welded with fillet welds equal to the thickness of the pad. The reinforcing pads shall have a vent hole.

13.5.4
Internal baffles shall have a minimum thickness of 13 mm (0.5 in.).

13.5.5
Unless otherwise agreed by the purchaser, baffles shall be cut from a spherical or 2:1 elliptical head.

13.5.6
Continuous welds shall be used for attachment of the baffles to the shell and choke tubes.

13.5.7
Threaded connections shall be ASME B16.11 Class 6000.

13.5.8
Unless otherwise specified, test ports are not required. The number, size and location of test ports shall be as specified by the Purchaser.

13.5.9
Drains should be 19 mm (¾ in.) diameter minimum, easily accessible, plugged and located in each separate bottle chamber.

13.5.10
Internal projections of cylinder nozzles on suction bottles shall be slotted, notched or drilled on both sides to prevent accumulation of liquid.

13.5.11
Unless specified by the pulsation study, when pulsation bottles are not used, the minimum piping diameter to and/or from the compressor cylinders shall be at least equal to the diameter of the compressor cylinder flanges.

13.5.12
When pulsation bottles are used, the piping between the pulsation bottles and the cylinder shall be at least equal to the diameter of the compressor cylinder flanges.

13.5.13
Unless otherwise specified, vessels are not required to be designed to accommodate insulation and/or guarding of hot metal surfaces.

13.5.14
Unless otherwise specified, lifting eyes are not required on pulsation bottles.

13.5.15
The forces and moments at cylinder connections at both ambient and operating temperature, including effects of thermal expansion and the weight of pulsation bottles, piping and other appurtenances, shall not exceed the manufacturer's allowable limits

13.5.16
Pulsation bottle flanges should align with cylinder flanges. Prying to align flange bolt holes or "drawing down" to pull piping into position is unacceptable. Before torquing, flange bolts should thread by hand with no flange contact. Flange gap without torque should not exceed 0.76 mm (0.030 in.) for one gasket or 1.52 mm (0.060 in.) for two gaskets with an orifice.

13.6 Welding and Fabrication

13.6.1
Unless otherwise specified, threaded connections shall not be seal welded.

13.6.2
Permanent backing rings for welding shall not be used.

13.6.3
Forged threaded fittings may be chased after welding.

13.6.4
Unless otherwise determined by the pulsation study, choke tube support tabs shall be 13 mm (1/2 in.) minimum thickness.

13.6.5
The choke tubes including supports shall be designed and fabricated to avoid failure during operation.

13.6.6
Pulsation bottle internal choke tubes should be located such that they will not impede flow to or from the compressor cylinders.

13.6.7
Unless otherwise specified, pulsation bottles are not required to be stress relieved when not required by the applicable pressure vessel code.

Annex L.10 provides additional guidance and best practices for pulsation bottles design and fabrication.

14 Piping and Appurtenances

14.1 Code
Unless otherwise specified, gas piping design, fabrication, inspection, and testing shall be in accordance with ASME B31.3. Unless otherwise specified, process gas, fuel and starting gas piping systems shall be seamless carbon steel or seamless stainless steel designed and fabricated in accordance with the agreed governing code. Service pressure and temperature requirements shall be specified by the purchaser, or by the packager in the quotation.

14.2 Design
The piping system should be designed following industry best practices. Refer to Annexes I, J, K and L for additional system piping guidelines and best practices. .

The piping system shall not obstruct any access opening or any routine maintenance location. Break-out flanges or unions should be included to facilitate disassembly for transportation and serviceability.

With the exceptions of mating flanges to compressor cylinder process gas connections or internal pulsation bottle choke tubes; connections, pipe, valves and fittings of 32 mm, 64 mm, 89 mm, 127 mm, 178 mm or 229 mm (1¼ in., 2½ in., 3½ in., 5 in., 7 in. or 9 in.) shall not be used.

High point vents shall be provided in liquid piping.

Plugged low-point drains shall be provided.

NOTE: Unsupported low point drain valves are subject to failure in vibrating service.

14.3 Flanges

The requirements of this Section do not apply to compressor, compressor cylinder and engine mating flanges.

Flanges shall be in accordance with ASME B16.5.

Unless otherwise specified, raised face weld-neck flanges shall be used for ASME Class 150 through Class 900 flanges. Ring type joints shall be used for ASME class 1500 and or higher.

Spiral wound metallic gaskets with centering rings in accordance with ASME B16.20 shall be used on all raised face flanges used in process gas piping.

When mating flanges are dissimilar metals, dielectric gaskets should be used.

Unless otherwise specified, all flanged connections shall have ASTM A-193, Grade B7 studs with ASTM A-194, Grade 2H hex nuts. Studs shall have full continuous threads and shall extend a minimum of two full threads outside each nut.

Where mating parts such as studs and nuts of austenitic stainless steel or material with similar galling tendencies are used, they shall be lubricated with an anti-seizure compound of the proper temperature specification and compatible with the specified process fluids.

Unless otherwise specified, no special coating is required for studs and nuts.

Bolt holes for flanged connections shall straddle lines parallel to the main horizontal or vertical centerlines of the equipment (two-hole positioning).

Unless otherwise specified, slip-on flanges shall not be used. Slip-on flanges, when used, shall be installed with full internal and external fillet welds.

Each orifice shall be paddle-type with the orifice bore diameter stamped on the handle.

14.4 Pipe Fittings

Fittings shall be Class 3000 minimum forged steel fittings that meet an applicable industry standard.

NOTE Typical standards include ASME B16.11 and MSS SP-97.

Threaded pipe plugs, including temporary shipping plugs, shall be solid steel, long-shank or hex-head plugs.

Malleable fittings shall not be used.

Socket weld piping over NPS 2 shall not be used in process or fuel gas piping.

Street elbows shall not be used in process or fuel gas piping.

Single step threaded reducing bushings shall not be used in process or fuel gas piping.

14.5 Threaded Joints

Pipe threads shall be taper threads, designed and installed in accordance with ASME B1.20.1.

Threaded joints shall not be used on piping larger than NPS 2.

The use of threaded connections in the process gas system should be minimized.

Threaded pipe nipples shall be schedule 160 minimum. All-thread nipples shall not be used.

Threads shall be coated with a non-locking pipe thread sealant. PTFE tape shall not be applied to threads of plugs inserted into oil passages.

Unless otherwise specified, threaded piping joints shall not be seal welded.

14.6 Flexible Hoses

Unless otherwise specified, hose shall not be used for process gas.

When used, flexible hose shall be suitable for the service and selected and installed according to the hose manufacturer's specified pressure and temperature service ratings and minimum bend radius.

NOTE: When hoses are used in oil make up service, the hose can be an issue in a fire. The addition of fire safe valves can provide additional safety.

14.7 Tubing and Fittings

Unless otherwise specified 300 series seamless stainless-steel tubing shall be used as a minimum.

Unless otherwise specified by the purchaser, carbon steel fittings may be used. Cast fittings shall not be used. Make and model of fittings shall be specified by the packager.

Tubing fittings shall use double ferrules.

All fittings on a package not supplied by a major component manufacturer shall be from the same tubing fitting manufacturer.

Fittings should be assembled to the fitting manufacturer's go/no-go gauge.

Tubing should be properly supported, protected, and routed in a clean, orderly manner to prevent damage from vibration and from personnel during normal operating and maintenance activities.

The tubing shall be suitable for the required pressure and temperature. To provide for mechanical strength and vibration resistance, tubing wall thickness shall not be less than the values listed in Table 6.

Table 6 - Tubing Wall Thickness versus Tubing Outside Diameter (O.D.)

Tubing O.D. mm (in.)	**Wall Thickness mm (in.)**
6.4 (¼)	0.89 (0.035)
9.5 (3/8)	1.24 (0.049)
12.7 (½)	1.65 (0.065)
19.0 (¾)	2.41 (0.095)
25.4 (1)	2.77 (0.109)

Working pressure for various tubing outside diameters and wall thicknesses are provided (in USC units only) for reference in Table 7.

Table 7 - Tubing Working Pressure, psig

MAWP of 304/316 Stainless Steel Tubing												
Tube OD	**Tube Wall Thickness (inch)**											
(inch)	**0.010**	**0.012**	**0.016**	**0.020**	**0.028**	**0.035**	**0.049**	**0.065**	**0.083**	**0.095**	**0.109**	**0.120**
1/16	5,600	6,830	9,280	11,620		-	-	-	-	-	-	-
1/8	-	-	-	-	8,420	10,640	-	-	-	-	-	-
3/16	-	-	-	-	5,480	7,010	10,060	-	-	-	-	-
1/4	-	-	-	-	4,030	5,140	7,450	10,080	-	-	-	-
5/16	-	-	-	-	-	4,050	5,860	7,980	-	-	-	-
3/8	-	-	-	-	-	3,340	4,800	6,570	-	-	-	-
1/2	-	-	-	-	-	2,470	3,530	4,790	6,290	-	-	-
5/8	-	-	-	-	-	2,080	2,960	4,010	5,240	6,090	-	-
3/4	-	-	-	-	-	-	2,450	3,300	4,290	4,980	5,800	-
7/8	-	-	-	-	-	-	2,080	2,800	3,640	4,210	4,890	-
1	-	-	-	-	-	-	1,810	2,440	3,160	3,650	4,230	4,700

NOTES

1. ASTM A269 or equivalent TP304 and TP316 fully annealed seamless tubing, 90 HRB maximum. 20 ksi basic allowable stress between 20°F and 300°F per ASME B31.3 201
2. Outer diameter used in pressure design calculations assumes maximum +0.005 in. manufacturing tolerance
3. Wall thickness used in pressure design calculations assumes -15% manufacturing tolerance for tubing sizes ½ in. and smaller, -10% manufacturing tolerance for tubing sizes larger than ½ in.
4. No mechanical allowances are accounted for in pressure design calculations (corrosion, bend thinning, etc.)
5. Tube fittings are pressure-rated by the manufacturer and may govern the MAWP of the system

14.8 Valves

Valves shall be suitable for the service and selected and installed according to the manufacturer's specified pressure, temperature and service rating.

Unless otherwise specified:

a) All valves shall be steel or stainless steel bodies with stainless steel trim.
b) Isolation valves on main process flow lines shall match the line size and be full port, with the exception that isolation valves around control valves may match the control valve size.
c) Ball valves over NPS 8 shall be trunnion style valves.
d) Manual ball valves over NPS 12 shall have gear operators. Gear operators should be considered for smaller high pressure manual ball valves.
e) Quarter turn manual actuator levers shall be unobstructed through the entire range of motion.
f) The packager shall indicate if and where lug valves or wafer valves will be supplied.

g) Discharge check valves shall be suitable for pulsating service.

Unless otherwise specified, double block and bleed valves are not required.

The purchaser shall specify any requirements for fire safe valves in addition to the requirements of 6.12.10. See Annex K.12 for additional guidance.

14.9 Pressure Safety Valves

14.9.1 General

There are too many possible configurations of packaged compressors and installations for this specification to be exhaustive. The goal of the following clauses is to ensure that the purchaser and packager have clear areas of responsibility and scope of supply with respect to over pressure protection, and, that the implementation of the over pressure protection takes into account the unique challenges and requirements of a reciprocating compressor package. The purchaser is responsible to review the installed compressor pressure system to ensure a reliable and adequate overpressure safety system that is compliant with all prevailing statutory codes and standards, for both on-skid and off-skid pressure equipment.

NOTE Refer to API Standards 520 Parts 1 and 2, and 521 for additional information.

The packager shall provide a list of all overpressure protection devices being provided in the packager's scope of supply.

The purchaser and packager should cooperate on the selection and sizing of all pressure safety valves. Unless otherwise specified, the packager shall provide a pressure safety valve downstream of each stage sized for 100% blocked flow, and a pressure safety valve on the inlet scrubber sized for a fire case, where the MAWP is lower than the first stage discharge MAWP.

NOTE: The compressor package may not include all required overpressure protection within its own boundary limits. The purchaser may need to consider off-skid piping and vessels in conjunction with the compressor package, to ensure a safe and reliable system that complies with all necessary codes and standards.

All pressure safety valve manufacturer datasheets shall be provided to the purchaser.

14.9.2 Sizing Basis / Set Pressures

14.9.2.1 General

Relief devices shall comply with the governing pressure vessel code, and their sizing and set point shall take into consideration all possible types of package equipment failure.

Unless otherwise specified, no additional pressure relief capacity is required.

Unless otherwise specified, the packager shall determine the size and the set pressure of all on-skid relief devices. Appropriate margin between operating and set pressure should be considered.

NOTE: While the required set-points are reflective of the MAWP of the system, it is important to be aware of the entire process operating envelope including recycle, upset conditions, and settle-out conditions, as well as the effect of pressure pulsation and line losses when evaluating set pressures. There may be occasions when a different style of relief device or an adjustment to the MAWP of a system is necessary to maintain sufficient separation between the maximum pressures seen by a system and the setpoint to prevent unwanted relief through a device.

Typical sizing bases can include, but are not limited to:

a) Blocked flow from the compressor
b) Vapor generation / fire case
c) Upstream control valve / regulator failure
d) Recycle valve failure
e) Leakage past a check valve

14.9.2.2 Blocked Flow Pressure Safety Valve Sizing

The capacity of pressure safety valves shall equal or exceed the maximum capacity of the compressor stage at:

a) maximum design speed
b) 110% of driver available power
c) minimum fixed clearance
d) the highest potential suction pressure
e) a discharge pressure equal to the pressure safety valve set point

14.9.2.3 Account for Back Pressure

If the relief devices vent to the purchaser's flare or vent header, the purchaser shall specify the maximum back pressure at the skid edge connection.

14.9.2.4 Flanged Pressure Safety Valves

Unless otherwise specified, pressure safety valves are not required to be flanged.

14.10 Heat Tracing

Unless otherwise specified, piping, vessels and instrumentation are not required to be designed to accommodate heat tracing and insulation.

14.11 Insulation and/or Guarding

Unless otherwise specified, insulation and/or guarding of hot piping surfaces is not provided.

14.12 Start-Up Screens

Unless otherwise specified, the packager shall install removable basket or cone type screens upstream of each suction pulsation bottle to prevent debris from entering the compressor cylinder(s).

A differential pressure gauge shall be installed to indicate the pressure drop across each start-up screen.

All piping and/or vessels downstream of the screen(s) shall be internally cleaned by mechanical or chemical means prior to assembly.

Unless otherwise specified by the purchaser or required by the compressor manufacturer, removable start up screens shall be minimum 150% flow area with #40 316 stainless wire mesh over steel cone/basket frame. A stainless steel frame should be used for sour or corrosive gas service.

Start-up screen(s) shall be installed in a removable spool piece(s) to facilitate removal and cleaning of the screen(s). Provision should be made for instrument pressure taps both upstream and downstream of screen(s).

14.13 Supports and Bracing

14.13.1 General

Piping systems furnished by the packager shall be properly supported to prevent damage from vibration or from shipment, operations or maintenance.

All process gas piping shall be supported using pipe clamps. Clamps should include non-metallic liners that prevent metal-to-metal contact.

All utility piping NPS 2 and larger shall be supported using pipe clamps.

U-bolts shall not be used as pipe supports on any process gas piping or any other piping NPS 2 and larger.

Pipe supports shall be welded directly to structural members, not to deck plate.

Connections shall be designed to minimize overhung weight to avoid failure due to vibration.

NOTE 1 Small bore connections are especially susceptible to failure, but they are not included in a typical design study. See Annex G.3, Annex L.1.3 and API 688, 2nd Edition, Annex F for small bore piping guidelines.

NOTE 2: Pressure safety valve mounting can introduce concerns about failure and loss of containment due to a lack of proper support. Refer to Annex L.4 and API 688, 2nd Edition, Annexes A3.9 and F for guidelines and best practices for pressure safety valve mounting.

Supports and bracing may be secured to pipe by clamping, but they shall not be welded directly to piping.

NOTE 3: Flange gussets are an exception to this clause. See Figure 6.

NOTE 4: Some government regulations may preclude the use of supports welded directly to process piping, for example 49 CFR § 192.161.

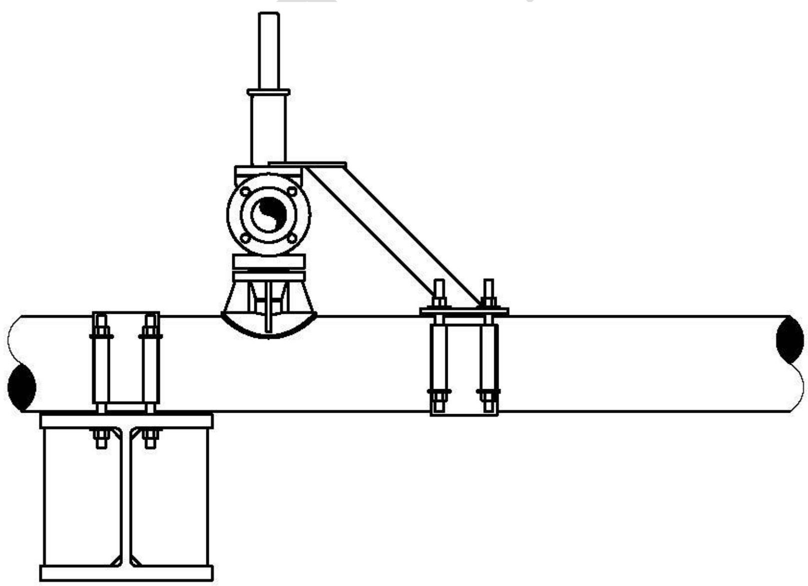


Figure 6 – Example of Clamped Pipe Support and Welded Flange Gussets With Repad

14.13.2 Vibration and Relief Loads

Vibration, relief event reaction loads and thermal growth shall be considered in the design of the mounting of pressure relief devices.

Pressure relief devices shall be mounted and braced securely so that the weight of the valve and associated piping, normal vibration and forces applied during operation (e.g., a relief event) do not overstress the pressure safety valve's connection.

Where tubing is supported to vessels, piping or machinery, it shall be securely affixed with isolators or support clips to prevent direct contact and abrading.

14.14 Piping Systems

14.14.1 General

The packager shall furnish all piping systems, including mounted appurtenances, for all equipment mounted on the skid.

Piping systems may include piping, isolating valves, control valves, pressure safety valves, pressure reducers, orifices, thermowells, sight flow-indicators, and all related vents and drains.

Purchaser and packager shall agree on packager's scope of off skid or interconnecting piping and field welds.

The packager's proposal shall state the piping scope of supply.

In addition to the requirements of this Section, Annex L.1 provides guidance and best practices for auxiliary systems and piping.

14.14.2 Piping Connections

14.14.2.1 General

Piping for connections to the purchaser's system shall terminate with flanged or threaded union connections at the edge of the skid or to a readily accessible location agreed to by the purchaser.

All purchaser connections shall be defined by the packager and provided to the purchaser.

14.14.2.2 Driver Connections

All connections to the driver shall incorporate sufficient flexibility to accommodate movement for coupling alignment and to prevent stress in the connection or in the piping.

14.14.2.3 Companion Flanges

Unless otherwise specified, companion flanges shall not be provided.

14.15 Process Piping System

The purchaser shall specify the extent of the process gas piping, valves, instrument connections and the package isolation strategy.

The process piping design pressures and temperatures shall be adequate for all specified operating and shutdown conditions without relieving though a pressure safety device.

Unless otherwise specified, the packager's process piping scope shall start at the scrubber inlet flange, include all interstage piping and end at the aftercooler outlet flange.

Full port isolation valves are required to be installed upstream and downstream of the compressor package. Unless otherwise specified, full port isolation valves are not provided by the packager.

A piston type check valve is required to be located downstream of the package and upstream of the isolation valve as close as possible to the compressor. Unless otherwise specified, the packager is not required to provide this check valve.

The purchaser may specify additional scope including, but not limited to:

a) Pressurization valve
b) Automated package isolation valves
c) Suction pressure control valve
d) Individual component isolation valves
e) Side stream connections and valving
f) Purge valves

14.16 Pressure Safety Valve Piping System

The purchaser shall specify the extent of pressure safety valve piping, valves and other components to be included with the package.

Unless otherwise specified, the packager's scope shall include a pressure safety valve on the discharge of each compressor stage piped individually to skid edge or to safe location(s) on the package.

The inlet piping diameter for any pressure safety valve shall not be smaller than the pressure safety valve inlet connection.

Unless otherwise specified, relief devices are not required to be installed on piping with the use of a tee.

The outlet piping for any pressure safety valve shall not limit the capacity of the valve. Vent piping diameter greater than or equal to the pressure safety valve outlet diameter shall be maintained throughout the entire length.

Unless otherwise specified, pressure safety valves shall be individually vented with vent stacks to atmosphere at safe locations.

Unless otherwise specified, pressure safety valve vent manifolds shall not be piped in common with any other vents or drain lines.

Atmospheric vents shall have weep holes at the low points in the vent piping and shall be located so as not to pose a potential fire hazard by directing gas toward ignition sources or into an enclosed area.

The purchaser may specify additional scope including, but not limited to:

a) Suction pressure safety valve for purchaser specified conditions
b) Pressure safety valve outlet manifolded to a single skid edge connection
c) Lockable isolation valves, bypass valves, test rings or test kits for each process gas pressure safety valve to allow for testing
d) Remote mounted pressure safety valves
e) Duplex pressure safety valves
f) Pilot operated pressure safety valves
g) Weather caps on the atmospheric vent stacks

NOTE Addition of isolation valves to PSV's typically increases the height of the valve assembly and adds mass. Both of these serve to reduce the mechanical natural frequency and increase the likelihood of vibration induced failure.

Specific attention is required to ensure that the stiffness of the valve assembly is adequate to ensure mechanical natural frequency is high enough to not induce vibration related problems. See Annex L.4 and API 688, 2nd Edition, Annexes A3.9 and F for guidelines and best practices for the design of supports.

14.17 Recycle Piping System

14.17.1

The packager shall furnish a starting recycle valve and piping. The starting recycle loop shall be located inside the suction and discharge block valves.

14.17.2

The Packager shall calculate and state the package settle-out pressure assuming shutdown at the design operating pressures and considering isolation of the package between the skid edge suction and discharge flanges (except where additional volume has been specified).

14.17.3

The recycle loop shall be sized to keep the compressor torque requirement below the torque delivery limits of the driver during starting and ramp-up to operating speed. The packager shall calculate the starting torque of the compressor at the settle-out pressure, to ensure the engine starter or electric motor is capable of re-starting without blowdown or partial depressurization, except where approved by the purchaser.

14.17.4

The recycle system shall be cooled or otherwise have low enough differential pressure to permit unloaded compressor operation without escalating the gas temperature above the alarm/shutdown limits.

The use of compressor cylinder end deactivation devices may preclude the need for a starting recycle loop.

The settle-out pressure shall be lower than on skid pressure safety valve setpoints, unless approved by the purchaser.

Unless otherwise specified, the packager's scope shall not include a capacity control recycle valve.

The purchaser may specify additional scope including, but not limited to:

a) Actuated startup unloading recycle valve
b) Manual or automatic recycle valve for capacity control
c) Isolation valves and a manual bypass around a recycle control valve
d) Low pressure volume vessel or other design strategy to limit settle out equalization pressure

Annex P.5 provides additional guidance for starting bypass lines and Annex P.6 provides additional guidance on recycle (suction make-up) lines.

14.18 Blowdown Piping System

The purchaser shall specify the extent of the blowdown gas piping, valves and instrument connections to be included with the package.

Unless otherwise specified, the packager's scope shall include a manual blowdown valve and piping to skid edge or a safe location.

Where the package vent header is tied to a remote vent or flare system, the Purchaser shall state the maximum backpressure at the skid edge.

When requested by the purchaser, the packager shall calculate and state the package depressurization time from the calculated equalization pressure, and considering isolation of the package between the skid edge suction and discharge flanges (except where additional volume has been specified). The Packager and Purchaser may agree on design strategies to regulate or control the depressurization time.

The purchaser may specify additional scope including, but not limited to:

a) Automatic blowdown valve
b) Sizing criteria for the valve considering time, freezing, noise, etc.

14.19 Fuel Gas Piping System

14.19.1 General

The fuel gas piping system shall include:

a) Piping from the skid edge to the engine
b) Pressure-reducing regulator with downstream pressure gage
c) Pressure safety valve sized for full-open regulator failure.
d) Lockable manual isolation valve(s)
e) Fuel particulate filter installed downstream of the regulator.

14.19.2 Fuel Gas Liquid Coalescer/Separator

Unless otherwise specified, a liquid coalescer/separator installed downstream of the regulator is not required. Unless otherwise specified, the liquid level control valves are not required to be automated.

NOTE This may be a requirement depending on the liquid content of the fuel gas.

14.19.3 Fuel Gas Automatic Shut-Off Valve

Unless otherwise specified, an additional automatic shut-off valve is not required upstream of the engine to shut off fuel and vent downstream fuel gas.

14.19.4 High Pressure Regulator

Unless otherwise specified, a high-pressure regulator is not required. If required, an additional PSV shall be provided to protect against full-open regulator failure, or the fuel gas system shall be rated for the upstream pressure.

14.20 Scrubber Drain Piping System

The purchaser shall specify the extent of the scrubber drain piping system to be included with the package.

Unless otherwise specified, the packager's scope shall include automatic and manual drain valves on each scrubber and piping or tubing to manifold or cascade to a single skid edge connection.

Manifolded drains shall be equipped with check valves on each scrubber except the highest pressure scrubber.

The purchaser shall specify if the following items are to be supplied by the packager:

a) Lockable isolation valves around the automatic drain valve
b) Automated isolation valve at skid edge connection or on each scrubber drain
c) Scrubber level monitoring and drain control utilizing the local control panel logic

d) Restriction orifices

14.21 Start Gas or Air Piping System

14.21.1 General

The packager shall supply the start gas supply piping system. It shall include:

a) Supply piping from the skid edge to the engine starter
b) A lockable manual isolation valve to isolate the supply system.
c) Air or gas starter
d) Strainer
e) Lubricator (where required)

14.21.2 Start Gas Supply Pressure Regulator

Unless otherwise specified, a high pressure regulator is not required. If required, an additional PSV shall be provided to protect against full-open regulator failure.

14.21.3 Multiple Cranking Cycles

The start gas supply system should have sufficient volume to be capable of a minimum of three consecutive cranking cycles.

14.21.4 Starter Vent Piping

The packager shall supply starter vent piping from starter to skid edge. The starter vent piping shall maintain the back-pressure or differential pressure requirements of the starter.

The starter vent piping shall be piped to a safe location.

If the starter vent piping is attached to process flare piping, a check valve shall be provided.

14.22 Minimum Air Intake System Design Requirements

14.22.1 General

The following features shall be considered in the design of an air intake system:

a) The engine manufacturer’s application and installation instructions should be consulted for specific requirements.
b) The routing and support design of the air intake lines should account for access by overhead crane to cylinder heads and large internal components that require lifting aids. Supports should be implemented to account for engine manufacturer’s guidance regarding vibration isolation, exposure to heat sources, and allowable weight loads on the engine connection flange(s).
c) The air intake location shall avoid localized effects on pressure or temperature due to other nearby site features.
d) Unless otherwise specified by the purchaser, piping and supports for remote mounted air cleaners shall be furnished by the purchaser.
e) The piping wall thickness shall be of sufficient size to prevent pipe collapse under at least two times the expected negative pressure differential (internal minus external air pressure).
f) Remote mounted air cleaners shall have internal surface corrosion protection of inlet piping.
g) Consideration should be given to the location of the engine combustion air inlet duct to prevent excess water, snow or debris ingestion to the filters.
h) There should be reasonable maintenance access to service the air filters.
i) Unless otherwise specified, an air filter pressure drop indicator is not required.

14.22.2 Air Intake Silencers

Unless otherwise specified, an air intake silencer is not required. The purchaser shall specify the noise attenuation requirement. The air intake silencer, if provided, shall be included in the intake air piping restriction calculations.

14.23 Exhaust System

14.23.1 General

Unless otherwise specified, the packager shall provide a complete exhaust system that meets the following minimum requirements:

a) The packager shall state the insertion loss dB(A) specification of the exhaust silencer.
b) Provision for proper anchoring and support with accommodation for thermal expansion
c) All material(s) shall be suitable for the maximum exhaust temperature.
d) Construction of corrosion resistant material or, if carbon steel, with sufficient corrosion allowance and externally coated with a finish suitable for the design temperature.
e) Exhaust system back pressure to be within engine manufacturer's specified limits.
f) Provisions to prevent rain water entering the system, to prevent liquids from draining toward the engine and for draining accumulated liquid.
g) Provisions for any required instrumentation

14.23.2 Site Specific Exhaust System Requirements

The purchaser shall specify any design requirements for the following:

a) Sound attenuation
b) Exhaust emission limits
c) Catalyst or provision for catalyst by others
d) Emission sampling ports
e) Personnel protection (insulation, guarding, access ladders or platforms)
f) Spark arresting capability
g) Exhaust stack height for emissions dispersion

Unless otherwise specified, an exhaust system capable of withstanding the pressure resulting from the ignition of unburned fuel or include provisions for relieving such pressure to a safe area without damaging the exhaust system is not required

NOTE: NFPA-37 can be referenced for requirements for stationary engine exhaust systems. NFPA-68 can be referenced for design guidance for engine exhaust systems, including excess pressure safety valves.

14.23.3 Insulation and Guarding

Unless specified otherwise, insulation and/or guarding of hot metal surfaces shall not be provided.

Shielding for on-engine exhaust components shall be limited to that provided by the engine manufacturer. Any additions, removals, or modifications to on-engine shielding shall be approved by the engine manufacturer.

14.24 Lube Oil Piping System

The packager shall complete the individual manufacturer’s furnished lubricating oil systems compliant with the manufacturer’s application guidelines.

Pressure piping downstream of oil filters should be free of internal obstructions or pockets that could accumulate dirt.

After fabrication, oil lines shall be cleaned and flushed per the manufacturer’s guidelines.

Sample ports should be located before and after the oil filter and labelled as such for use in periodic oil analysis.

The packager shall supply a valved connection to drain the crankcase.

The packager shall supply a means to easily fill the crankcase with oil that does not flow through the oil level controller.

Careful attention should be given to the compressor manufacturer's oil system requirements.

Pressure loss through all the components (piping, cooler, valves etc) should be considered when designing the lubrication system.

The purchaser may specify additional scope including, but not limited to:

a) Duplex frame oil filters
b) Cylinder lubricator feed filters
c) Cylinder lubrication consumption metering
d) Cylinder lubrication heater
e) Heat tracing of prelube pump suction line
f) Valved oil drain line at skid edge
g) Motor driven cylinder lubricator
h) Waste oil tank

14.25 Coolant Piping Requirements

14.25.1 General

The packager shall provide a complete coolant piping system with all piping and appurtenances to comply with the engine and/or compressor manufacturers' application guidelines. The system shall be designed to circulate the necessary coolant flow rate at the manufacturer specified temperature limits and maximum heat duty of each circuit, operating at the purchaser specified altitude and maximum ambient temperature.

Coolant systems may include a compressor lube oil cooler, liquid cooled packing on one or more cylinders and jacketed compressor cylinders, either forced circulating, static, or thermosiphon. Unless otherwise specified, coolant piping and equipment are not pressure code systems. Piping design shall consider thermal expansion and be suitably supported with clamps to prevent damage from vibration or normal operation. Some connections may have flat face flanges and gaskets.

Unless otherwise specified, the package piping system shall include as a minimum:

a) Complete interconnect piping between equipment installed on the package skid, i.e. engine, compressor, heat exchangers, and pumps.
b) Where heat exchangers or coolers are installed off skid, the packager to specify if interconnecting piping has been included in the scope.
c) Thermostatic temperature control valves for each circuit
d) Isolation, vent and drain valves to ensure complete filling and draining
e) Flexible connections on equipment that shall be moved or adjusted for alignment purposes, or to compensate for thermal expansion of piping
f) Expansion tank for each circuit with level sight glass, low level shutdown switch, vent valves, and pressure cap

   NOTE 1: Expansion tanks are not ASME rated [less than 97 kPa (14 psig) design pressure].

g) Removable strainers at the inlet of each coolant circulation pump.

h) High temperature alarm and shutdown protection
i) Flow balance valves at the outlet of each heat load, where required

14.25.2 Optional Equipment

The purchaser may specify additional equipment as follows:

a) Coolant drain/holding tank for service
b) Valved fill connections or transfer pumps at operator level
c) Temperature indicators (local or panel mounted) on the inlet and/or outlet of each cooler
d) Coolant sight flow indicators
e) Post shutdown circulating pump
f) Insulation or guarding of hot piping for personnel protection
g) Coolant preheat systems for cold starting

Annex L.5 provides additional guidance for cooling systems.

14.26 Vent and Drain Systems

The packager's scope shall include pipe or tubing from each gas vent and each gas/oil drain to one or more skid edge connections or to one or more safe locations.

Gas operated controller and actuator vents shall be tubed to a safe location or a skid edge connection.

15 Distance Piece Vent and Drain and Packing Vent/Drain Arrangements

15.1 General

Process gases may contain compounds that are flammable, corrosive, toxic, or otherwise incompatible with compressor crankcase components and hazardous for the environment around the compressor package. The purpose of the compressor distance piece is to provide an isolated cavity in which to collect leaked process gases and injected lubricant from the pressure packings. The distance piece vents, drains and pressure packing vent/drain systems are configured to route these leaked process gasses and lubricants from the distance pieces to safe disposal.

The packager shall adhere to the compressor manufacturer's application guidelines and prevailing local codes and standards for emissions and venting.

The purchaser shall provide the following information:

a) Availability and type of purge gas
b) Availability of vacuum source or vapor recovery system
c) Restrictions on venting
d) Requirement for Drain retention on skid
e) Other vents tied to the package vent/drain system

15.2 Distance Piece Vent and Drain Systems

The purchaser and packager shall agree on the design of the vent and drain systems. Both purchaser and packager scope of supply shall be defined so that leaked process gases and liquids from the compressor package can be properly disposed.

a) The purchaser shall specify the venting method being used for the package at skid edge: to atmosphere, to flare with back-pressure, a vacuum system or captured and reinjected.
b) The purchaser shall specify the drain method being used at skid edge - gravity, pressurized or pumped.

c) Unless otherwise specified by the purchaser, an on-skid separation pot shall be provided by the packager. A separation pot is required in the vent and drain system to separate the liquids and gases for their disposal.
d) Vent and drain lines from the distance pieces will contain gas, liquid or a combination of both. The vent and drain connections shall be configured so that gases or liquids cannot transfer from one distance piece compartment (inner or outer compartment if applicable) to another on the same throw.
e) Vent and drain lines from the distance pieces shall be sized appropriately. Anytime two lines join, the downstream line shall increase in size to accommodate their combined flow.
f) Packing vent/drain lines from multiple pressure packing cases may be connected to a common packing vent/drain header and routed to the oil separation pot.
g) Distance piece compartment vent and drain lines may be connected to a common header with the equivalent inner or outer distance piece compartment on the other throws. The distance piece headers shall be routed to the oil separation pot.

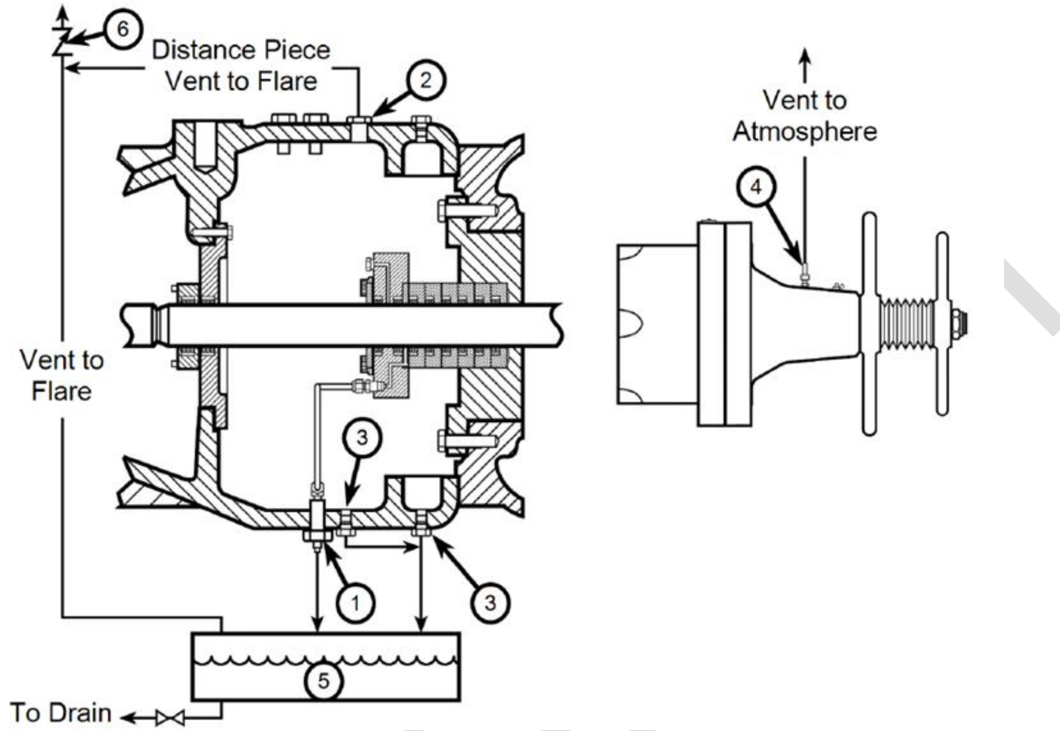
Annex J provides guidance and examples of manifolds for distance piece vents and drains and packing vents/drains.

NOTE Compressor packing glands typically have a combined single vent/drain connection on the lower half of the gland plate. Distance piece compartments have a separate vent connection on the top and a drain connection on the bottom.

15.3 Single Compartment Distance Piece Vent and Drain Configuration

Distance piece drain lines shall not be combined with packing vent/drain lines to ensure packing vent gas does not flow back through the distance piece drains, preventing proper distance piece drainage. A typical single compartment vent and drain configuration is represented in Figure 7.

Unless other specified by the purchaser, all single compartment distance piece packing vents/drains may be routed to a manifold terminating at the edge of the skid. The manifold is typically connected either to a vent gas collection system or flare system that is not part of the package scope.



1. Packing vent/drain
2. Distance piece vent
3. Distance piece vent
4. Variable volume clearance pocket gas vent
5. Oil separation pot
6. Low crack pressure check valve

Figure 7 – Single Compartment Vent and Drain Configuration

15.4 Capacity Control Device Vents

The packager shall follow the compressor manufacturer's recommendation for connecting the capacity control device vents. These vents shall not be connected to the distance piece vents.

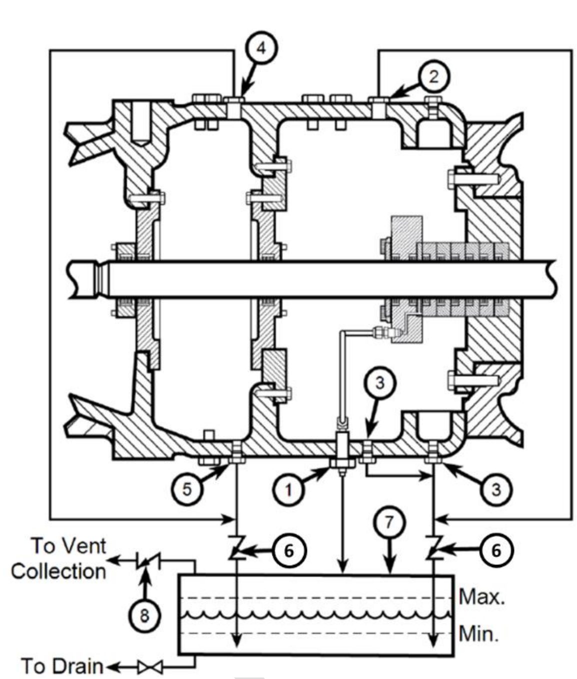
15.5 Two Compartment Vent and Drain Configuration

Distance piece drain lines shall not be combined with packing vent/drain lines to ensure packing vent gas does not flow back through the distance piece drains, preventing proper distance piece drainage. A typical long two compartment vent and drain configuration is represented in Figure 8.

Unless otherwise specified by the purchaser, the outer distance piece vent and drain on each throw may be combined and routed to a manifold terminating at the edge of the skid.

Unless otherwise specified by the purchaser, the inner distance piece vent and drain on each throw may be combined and routed to a manifold terminating at the edge of the skid.

Unless other specified by the purchaser, all two compartment distance piece packing vents/drains may be routed to a manifold terminating at the edge of the skid.



1. Piston rod packing vent/drain
2. Distance piece vent - outboard
3. Distance piece drain - outboard
4. Distance piece vent - inboard
5. Distance piece drain - inboard
6. Check valve (only for non-lube applications)
7. Oil separation pot
8. Low cracking pressure check valve

Figure 8 – Long Two Compartment (Type 3) Vent and Drain Configuration

15.6 Purge

Unless otherwise specified, a purge system is not required. Figure 9 shows a typical arrangement of the internal compressor components to support most external purge arrangements. There are many variations. The purchaser and packager shall coordinate the design based on the compressor manufacturer's application requirements and the purchaser's specified site requirements, process gas and purchaser's purge gas supply conditions.

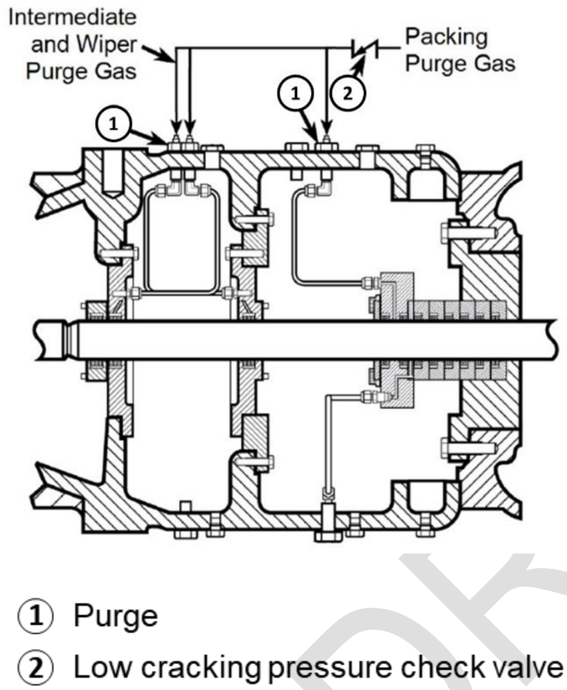


Figure 9 – Long Two Compartment (Type 3) with Purge

15.7 Separation Pot

Unless otherwise specified, a separation pot shall be furnished by the packager to separate vented process gas from drained lubricants. The minimum requirements for the pot shall be:

a) Volume for five days of normal pressure packing lubricant flow.
b) Visual level indicator
c) Manual drain valve
d) Vent or over-pressure protection sized to freely flow the total of the individual packing vents in a worn condition combined with one packing in a failed condition.

Unless otherwise specified by the purchaser, the pot shall not be classified as a pressure vessel.

When a two-compartment distance piece is used, the vent and drain system design shall not allow the inboard and outboard distance pieces to directly communicate. Consult with the compressor manufacturer for specific recommendations. A check valve shall not be installed in the packing vent/drain line.

NOTE 1: It is very important that the separation pot is filled with oil before initial start up.

NOTE 2: If mechanical check valves are used, lubricant may tend to accumulate in the distance piece.

16 Protection, Control and Instrumentation

16.1 General

Each compressor package shall be equipped with a local protection (mechanism or mechanisms put in place to prevent equipment from operating in such a way that it would sustain damage or fail outright) and control (mechanism or mechanisms in place to maintain equipment operation at a desired setpoint, often incorporating the same items as used for "protection", however with different limits or set points) panel.

The level of compressor package instrumentation, protection and control shall be specified by the purchaser.

The protection system shall meet the minimum requirements specified by the compressor and driver manufacturers.

The purchaser shall specify if control capability is required for:

a) automated start and stop sequencing
b) isolation valve control
c) capacity control
d) remote operation, or
   remote monitoring.

Additional guidance and recommendations for protection, control and instrumentation can be found in Section 11 of *GMRC High-Speed Compressor Package Guideline for Field Gas Applications*[40].

16.2 Protection Capability

16.2.1 General

Each compressor package shall be equipped with sensors, a logic device and actuators to shut down the equipment to protect personnel, the environment and the equipment when a measured parameter exceeds a shutdown safety set point.

The minimum parameters to be monitored are a function of type and complexity of the driver, the number of cylinders and stages on the compressor and the other equipment included on the package.

16.2.2 Shutdown

A shutdown (S/D) shall be initiated when a shutdown parameter set point has been reached.

Gas engines shall be shut down by both fuel and ignition. The fuel shall be shut off immediately and the ignition may be shut off after a short delay.

Modern gas fueled spark ignited engines are equipped with integrated control systems which can shut off the ignition and close an engine mounted fuel valve. The shutdown capability can be activated by a software signal. When an additional fuel shutoff valve is furnished (see 14.19.3) the panel shall control its function.

The purchaser shall specify motor shutdown method. Electric motors may be shut down by opening fail open contacts (constant run signal) or pulsing fail closed momentary contacts (pulse control).

Post lube and delayed cooler shutdown may be used for cool down.

16.2.3 Emergency Shut Down (ESD)

The local control and protection panel shall have a manual ESD switch and provision for a remote ESD. The ESD switch shall be of a design and color that is readily identified in the event of an emergency, and shall not be blocked or obscured in any way.

Unless specified otherwise by the purchaser, an ESD shall stop all systems immediately without delay.

Unless specified otherwise by the purchaser, an ESD will only affect the compressor package, sometimes referred to as a unit ESD as opposed to a plant ESD.

The packager and the purchaser shall agree on any parameter-based shutdowns that are to be treated as ESDs.

Unless otherwise specified, the ESD protection shall not be divided into ESD and emergency shut down and de-pressurization (ESDD). The blow down valve shall not open on an ESD but shall open on an ESDD. The packager and the purchaser shall agree on other shut down valve operation for the ESD and ESDD.

16.2.4 Alarms

When utilized, an alarm occurs when a parameter alarm setpoint has been reached prior to the shutdown setpoint being reached.

Unless otherwise specified, when the specified installation location is normally unmanned and remote monitoring is not specified, alarms are not required.

Unless otherwise specified or proposed, when the specified installation location is normally manned or when remote monitoring is specified, programming provisions shall be included for alarms on all shutdown parameters monitored with analog sensors.

Unless otherwise specified or proposed, alarms are not required for parameters monitored with physical switches such as level switches or vibration switches.

Unless otherwise specified or proposed, alarms are not required for parameters monitored by engine or compressor OEM supplied systems when those systems do not have alarm capability.

16.2.5 Fail Safe

Circuits and actuated valves shall be arranged so they go to a safe condition on loss of electrical signal or on loss of instrument air or gas.

16.2.6 Class A, B and C Alarms and Shutdowns

The packager shall specify which alarms and shutdowns are classified as Class A, B or C:

a) Class A are always active
b) Class B become active after a timer expires
c) Class C become active when the measured value clears a setpoint (example low suction pressure is not active until the suction pressure rises above the setpoint)

16.2.7 Test Mode

A test mode feature shall be provided to enable testing of the individual shutdown functions without causing a shutdown. The test mode shall automatically expire after a set period of time. A security system to prevent unauthorized use of the test mode should be provided. The control system should indicate when the test mode is active.

16.2.8 First Out

The panel shall indicate which parameter was the first-out cause of the shutdown.

16.2.9 Blow Down Valve

When an actuated blow down valve (BDV) is specified, the purchaser shall specify if the BDV is to open on an ESD, on a shutdown and/or on a normal stop.

16.2.10 Minimum Compressor Protection

Compressor protection parameters are listed below. The list is intended to define the minimum requirements. Additional requirements may be added by the packager or specified by the purchaser. If the compressor manufacturer's minimum requirements exceed what is specified in the list, the manufacturer's incremental requirements shall prevail.

a) High discharge temperature shutdown, each cylinder (Class A)
b) Low suction gas pressure shutdown, first stage (Class C)
c) High suction gas pressure shutdown, first stage (Class A or C)
d) Low discharge gas pressure shutdown, each stage (Class C)
e) High discharge gas pressure shutdown, each stage (Class A on final stage)
f) Low cylinder lubricator flow or no-flow shutdown (Class B)
g) Low frame oil pressure shutdown (Class A with prelube, or Class B)
h) Low frame oil level shutdown (Class A)
i) High frame vibration shutdown (Class A)
j) High Compressor Oil Temperature shutdown (Class A)
k) Low compressor oil temperature (permissive)

16.2.11 Minimum Engine Driver Protection

Engine driver protection parameters are listed below. The list is intended to define the minimum requirements. Additional requirements may be added by the packager or specified by the purchaser. If the engine manufacturer's minimum requirements exceed what is specified in the table, the manufacturer's incremental requirements shall prevail.

a) Low engine oil level shutdown (Class A)
b) Low jacket coolant level shutdown (Class A)
c) Low auxiliary coolant level shutdown (if equipped) (Class A)
d) Low engine oil pressure shutdown
e) High jacket coolant temperature shutdown
f) Low jacket coolant temperature (permissive)
g) High auxiliary coolant temperature shutdown (if equipped)
h) High engine vibration shutdown (Class A)
i) Engine overspeed shutdown
j) High engine oil temperature shutdown
k) Low engine oil temperature (permissive)

16.2.12 Minimum Electric Motor Driver Protection

All driver motors shall have a high vibration shutdown. Driver motors larger than 373 kW (500 hp) shall also have a high winding temperature shutdown for each phase, and a high bearing temperature shutdown for each bearing. Additional requirements may be added by the packager or specified by the purchaser. If the motor manufacturer's minimum requirements exceed the above , the manufacturer's incremental requirements shall prevail.

16.2.13 Minimum Protection for Other Package Components

Other package component protection parameters are listed below. The list is intended to define the minimum requirements. Additional requirements may be added by the packager or specified by the purchaser. If the component manufacturer's minimum requirements exceed what is specified in the table, the manufacturer's incremental requirements shall prevail.

a) High liquid level, each scrubber LSHH (Class A)
b) Manual ESD switch (Class A)
c) High cooler fan vibration shutdown (see below) (Class A)

If the cooler fan is driven by a separate electric motor, only the cooler shall be shut down on cooler fan vibration VSHH.

16.3 Control Capability

16.3.1 General

The purchaser shall specify the control functions to be included in the protection and control system.

16.3.2 Minimum Control

On the simplest packages, the protection and control system may provide protection only.

When a shutdown is active on an engine drive package, the control system shall prevent a start via the engine fuel shut off and ignition shut off but need not prevent cranking of the engine.

When a shutdown is active on a motor drive package, the control system shall prevent a start via the motor run/stop circuit(s).

All other start/stop/load/unload functions may be controlled by local valves and manual switches on the package.

16.3.3 Manual Start/Stop

When manual start/stop control from the panel is specified the control system shall include capability for the operator to:

a) Start and stop the main driver
b) Start and stop any auxiliary motors
c) For a gas engine, purge the engine and exhaust system prior to starting by cranking the engine with the fuel shut off and the ignition system disabled

16.3.4 Manual Speed Control

When manual speed control from the panel is specified the control system shall include capability to vary the driver speed setting from minimum to maximum continuous speed.

16.3.5 Panel Control for the Startup Recycle Valve

When start unload control from the panel is specified, the control system shall include capability to control a startup recycle valve (open/closed actuated valve) on the recycle line. This is sometimes referred to as start bypass control. See definitions for recycle vs bypass.

Unless otherwise specified, the startup recycle valve shall fail open (FO).

If the valve actuation is not visible to an operator at the panel location, the panel should have the capability to monitor and display the startup recycle valve position.

16.3.6 Automatic Speed Control

When automatic speed control is specified the control system shall include capability to vary the driver speed. The purchaser shall specify the speed control parameter(s).

16.3.7 Automatic Recycle Control

When automatic recycle control is specified the control system shall include capability to vary the recycle control valve position. The purchaser shall specify the control parameter(s).

16.3.8 Panel Automatic Shut Down Valve Control

Unless otherwise specified, panel automatic shutdown valve control is not required. When panel automatic shutdown valve control is specified, the control system shall include a discrete output to actuate each isolation valve.

Unless otherwise specified, panel shutdown valve position monitoring is not required. When panel shutdown valve position monitoring is specified, the control system shall include two discrete inputs for each isolation valve to confirm fully open and fully closed positions. The control system shall include an adjustable timer for valve opening or closing and shall indicate when a valve has not changed state within the set time limit.

Unless otherwise specified by the purchaser, shutdown isolation valves shall fail in the closed position.

The control system shall contain a provision to force each discrete output to stroke the respective valve.

The purchaser shall specify which valves are to be controlled by the local panel and which are to be included in the shutdown sequence :

a) suction isolation valve
b) discharge isolation valve
c) side stream isolation valve(s)
d) fuel isolation valve
e) scrubber drain isolation valve(s)
f) blowdown valve (fail open unless specified otherwise)
g) startup recycle valve (fail open unless specified otherwise)
h) recycle control valve (fail open unless specified otherwise)

16.3.9 Panel Automatic Process Piping Purge Control

When panel automatic purge control is specified, the control system shall include a discrete output to actuate a purge inlet valve immediately downstream of the inlet isolation valve and a discrete output to actuate a purge vent valve (or the blow down valve) upstream of the discharge isolation valve.

The control system shall include capability to confirm purge flow by pressure rise or other means.

The purge cycle shall include cycling the startup recycle valve or the recycle control valve to purge the recycle line. Purge vents shall be piped to a safe location.

NOTE: Additional inlet valves or vent valves may be required to purge other dead legs.

16.3.10 Panel Automatic Start/Load/Unload/Stop Control

When panel automatic start/load/unload/stop control is specified, the control system shall include all necessary programming and outputs so that from a single operator input, the system can perform all prerequisite preheat, prelube, and purge steps, open the recycle valve, close the blowdown valve, start the prime mover (including, for a gas engine, a purge cycle of the engine and exhaust system), cycle through all class B timers, open the process shutdown isolation valves and load the compressor.

The system shall also include all necessary programming and outputs so that from a single operator input, the system can unload, cool down, stop, post lube and close the shutdown valves.

During the start and stop cycles the control system shall indicate the current state and the permissive or countdown timer to the next step.

When specified, the panel program shall include the option, for commissioning, to pause at each step until the operator releases the program to proceed.

16.3.11 Automatic Compressor Cylinder Capacity Control Devices

When automatic compressor cylinder capacity control devices are used, additional coordination is necessary and shall be a joint effort of the purchaser, packager, compressor manufacturer, device manufacturer and the control system supplier.

Load steps shall be defined and hard wired or programmed.

Each load step shall be included in the scope of the pulsation and torsional analyses.

16.3.12 Remote Monitoring

The purchaser shall specify the method and extent of any remote monitoring capability.

16.3.13 Data Storage and Trending

The purchaser shall specify the method and extent of any data storage and trending capability.

16.3.14 Remote Start/Stop

When remote start/stop capability is specified, automatic start/load/unload/stop capability is required.

The following personnel safety devices shall also be included as a minimum:

a) Local / remote switch at the compressor package with lock out capability.
b) A visual and audible warning device that will alert personnel of an impending remotely initiated start.

The purchaser will specify the time requirements for the warning before a remote start can occur. A remote ESD or the removal of a remote run permissive shall shut the unit down in the local mode.

16.4 Instrument and Control Hardware Requirements

16.4.1 Instrument and Control Enclosures

Unless otherwise specified, all enclosures shall be suitable for outdoor locations, using NEMA4 or equivalent. Consideration should be given to other site ambient conditions.

16.4.2 Instrument and Control Hazardous Area Classification

Instruments and control components shall be suitable for the area classification in the destination jurisdiction as specified by purchaser. Unless otherwise specified by the purchaser, Instruments and control components shall be in accordance with NFPA 70 for Class I Division 2 Group D areas.

NOTE: API RP 500 and 505 provide guidance regarding electrical area classification.

16.4.3 Visibility and Accessibility

All controls and instruments should be located and arranged for visibility and easy access by operators and maintenance personnel.

16.4.4 Maximum Operating Limits

All instruments and controls shall be rated to withstand the maximum temperature and pressure of the respective system. Gauges should be selected so the expected operating value is in the middle third of the instrument's range.

All instruments and controls shall be rated to operate throughout the site ambient operating temperature range. All instrument and controls shall be rated to withstand (non-operating) the minimum in-transit and site ambient temperature.

16.4.5 Mounting

All instruments and controls shall be securely supported to eliminate vibration and undue force on instrument piping, tubing and equipment, to prevent damage during shipment, storage, operation, and maintenance.

16.4.6 Control Panel

16.4.6.1 General

Unless otherwise specified by the purchaser, a control panel shall be provided for each compressor package.

16.4.6.2 Purchaser Supplied Control Panel

When the control panel is not included in the packager's scope of supply, the purchaser shall specify if any of the following are to be included in the packager's scope:

a) Mounting of the panel on the package
b) Extent of package wiring for end devices, i.e. mounting of end devices only up to skid edge junction box(es)
c) Use of the panel for any shop testing including provisions for panel related delays
d) Hosting panel supplier personnel
e) Wire labels
f) Drafting or review of panel related documents:
   1) Control system theory of operation document drafting or review
   2) Alarm and shutdown set points
   3) Panel wiring diagrams or schematics
   4) Cause and effect diagrams

16.4.6.3 Panel Mounting

Unless otherwise specified by the purchaser or by the packager, the panel shall be skid mounted.

When mounted on the skid, control panels shall be positioned to allow sufficient access for operation and maintenance, and away from high heat sources. All control panels shall be equipped with suitable lifting lugs.

Skid-mounted panels shall be securely supported to minimize vibration and to prevent damage during shipment, storage, operation and maintenance.

When an off-skid panel is mounted on a fabricated stand, safe lifting of the combined panel and stand should be reviewed.

16.4.6.4 Panel Penetrations

Unless otherwise specified or agreed to by the purchaser, wiring gland or conduit penetrations shall be on the bottom of the panel enclosure.

16.4.6.5 Panel Data Displays

The purchaser shall specify the operator interface.

16.4.6.6 Panel Beacons, Strobes or Horns

The Purchaser shall specify any requirements for beacons, strobes or horns. When a beacon, strobe and/or horn is required, there shall be a means on the panel face to acknowledge and silence or shut off the device(s).

16.4.6.7 Panel AC Power Supply

Panels powered with alternating current (AC) shall have an externally accessible panel power switch and indicator.

The incoming panel power supply shall be protected by fuses or circuit breakers.

Wiring and components for AC shall be segregated in one area of the panel. Exposed AC contacts should be covered with clear plexiglass.

16.4.6.8 Panel Expansion Capacity

The purchaser shall specify the type and quantity of spare analog/digital input/output channels, relays and/or fuses.

16.4.7 Pressure Instrumentation

16.4.7.1 Pressure Gauges

Pressure gauges shall have a minimum proof pressure at or above the PSV set point.

Pressure gauges should have the normal operating range equal to approximately half of the displayed full-scale range.

Analog pressure gauges should have uniform graduated markings. Pressure gauge bourdon tubes, sockets and tips shall be made of 316 stainless steel as a minimum.

Unless otherwise specified, liquid filled pressure gauges are not required.

Unless otherwise specified, pressure gauge calibration certificates are not required

16.4.7.2 Pressure Transmitters

Pressure transmitters shall have a minimum proof pressure at or above the PSV set point.

Pressure transmitters should have a minimum accuracy of +/-1% of full range.

Pressure transmitter wetted components shall be made of 316 stainless steel as a minimum.

Unless specified by the purchaser, programmable pressure transmitters, transmitters with integral displays and transmitters with digital communication protocol capability are not required.

16.4.7.3 Pressure Switches

Except for pressure switches integrated with gauges, mechanical pressure switches should not be used.

16.4.7.4 Pressure Instrument Isolation Valves

All pressures gauges, transmitters and switches in hydrocarbon gas service shall be furnished with isolation valves. The isolation valve should be mounted at the process sensing connection.

The purchaser may specify additional scope including:

a) Welded or flanged root valves at each instrument connection on process, fuel and start gas piping
b) Stainless steel block and test instrument valves at each pressure instrument
c) Multi valve manifolds at each differential pressure instrument
d) Isolation valves at each instrument connection on all auxiliary systems

A common connection may be used for multiple pressure instruments measuring the same pressure if they have additional isolation valving. For example: pressure protection and pressure control may use a common root valve if each has a separate block and bleed valve.

16.4.8 Temperature Instrumentation

16.4.8.1 Temperature Gauges

Dial type temperature gauges should have the normal operating range equal to approximately half of the displayed full-scale range.

Dial type temperature gauges should have uniform graduated markings.

Dial type temperature gauges for local mounting shall be heavy duty and corrosion resistant and glass-front.

Capillary tube temperature gauges may be used.

Unless otherwise specified, liquid filled temperature gauges are not required.

16.4.8.2 Temperature Elements and Transmitters

Temperature sensing elements should be J or K type ungrounded thermocouples (TC) or 100 Ohm platinum (PT100) resistance temperature detectors (RTD). RTDs should be 3 or 4 wire single element or dual element 6 or 8 wire RTDs.

Unless otherwise specified by the purchaser, RTD or TC elements may be connected as dedicated RTD or TC inputs in the panel or they may be connected to local transmitters and connected as analog inputs in the panel. Thermocouples shall be connected with compatible thermocouple extension wire and terminal blocks.

Unless specified by the purchaser, programmable temperature transmitters, transmitters with integral displays and transmitters with digital communication protocol capability are not required. When so specified for process gas service, the transmitters shall be mounted separate from the sensor element heads.

Temperature elements should be mounted with a connection head. The connection head should allow element replacement without disassembly of cable glands or conduit. The connection head should hold the element against the inside end of the thermowell. Hockey puck style transmitters may be mounted in connection heads.

Temperature elements provided by the engine manufacturer and connected to an engine control module provided by the engine manufacturer may be the engine manufacturer’s standard type and installation.

Unless otherwise specified by the purchaser, electric motor winding RTDs are to be connected to the motor starter in the motor control center and not to the local panel. When the purchaser specifies that winding RTDs are to be connected to the local panel, one RTD per phase (total of three) shall be connected. Spare winding RTDs may be terminated at the motor junction box.

16.4.8.3 Temperature Switches

Except for temperature switches integrated with gauges and electric overload protection switches, mechanical temperature switches should not be used.

16.4.8.4 Thermowells

All temperature gauges and sensing elements in hydrocarbon gas service, pressurized service or installed at a submerged access point shall be mounted in corrosion resistant thermowells such as 300 series stainless steel as a minimum.

Unless otherwise specified by the purchaser, thermowells may be threaded or welded. Threaded thermowells shall be a minimum of 12.7 mm (½ in.) NPT.

16.4.8.5 Thermowell Mounting

Thermowells shall be inserted into the main fluid flow to an insertion depth of 6.4 mm to 12.7 mm (¼ in. to ½ in.) of the pipe inside diameter. Thermowells shall not impede flow and shall not reduce the flow area so as not to exceed the specified maximum flow velocity.

Thermowells for pipe smaller than 102 mm (4 in.) NPS or other locations where adequate immersion cannot be obtained perpendicular to the pipe, may be installed in lateral O-lets, elbows or in short enlargement sections. Short enlargement sections should use offset reducers.

Thermowells for compressor cylinder discharge temperature should be mounted, in order of preference:

a) in the cylinder discharge nozzle when the port is provided by the compressor manufacturer, or
b) in the cylinder nozzle of the discharge pulsation bottle, or
c) in the discharge bottle shell near the nozzle.

Unless otherwise specified, thermowell vibration calculations per ASME PTC 19.3 TW 2016 are not required.

16.4.9 Level Instrumentation

16.4.9.1 Level Gauges

Visual level indication shall be provided for engine and compressor crankcases and/or crankcase oil level controllers, oil make up tanks, lubricator gear boxes, motor bearing housings and coolant surge tanks.

Visual level indication shall be provided for gas scrubbers at the normal liquid level control range and at the liquid level shutdown elevations.

16.4.9.2 Level Transmitters

Unless otherwise specified, level transmitters shall not be required.

16.4.9.3 Level Switches

Level switches may be float switches or other technologies where specified by the purchaser. Level switches mounted directly on scrubbers shall be protected from internal turbulence.

16.4.9.4 Scrubber Level Controls

Scrubber level controls may be self-contained on scrubbers. Unless otherwise specified, level controlled by the panel with a level sensor input and an output to a dump valve is not required

Scrubber level controls may be directly mounted on scrubbers. Unless otherwise specified, level controls are not required to be mounted in a bridle mounted on flanges with isolation valves. Scrubber high level protection shall not be mounted in the same bridle as the level controls. Bridles shall be equipped with high point vent connections and valved low point drain connections. Special consideration shall be given to supporting bridles.

Gas scrubbers upstream of reciprocating compressors shall be equipped with high liquid level protection. High level shutdown switches shall be wired fail safe, so the contacts open on high level.

Scrubber level control and high level protection shall not use a common sensor.

16.4.9.5 Utility Level Controls

Single devices with combinations of level switches, level controllers and level gauges may be used in utility service.

16.4.10 Process Gas Flow Measurement

Unless otherwise specified or proposed, flow measurement is not required.

NOTE: Pressure pulsation inherent in reciprocating compressor piping can negatively affect flow measurement accuracy.

16.4.11 Instrument Air/Gas

When air is to be used, the packager shall ensure complete separation between the air and process gas or engine fuel gas systems. This means the systems must be physically separated and unable to be accidentally connected.

NOTE: Allowing any amount of air to enter the system and mix with compressed gas can result in an explosion. Many compressor packages and applications have historically used gas for instruments and controls and still do.

Where process gas is used for instrument gas it shall be regulated from a suitable source.

Instrument gas lines should not enter the panel enclosure.

Instrument air/gas branch connections to each end device shall have an isolation valve. One spare branch with a plugged isolation valve should be provided.

Separate pressure regulators should be provided for groups of actuators with different operating pressures.

Where wet process gas is used for instrument gas supply, it should be supplied through a coalescing filter to prevent liquids from condensing and/or freezing at low ambient temperatures.

The purchaser shall provide a clean and dry instrument air or gas supply at all operating and ambient temperatures and pressures.

The packager's scope shall include pipe or tubing from a single skid edge connection manifolded to each end device with an isolation valve for each device. Pressure regulation shall be supplied to meet the limitations of end devices. The purchaser may specify additional scope including:

a) Centralized instrument air or gas manifold with a valved drain
b) Spare valved branch connections
c) Galvanized or stainless steel manifold, piping and/or valves
d) Individual pressure regulation for each end device
e) Low instrument air or gas pressure alarm or shutdown instrumentation

If instrument air or gas is supplied independent of the process or fuel gas system, the over-pressure protection shall be by the purchaser.

If the instrument air or gas take-off is located on the skid, the packager shall supply the relief device to protect the instrument gas system.

16.4.12 Tubing

Refer to 14.7 for tubing and fitting requirements.

17 Electrical

17.1 Codes and Standards

The package shall meet or exceed the requirements of the latest editions of the applicable mandatory codes as specified by the purchaser based on the package installation location.

17.2 Area Classification

Electrical systems shall be suitable for the area classification in the destination jurisdiction as specified by purchaser. Unless otherwise specified by the purchaser, electrical systems shall be in accordance with NFPA 70 for Class I Division 2 Group D T2 areas.

NOTE API RP 500 provides guidance regarding electrical area classification.

17.3 Working Clearance

Working Space for equipment operating 1000 volts, nominal, or less to ground and likely to require examination, adjustment, servicing, or maintenance while energized shall comply with dimensions listed in the NFPA 70.

17.4 Electrical and Control System Power Supply

17.4.1 Electrical System Diagram and Load List Requirements

The packager shall provide electrical system single line diagrams (where upper-level details like generators, main transformers, and large motors are shown), wiring diagrams and load list, for the package electrical system.

17.4.2 Control System

The purchaser shall specify the available control system power supply. Data shall include:

a) source (UPS or utility)
b) redundancy
c) voltage
d) phase
e) frequency
f) short circuit current.

17.5 Grounding and Bonding

Major components not welded to the skid shall have individual ground wires securely attached to the skid. This includes prime mover, compressor, cooler, panel enclosure, transmitter racks, auxiliary motors and scrubbers. Skids shall have unpainted grounding lugs on at least two opposite corners of the skid. Copper grounding hardware shall be coated with antioxidant.

17.6 Lighting, Receptacles and Miscellaneous

Lighting and convenience receptacle requirements shall be specified by the purchaser.

17.7 Cable Tray and Conduit Raceway Systems

17.7.1 Cable Tray Design and Material

Unless otherwise specified, cable trays shall be aluminum material with non-corrosive fasteners.

17.7.2 Cable Tray Installation

Cable trays should:

a) Be oversized by 20%
b) Be free of sharp corners and edges from cutting.

c) Not be used to store excess cable length
d) Be supported at least every 3 m (10 ft), or as per NEMA VE2 manufacturer recommendation, whichever is shorter.
e) Not be run next to hot piping and components.
f) Be raised to avoid collection and trapping of fluids in the trays.
g) Comply with cable bend radius specifications
h) Avoid creating trip hazards or blocking frequently serviced components.
i) Be grounded per NFPA 70 requirements and manufacturer's specifications.

17.7.3 Conduit Design

Separate conduits should be provided for segregating the following wiring classes:

a) Three phase AC power
b) Single phase AC power
c) Instrumentation power and discrete control – discrete
d) Instrumentation – Analog
e) Thermocouple extension wire
f) Intrinsically safe or non-incendive
g) Communications

17.7.4 Conduit Installation

All conduit should be:

a) Square cut, reamed and free of burrs and sharp edges prior to pulling wires.
b) Mounted in a workable and economical manner.
c) Supported as per NFPA 70
d) Securely fastened as per NFPA 70
e) Supported to avoid conduit laying in liquid
f) Should enter the bottom of junction boxes, instruments or device enclosures
g) Should be arranged to drain away from the device to a low point drain

Conduit runs should not:

h) Have more than three 90-degree bends without installing a pull fitting in an accessible location.
i) Be run in close proximity to hot piping and components.
j) Create trip hazards or block frequently serviced components.
k) Be supported from process piping

NOTE Refer to NFPA70 Article 344 for rigid metal conduit and Article 350 for liquid-tight flexible metal conduit.

17.7.5 Flexible Metal Conduit

Flexible metallic conduit and fittings, if used, shall be liquid-tight, listed, include equipment bonding conductor as per NFPA 70, and suitable for the specified area classification.

For Class I Division 2 locations, flexible metallic conduit shall have a liquid-tight, thermosetting or thermoplastic outer jacket. For a Class 1 Division 1 location, an NFPA approved explosion proof flexible coupling and approved fittings shall be provided.

Conduit used for temperature sensing elements shall terminate with a flexible metallic conduit of sufficient length to permit access for maintenance without removal of the conduit. All other conduit terminations may use flexible metallic terminations for the same purpose. Flexible conduit length shall be minimized.

17.7.6 Conduit Seals

Unions suitable for the area classification shall be located between seals and equipment so that the equipment may be removed for maintenance or replacement.

Conduit seals shall not be packed or poured prior during fabrication unless specified by purchaser.

17.8 Wire and Cable

17.8.1 General

All wiring (including power and instrumentation leads) within limits of any skid area shall be installed in accordance with the area classification as specified by the purchaser.

All wiring shall be resistant to heat, moisture, and abrasion. Stranded copper conductors shall be used within the confines of the skid and other areas subject to vibration. All wiring shall be suitable for environmental/ambient temperatures.

All wiring shall be protected against mechanical damage, properly supported to minimize vibration, heat, moisture, and isolated or shielded to prevent interference between voltage levels.

All electrical wiring systems shall comply with manufacturer's specifications and all applicable codes and regulations.

All cable and wire shall be stranded copper, listed and labelled per NFPA 70, and approved for the service environment and rating. All wires should be continuous without joints or splices.

NOTE Where AWG is specified in this Section, wire size with area equal to or greater than the cross-sectional area of the specified AWG is acceptable.

17.8.2 Insulation

Proper lubrication and care must be taken to ensure that all cables and wire are pulled without damage to the conductors or insulation material.

17.8.3 DC Control Wiring

24 volt DC control wiring shall be single-pair, multiple-pair or multiple-conductor cables rated 300 volts at 90°C (194°F) or greater with PVC jacket. Single-pair cables shall be constructed with individual shields, and multiple-pair cables shall be constructed with individual and overall shields.

The minimum conductor size for instrumentation cable shall be #18 AWG for single pairs and triads and for multiple pairs and triads. Multiple conductor cables shall be #14 AWG.

17.8.4 AC Control Wiring

120 volt AC control wiring shall ~~should~~ meet NFPA 70 requirements, and be rated 600 volts at 90°C (194°F) or greater. The minimum conductor size for AC control wiring shall be #14 AWG.

17.8.5 Power Wiring

Low voltage (600 volts or less) power wiring shall meet NFPA 70 requirements, and be rated 600 volts at 90°C (194°F) or greater. The minimum conductor size for power wiring shall be #12 AWG.

17.8.6 Thermocouple Wiring

Thermocouple extension cables should be individual shielded pairs with PVC jacket and overall shield over multiple pairs. The ASTM E320/E320M E230/E230M type code for thermocouple extension cable must match the end device code (e.g., J, K, T, etc.). The thermocouple extension cable should be rated 300 volts at 90°C (194°F) or greater. The minimum conductor size should be #20 AWG.

17.8.7 Communication Wiring

Serial communication wiring shall be single-pair or multiple-pair cables rated 300 volts at 90 °C (194°F) or greater with PVC jacket. Single-pair cables shall be constructed with individual shields.

Ethernet cables shall be Cat 5e or Cat 6. Ethernet cables shall be constructed with individual shields.

Fiber Optic Cables shall be Single Mode OM1 or OM3 with LC Connectors.

17.8.8 Instrumentation Shielding

Instrument cable individual and overall shields should be grounded at one end only. This should usually be at the end of the cable run nearest the on-skid junction box or at the control panel controlling device. At the non-grounded end of the shield, the drain wire and shield should be cut flush with the end of the jacket and secured with heat shrink insulation taped. The jacket should end as close as possible to the single conductor termination points.

17.8.9 Terminations

All conductor splices, tags and terminations for power, control, instrumentation and drain wires and ground wires shall be made using pressure connectors or terminal blocks in junction or terminal boxes only, and lugs rated for the particular service and conductor.

Devices supplied with flying leads (leads not permanently attached to the device) may be terminated with wire nuts installed in fittings. Wire nuts shall be electrical taped.

17.8.10 Armored Cable

Unless otherwise specified, metal clad armored cabling with overall jacket of suitable polymeric material may be provided as an option in lieu of conduit. The cabling shall be protected from damage during normal maintenance operations. The cabling should be supported and may be attached to cable trays and installed with proper cable termination fittings and seals.

17.8.11 Cable Seals

All cable seals shall be packed or poured prior during fabrication unless otherwise specified by purchaser.

17.8.12 Cable and Wiring System Optional Features

Consideration should be given to the use of the following optional cable and wiring features:

a) Halogen-free cables that will not cause corrosion to metals when burned.

NOTE 1: When halogen-containing cables burn in a fire, the gases generated in combustion of the sheathing and insulation may cause sufficient corrosion to metals that secondary effects after the fire are larger than damage caused by the fire itself.

b) Flame retardant cables that self-extinguish when the source of flames dies out.

NOTE 2: Fire resistant cables continue to maintain cable/circuit integrity during a fire, allowing emergency circuits, such as alarms and shutdowns, to function.

17.8.13 Color Coding

Color coding of wires and cables shall follow all applicable codes as required. Manufacturer standard color coding can be utilized if color coding is not identified by purchaser.

All ground wiring and cables shall be green or green with yellow stripe.

17.8.14 Wire Tagging

Unless specified by the purchaser, all instrumentation tagging shall follow ANSI ISA tagging requirements.

All wires should be identified at each termination point. Coding designation should correspond to the drawing(s) and indicate the service and relative position of the wire in the circuit. All tags and markers should be accessible for easy viewing. The packager should provide all required markers and tags, which should be of a permanent type that can withstand humid environments. Hand printed labels shall not be used.

17.9 Enclosures and Junction Boxes

17.9.1

Any on-skid junction box for termination of on-skid instrumentation should be a NEMA 4 steel gasketed enclosure with sub-panel as a minimum. The packager should furnish all materials for termination including terminals, wire-way, DIN rail, drains and grounding hardware to facilitate interconnection.

17.9.2

Unless otherwise specified, all terminal boards in junction boxes and control panels are not required to have at least 20% spare terminal points.

17.9.3

Terminals should be of the high-density type, rated for 600 volts up to 30 amps. Terminals should accommodate wire size to #10 AWG.

17.9.4

Terminal blocks should be mounted to DIN rails and supplied with all associated wire markers, labels, end stops, jumpers and fuse block sections.

17.9.5

Terminal blocks for use with thermocouple wiring should be specifically designed and approved for use with the particular type of thermocouple installed. A terminal block for the shield of each thermocouple extension wire should also be provided.

17.9.6

Each wire should terminate at a screw type terminal block or terminal strip without a ferrule.

17.9.7

Junction boxes should be provided with external grounding lugs and attached to the package skid with #2 AWG green insulated wire.

Precautions shall be taken in the installation of armored marine cable to avoid energizing the outer sheath.

17.9.8

Power Termination when not identified are assumed to be 75°C (167°F) rated.

17.10 Batteries

Batteries shall be safely enclosed and protected in battery boxes that are vented to atmosphere.

The batteries, and the box, should be secured in place, in a safe location that minimizes exposure of the batteries to personnel, ignition sources and significant vibration. The battery box should include a non-metallic cover, or a non-metallic liner, with a positive and secure means of closure.

A voltage regulator should be supplied by the packager in battery supply systems.

A lockable disconnect point should be supplied in battery supply systems to aid in energy isolation procedures

NOTE A best practice is to locate batteries as far away as practical from fuel sources.

Additional guidance for batteries is provided in Annex L.3.

17.11 Heat Tracing

Heat tracing shall be pre-installed and insulated prior to fabrication completion.

17.12 Fire and Gas Detection

Unless otherwise specified, the packager is not required to supply fire and gas detection.

17.13 Auxiliary Electric Motors

The packager shall specify the power, voltage, frequency, applicable motor specification, area classification, duty, temperature rating, and insulation class for all auxiliary motors being supplied.

17.14 Electric Engine Starting Systems

Unless otherwise specified, an electric starting motor with starter control is not required.

Unless otherwise specified, a battery set for the starting motor is not required

Battery sets shall have sufficient amperage to start the engine at the lowest specified ambient temperature and shall have sufficient overall capacity for 3 consecutive starts.

18 Corrosive Gases – H_2S and CO_2

18.1 General

When sour or corrosive gases are present in the specified gas analysis, the items covered in this Section are applicable.

MR0175[31]/ISO 15156[28,29] offers guidance to assist in selection of metallic materials that may have enhanced resistance to corrosion and sulfide stress cracking. Any specific requirements are subject to applicability, review, interpretation and mutual agreement of the purchaser and the packager.

In addition to requirements specified in this Section or in NACE MR0175/ISO 15156, the equipment manufacturer's and packager's recommendations should be consulted where sour or corrosive gas mixtures are present.

Both the purchaser and the packager shall review material selections to ensure those materials used in pressure piping, vessels, wetted valves and instruments, are suitable for the specified process gas mixtures, pressures and temperatures. Some common materials for corrosive gases are suggested in Annex H.

The packager shall specify all material selections and equipment design features that are included for compatibility with sour or corrosive gases. The purchaser is responsible for reviewing the material selections and equipment designs offered, to ensure the suitability for the intended application or service.

The purchaser is responsible for ensuring that the packaged compressor installation meets all codes and standards for operation as defined by the governing jurisdictional authority, including but not limited to those regulations associated with atmospheric venting of sour gas, and permissible release volumes and rates.

Warning - Hydrogen sulphide is extremely toxic and poses significant health and safety hazards to personnel. Specialized work practices and safety equipment are mandatory for services with gas mixtures containing even small amounts of hydrogen sulphide. Any concerns with respect to toxicity or safety, are outside the scope of this standard.

NOTE 1: These requirements are focused solely on the design and provision of materials that are expected to have a greater tolerance to the corrosive effects of H_2S and/or CO_2.

NOTE 2: The consequences of incorrect material selection can be significant. Best practice is to consult with experienced sources familiar with similar applications.

18.2 H_2S Concentrations

18.2.1 General

NACE Standard MR0175[31] defines minor and major concentrations of H2S based on total pressure and mol % or PPM content.

18.2.2 Minor Concentrations of H_2S

18.2.2.1 Definition of Minor H_2S Concentrations

A gas mixture is generally considered to have a Minor H_2S Concentration if:

a) H_2S mol % is less than 10% and total pressure is less than or equal to 0.45 MPa (65 psia), or
b) H_2S mol % at total pressure above 0.45 MPa (65 psia) is less than or equal to the mol % calculated by equation 4.

$$\text{mol \%} = C / P_t \tag{4}$$

Where, mol % = the maximum permissible molecular fraction of H_2S in the gas mixture, %

P_t = total pressure, MPa (psia)

C = 0.0345 MPa for P_t in SI units (5 psia for P_t in USC units)

18.2.2.2 Minimum Requirements for Gases with Minor H_2S Concentrations

Unless otherwise specified by the purchaser, where the H_2S concentration of the gas mixture is a minor concentration per 18.2.2.1, the following requirements shall apply.

a) The manufacturer's standard materials may be used in the compressor, pressure vessels, pressure piping, gas cooling systems and instrumentation.
b) Copper or copper alloys shall not be used for any gas wetted components.
c) All elastomeric seals shall be suitable for the specified gas analysis and the intended service.

d) All vents (including the crankcase breather) and drains shall be piped to the edge of the skid. Vents shall terminate to safe areas.

18.2.3 Major Concentrations of H_2S

18.2.3.1 Definition of Major H_2S Concentrations

A gas mixture is generally considered to have a Major H2S Concentration if:

a) H2S mol % is greater than 10% at any total pressure, or
b) H2S mol % is greater than 0.077% and total pressure is higher than 0.45 MPa (65 psia), or
c) At total pressure above 0.45 MPa (65 psia), H2S mol % is more than the mol % calculated by equation (4)

18.2.3.2 Minimum Requirements for Gases with Major H_2S Concentrations

Where the H2S concentration of the gas mixture is a major concentration per 18.2.3.1, the compressor and package shall be designed to avoid susceptibility to stress corrosion cracking and to prevent leakage of sour gas into the crankcase and into the atmosphere. Unless otherwise specified by the purchaser, the following minimum requirements shall apply.

a) All items b) thru d) in 18.2.2.2

b) The hardness of carbon and low alloy steel parts which come in contact with the process gas stream shall not exceed a hardness of Rockwell C22 and the yield strength shall not exceed 621 kN/m2 (90 ksi).

c) The base material of piston rods shall be either carbon steel with a maximum hardness of RC22 or stainless steel. A suitable hard coating shall be applied in the packing travel area. The rod material will be considered acceptable as long as the base hardness and yield strength remain within the manufacturer's specified values. Threads shall be rolled after heat treatment, and an increase in hardness around thread surfaces due to thread rolling is acceptable.

d) Packing and piston ring material shall be non-metallic.

e) A two-compartment distance piece per 6.9.2 Figure 3 (Type 2) or Figure 4 (Type 3)

f) A suitable distance piece vent, vacuum, and/or purge system shall be provided, in compliance with the compressor manufacturer's application requirements.

g) Compressor valve components shall be the compressor manufacturer's recommended material selection for the service.

h) All process gas wetted compressor cylinder bolting shall be ASTM A193 Grade B7M.

   NOTE: Cylinder and distance piece bolting outside the process gas containment are not considered "wetted".

i) Carbon steel pressure vessel materials shall have an appropriate corrosion allowance, 3 mm (1/8 in.) minimum

j) All instrumentation that comes in contact with the process gas (e.g., liquid level controls, shutdowns, bourdon tubes, process valves, pressure safety valves, etc.) shall be suitable for sour and corrosive gas service.

k) When specified by the compressor manufacturer, a compounded or synthetic cylinder oil lubrication system shall be provided complete with separate day tank, filters, valves, piping and appurtenances.

18.2.4 Optional Requirements

Depending on the criticality and severity of the service, the following additional requirements may be specified by the purchaser, the packager or the compressor manufacturer.

a) Suction port oil injection shall be used when carbon steel compressor valves are used.
b) Stainless steel compressor valve components.
c) Stainless steel tube fittings.
d) Erosional velocities should be considered for piping systems with two phase flow regimes. Maximum gas velocity can be calculated as follows in Equation 5:

In both SI and USC units:

$$V_e = \frac{c}{\sqrt{\rho_m}} \tag{5}$$

Where:
V_e = maximum velocity in m/sec (ft/sec)
ρ_m = gas density in kg/m^3 (lb/ft^3)
c = empirical constant for which API 14E recommends 122 using SI units (100 using USC units) for continuous service

e) Hydrogen Induced Crack (HIC) resistant fine grain carbon steel should be used for pressure vessel material.
f) No threaded connections in carbon steel piping, pulsation bottles and scrubbers.
g) Threaded shoulder plugs with soft iron or stainless steel gaskets on cooler headers
h) A corrosion resistant alloy steel for process gas cooler tubes.
i) 100% radiographic testing for all process piping, pulsation bottles and scrubbers.
j) Ultrasonic or radiographic testing for process gas cooler headers.
k) Post weld heat-treatment for all carbon steel process piping, pulsation bottles, scrubbers and cooler headers.
l) Electronic H_2S monitoring and alarm systems.

18.2.5 Other Requirements

Gas containing H_2S shall not be used in engine starters.

18.3 Carbon Dioxide

18.3.1 General

In the presence of water, CO_2 can cause corrosion of unprotected iron and steel components. This can be severe during idle periods when metal temperatures are low. Figure 10 may be applied to determine the requirements when CO_2 and water are present in the specified process gas analysis.

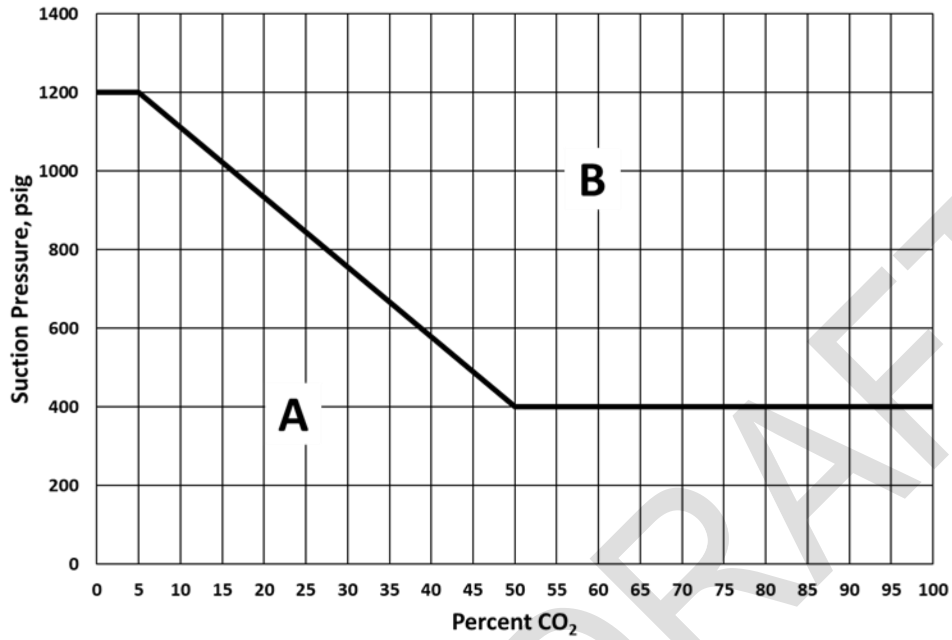


Figure 10 – Allowable CO_2 Concentration

18.3.2 Concentrations of CO_2 in Region 'B'

Unless otherwise specified by the purchaser or the packager, for CO_2 concentrations within Region B of Figure 10, the packager's and manufacturers' standard materials shall be used in the compressor, cooling system and package.

18.3.3 Concentrations of CO_2 in Region 'A'

Unless otherwise specified by the purchaser, for CO_2 concentrations within Region A of Figure 10, the following minimum requirements shall apply.

a) All elastomeric seals shall be suitable for the specified gas analysis and the intended service.
b) The base material of piston rods shall be stainless steel with a suitable hard coating in the packing travel area.
c) A two compartment distance piece per 6.9.2 Figure 3 (Type 2) or Figure 4 (Type 3).
d) When specified by the compressor manufacturer, a compounded or synthetic cylinder oil lubrication system shall be provided complete with separate daytank, filters, valves, piping and appurtenances.
e) Compressor valve components shall be stainless steel or the compressor manufacturer's standard for CO_2 service.
f) Suction port oil injection shall be provided when carbon steel valves are used.
g) Tube fittings shall be stainless steel.
h) All process gas wetted compressor cylinder bolting shall be stainless steel.

   NOTE: Cylinder and distance piece bolting outside the process gas containment are not considered "wetted".

i) All instrumentation that comes in contact with the process gas (e.g., liquid level controls, shutdowns, bourdon tubes, process valves, pressure safety valves, etc.) shall be suitable for corrosive service.
j) Erosional velocities should be considered for piping systems with two phase flow regimes. Maximum gas velocity can be calculated using Equation (5) in 18.2.4 (d).

18.3.4 Process Piping Shut Down and Maintenance Purge

Unless otherwise specified, the packager shall make provision for venting and purging of the process gas system for shut down and maintenance purposes.

NOTE: Leaving gas compressor systems with sour or corrosive gas mixtures pressurized while shut down for extended periods can form corrosive acids that damage metallic components.

19 Offshore and/or Marine Environments

19.1 General

The objective of this Section is to define the appropriate design practices to consider in addition or in substitution to items required in other Sections, when a packaged reciprocating compressor is to be in an offshore, marine or coastal environment.

19.2 External Parts

Unless otherwise specified, all components, other than those listed below, shall be painted, or otherwise coated to protect against corrosion.

a) Galvanized steel grating, stairs and associated galvanized fasteners
b) Concrete structures
c) Any component made of plastic and plastic coated materials
d) Any component made of nonferrous material
e) Mating machined surfaces
f) Stainless steel

External parts subject to rotary or sliding motions (such as control linkage and adjusting mechanisms) should be of corrosion resistant materials suitable for the site environment.

19.3 Electrical Area Classification

The purchaser shall specify any additional regulatory electrical area classification requirements.

NOTE: API 500 and API 505 provide guidance regarding electrical area classification.

19.4 Natural Gas Engine

19.4.1 Air Intake System

All components of the off-engine air intake system shall be made from stainless steel or other non-corroding material.

Paint or similar coating shall not be applied to the internal surfaces of combustion air ducting downstream of the air filter.

19.4.2 Exhaust Silencer

The exhaust silencer, spark arrester, flexible ducts and connections shall be manufactured of stainless steel or other non-corroding material.

19.5 Electric Motor

The motor manufacturer shall be notified of the offshore service conditions.

19.6 Compressor

19.6.1 Tubing and fittings

The tubing and fittings located on the compressor shall be stainless steel.

19.6.2 Dry Sump

The purchaser shall specify the roll and pitch of the vessel to determine whether a crankcase dry sump system might be required.

19.7 Cooling system

19.7.1 Air Cooled Heat Exchanger

Unless otherwise specified:

a) The cooler structure and section side frames (a metal support which is used to assemble the header boxes together prior to the tubes being installed) shall be hot dip galvanized or zinc metalized.
b) Carbon steel cooler headers shall be zinc metalized.
c) Cooler tubes shall be made of chloride resistant materials. If carbon steel tubes are used, the bare tube ends shall be epoxy coated.
d) Cooler tube fins shall be made of marine-grade aluminum, such as 5005 aluminum alloy.

19.7.2 Shell and Tube and Plate and Frame Heat Exchangers

When seawater is used as a cooling medium any components exposed to seawater shall be made of chloride resistant materials. The purchaser shall specify the maximum seawater outlet temperature.

19.8 Skid

19.8.1 General

For offshore installations, use of concrete shall be avoided.

The purchaser shall specify the skid mounting method and underlying support structure.

The purchaser is responsible for a skid dynamic analysis per 23.4 with the analysis including the underlying support structure.

The purchaser may specify baseplate design and fabrication requirements to minimize corrosion.

Typical requirements might include seal welding, sealed compartments, inspection hatches and weld debris removal.

19.8.2 Forced Mechanical Response Analysis

For any package installed on a fixed or floating offshore structure, a forced mechanical response analysis of the compressor package and process piping shall be conducted if the package is larger than 373 kW/throw (500 hp/throw), larger than 746 kW (1000 hp) in total, or if the gas rod load harmonics of 3X or higher are greater than 5% of rated rod load for bottles on a single cylinder or greater than 7.5% of the vector sum of forces at each order for bottles on two or three cylinders.

The analysis shall consider the mass and static stiffness of the underlying support structure and cover the frequency range from 0 Hz to the lesser of 150 Hz or 10X.

NOTE: A best practice is to carefully look for all significant excitation frequencies and conduct the analysis up to at least 1.5 times the highest significant excitation frequency. Analysis at higher frequencies may be prudent in some cases.

The mechanical natural frequencies of the package shall not fall within the frequency ranges of +/-20% of the main excitation frequencies below 35 Hz, and +/- 10% of the main excitation frequencies above 35 Hz.

19.8.3 Drip Lip

Unless otherwise specified, the skid shall be furnished with a minimum 77 mm (3 in.) drip-lip and shall be furnished with a minimum 51 mm (2 in.) NPT drain connection in each corner, and from any trapped volume in the baseplate. This drain system is not intended as secondary containment.

19.9 Marine Transportation

The packager shall make provision for securing the package during marine transport (sea-fastening). The purchaser shall specify the maximum pitch and roll angles of the marine transport vessel. Unless otherwise specified the package sea fasteners shall be designed for 0.5 G horizontal acceleration.

19.10 Control and Instrumentation Systems

19.10.1 Instrument Housings

Instrument housings shall be made of corrosion resistant materials such as AISI 316. When approved by the purchaser, non-metallic UV resistant housings may be used.

19.10.2 Control panel construction

If the package is supplied with a control panel, it shall be made of AISI 316L stainless steel.

19.10.3 Junction boxes

For compressor packages using a remote-control panel, instrumentation junction boxes shall be located at the edge of the package.

Junction boxes shall be made of AISI 316L stainless steel or UV resistant non-metallic material.

19.10.4 Cable glands

Cable glands shall be supplied with serrated washers to ensure positive grounding to metallic junction boxes or ground tags for non-metallic junction boxes.

19.10.5 Tubing and fittings

Unless otherwise specified, tubing and fittings shall be AISI 316 stainless steel or higher grade material.

19.11 Valve Material

Valves 38 mm (1½ in.) and smaller in gas service should have a stainless-steel stem.

19.12 Painting and Coating

19.12.1 General

Unless otherwise specified by the purchaser, the surface preparation, paint and application shall be in accordance with the packager’s severe duty or marine coating specification. The packager’s painting specification shall be submitted in the proposal for the purchaser's review. The purchaser should carefully review the packager’s paint and coating specifications, application and inspection procedures in order to ensure that adequate surface preparation, coverage and film thicknesses are achieved in all required areas of the package

19.12.2 Surface Preparation

Unless otherwise specified by the purchaser, surfaces should be prepared for painting in accordance with Table 8:

Table 8 – Method of Surface Preparation

Component	Normal Environment	Severe Corrosive/Marine Environment
Engine, Compressor, Coolers, Valves, Control Panels and Exhaust Silencer	Manufacturer Standard	Manufacturer Standard
Skids, Scrubbers, Bottles, Piping and Support Structures	SSPC-SP6 (Commercial blast cleaning)	SSPC-SP10 (Near white metal blast cleaning)

19.12.3 Application

19.12.3.1

Unless otherwise specified by the purchaser, paint shall be applied to the coating manufacturer’s specifications.

19.12.3.2

Paint should be applied by spray to obtain a minimum dry film thickness as specified by the paint manufacturer.

19.12.3.3

Unless otherwise specified, hoses, wiring harnesses, grounding lugs, name and data plates, safety placards, finish painted instruments, non-metallic products, rotating parts of machinery, machinery mating surfaces, finned tubes surfaces, belts, sheave grooves and temporary closures should not be painted. Painting of corrosion resistant components is not required.

19.13 Inspection Testing and Documentation

Unless otherwise agreed, the packager shall measure and log the following as a minimum:

a) Blast profile for each item
b) Date, time, temperature and relative humidity when each coat is applied to each item
c) The dry film thickness of each coat
d) Any other critical parameter specific to the coating per the coating manufacturer

20 Marking and Documentation

20.1 Rotation Arrows

Rotation arrows shall be cast in or attached to each major item of rotating equipment.

20.2 Material

Nameplates, rotation arrows and fasteners shall be metallic corrosion resistant material.

20.3 Legibility

Nameplates shall be stamped or otherwise permanently marked with characters that are neat and will remain legible for the life of the equipment.

20.4 Package Nameplate

The package shall include a nameplate. The nameplate shall include packager's name, date of fabrication, job number and be securely affixed in a conspicuous place.

20.5 Warning Signs and Labels

The purchaser and packager shall agree on the number and location of warning signs and labels.

Warning labels applied to major components by the original equipment manufacturer shall be left intact and legible, except when no longer applicable due to package design.

All warning signs and labels shall be securely affixed in conspicuous places and/or where the hazards exist.

NOTE Warning signs and labels typically identify hazards such as rotating machinery and belts, electric shock, and confined spaces. In addition, safety markings communicate basic information such as energy isolation points, maximum load ratings, and safe starting/loading/shut down/purging.

21 Cold Weather / Enclosed Package

21.1 General

The objective of this Section is to define the appropriate design practices to consider in addition or in substitution to items required in other Sections, when a packaged reciprocating compressor is subject to one or more of the following:

a) located in areas where the ambient temperature may drop below 5˚C (40˚F)
b) subjected to significant frost or snow
c) installed within an individual building or enclosure

NOTE 1: The minimum ambient temperature is not a strict limit as to when cold weather design practices should be included. There are numerous environmental factors that need to be considered in assessing a minimum ambient design temperature, including frequency and duration of low temperatures, dew point, expected snowfall, etc. Below 5˚C (40˚F) there is risk of freezing or ice formation in unprotected equipment, impaired flow of lubricants, and inability to start cold equipment.

NOTE 2: Enclosed packages are generally understood to be individual packages inside a building supported by the package skid. However, there are many other ways a package may be enclosed such as a specialized housing or inside a common building. Regardless of how the package is enclosed, it should be reviewed against the requirements of this Section. Communication between the purchaser and packager is critical to facilitating a safe and reliable package.

Additional guidelines and best practices for enclosed packages and cold weather conditions are provided in Annexes I, N.4 and S.2

21.2 Equipment Manufacturers Requirements

The equipment manufacturer or packager's recommendations should be consulted for operation in low ambient temperature environments.

All electrical equipment shall be suitable for the designated indoor electrical area classification, which may differ from the area classification for outdoor fixtures.

21.3 Engine and Compressor

The packager shall provide the engine and compressor manufacturer's specified lubricating oil requirements in the operating manuals. The purchaser should exercise care and diligence to ensure that appropriate lubricant types and viscosities are used.

When on-skid lubricating oil storage tanks are specified for outdoor cold weather installation, the packager shall furnish the insulation and heat tracing that is necessary on the tank and piping to ensure adequate oil flow is supplied to the oil level regulators.

21.4 Starting Control Logic

The control logic shall prevent the package from starting if the crankcase (compressor, engine or both) oil temperature is below the temperature limit specified by the manufacturer. On gas engine drive units, the control panel logic shall prevent the engine from starting if the jacket water temperature is below the minimum specified by the manufacturer.

When the unit control panel is not furnished by the packager, the Purchaser shall ensure any minimum temperature starting interlocks are incorporated into the control panel logic system.

21.5 Lubricating Oil and Jacket Water

21.5.1

Unless otherwise specified, for cold starting at the minimum ambient temperature, a suitable crankcase oil and/or jacket water heating system is not required. The packager shall specify the heating system type, any electric power supply requirements or heat medium circulation fluid and temperature.

21.5.2

When specified, circulating heating systems shall be installed in the engine or compressor piping systems at the specific tie-in locations specified by the engine or compressor manufacturer. Circulating systems shall have adequate isolation valves to permit maintenance of the system components.

21.6 Combustion Air

Unless otherwise specified for operation at the minimum ambient temperature, an engine combustion air heating system is not required. Consideration should be given to the location of engine combustion air intake piping, routing away from areas where snow or ice can accumulate and be ingested**.**

21.7 Piping and Pressure Vessel Considerations

Any piping that may contain liquid pockets, should have accessible low point drains.

Unless otherwise specified, insulation and heat tracing of any outdoor vessel liquid sections, drain lines or piping that may contain liquid water and are vulnerable to freezing are not required

21.8 Air-Coolers

21.8.1

The packager or air cooler manufacturer shall ensure the cooler fan performance has been calculated at the minimum ambient temperature to ensure the fan and fan drive system or motor are not overloaded in cold weather. The cooler fan should be capable of operation at the design blade pitch and speed setting throughout the maximum to minimum ambient temperature range. If a reduced fan blade pitch is required for low ambient temperatures, it shall be specified and any limitations clearly stated in the operating information.

21.8.2
The packager shall ensure that cooling sections and piping systems are fully drained of water used for hydrotest or shop run test.

21.8.3
Unless otherwise specified, water cooler sections shall be designed for the use of a coolant mixture of 50% ethylene or propylene glycol and demineralized water.

21.8.4
When specified by the packager or the purchaser, a variable speed driven fan and/or either manual or automatic temperature controlled louvers shall be furnished on one or more finned tube cooling sections.

NOTE: This can be effective for minimizing the risk of freezing of liquids within cooler sections and/or generating excessive gas condensation or hydrate formation.

21.8.5
Variable frequency drive (VFD) is recommended for electric motor driven cooler fans. All cooler drive electric motors shall be rated for inverter duty. Unless otherwise specified, the purchaser shall furnish the VFD.

21.8.6
The purchaser or the packager should consult with the cooler supplier to determine whether a warm air recirculation system (a system designed to recirculate warm exhaust air to the inlet) and/or other increased approach temperature design is recommended or will be required to minimize the risk of freezing, hydrate formation and/or excessive condensation in individual gas cooling sections.

21.8.7
Gas cooler headers should be free draining to minimize the accumulation of liquid.

21.8.8
When specified by the packager or the purchaser, methanol injection nozzles shall be furnished upstream of each gas cooler section inlet nozzle.

21.9 Outdoor Instrumentation

21.9.1
All instruments shall be suitable for the ambient conditions in which they are installed. Where this is not possible, instruments installed outdoors or unprotected shall be winterized.

21.9.2
The following requirements for instrumentation located outdoors should be considered, and if deemed applicable, should be specified by the purchaser or the packager:

a) An electric heater should be furnished inside the unit control panel.
b) Outdoor level gages, bridles and chambers should be protected and winterized by furnishing insulation and heat tracing.
c) Where wet process gas is used for instrument gas supply, it should be supplied through a coalescing filter to prevent liquids from condensing and/or freezing at low ambient temperatures.

d) The Purchaser shall provide a clean and dry instrument air or gas supply at all operating and ambient temperatures and pressures.
e) Removable insulation blankets should be furnished on outdoor control valves or regulators.
f) Instrument sensing lines or capillaries should be protected.

21.10 Buildings and Enclosures

21.10.1

Steel buildings or enclosures generally used for oilfield production equipment including packaged gas compressors may be rigid frame type affixed to a foundation surrounding the packaged compressor skid, or self-framing steel type that is supported on the compressor skid as a complete module.

Except as specified in this Section, the design of these buildings including materials, insulation, coatings, roof pitch, wind, snow and seismic loads, construction, etc., is outside the scope of this specification. Unless otherwise specified by the purchaser, where buildings are used, the Purchaser shall be responsible for ensuring that the building classification and design is appropriate and compliant with any prevailing codes and standards.

21.10.2

The following requirements for buildings and enclosures housing a gas compressor package should be considered and, if deemed applicable, should be specified by the purchaser or the packager.

a) Where a self-framing building is installed and supported on the compressor skid, the skid lifting lugs should be designed to facilitate lifting and moving the module with the building installed.
b) Where supplemental building heating is required, the design case should be with the unit shut down at minimum ambient temperature.
c) Where a building is provided, the governing design case for ventilation should be with the unit operating at rated power at maximum ambient temperature.
d) Engine combustion air may be drawn from inside the building or ducted outside to an appropriate location. A diverting duct may be furnished to select inside/outside combustion air.
e) Where combustion air is drawn from inside the building, adequate replacement air vents should be provided. Engine air filter housings should be located to provide suitable access to service engine air filters.
f) Careful consideration should be given to routing of intake and exhaust ducting, to facilitate maintenance access. Exhaust gases must terminate outside the building in a safe location.
g) The complete exhaust piping system inside the building or other enclosure shall be insulated. The insulation on flanges and expansion joints shall be removable and reusable.

   NOTE: Insulating the exhaust piping system provides personnel protection, reduces heat radiation, reduces a potential ignition source and limits exhaust heat loss.

h) Safe egress of personnel and access to equipment necessary for routine and major maintenance should be considered in the design.
i) On an enclosed package, unless otherwise specified, a service crane shall be provided to lift heavy items for maintenance and repair. The load rating of the crane shall be clearly identified, and the crane should be compliant with all applicable codes and standards. The crane should be sized to lift the heaviest compressor cylinder body. The purchaser shall specify any requirement for a parts lay-down area within the building.
j) Fill and drain connections for clean oil, waste oil and coolant shall be accessible.
k) The purchaser and packager shall agree on the provision for spill containment.

l) Adequate lighting for operation and maintenance, including exterior entrances and landings, shall be provided.
m) The purchaser shall specify any requirement for combustible or toxic gas detection systems and/or UV flame detection systems.
n) Combustible gas vents shall terminate outside the building to a safe location. These vents may include the following:
    1) Instruments, including valve bonnets, pneumatic controllers, etc
    2) Pressure safety valves
    3) Pressure regulating valves
    4) Engine starter exhaust
    5) Compressor cylinder capacity control devices
    6) Distance pieces
    7) Piston rod packing
    8) Pneumatic motor and pump exhaust
    9) Fuel gas vent valve
    10) Compressor and engine crankcase vents
    11) Blowdown vents

22 Pulsation, Mechanical Vibration, And Piping Flexibility Analysis And Control

22.1 General

The objective of this sub clause is to define the appropriate design practices to, where possible, reduce the dynamic forces from the many sources of reciprocating compressor mechanical and pulsation-induced vibration to reasonable levels. In addition, it is to minimize the amplification of these forces to prevent excessive vibration and dynamic stresses.

NOTE: In the design of the compressor system to accomplish pulsation and vibration control, it is important not to sacrifice equipment access and maintainability.

22.2 Requirements

22.2.1 General

All references to API Standard 688 in this Section 22 shall mean API Standard 688, 2nd Edition. Unless otherwise specified by purchaser, the requirements for pulsation and vibration control shall be in compliance with API Standard 688, except that the requirements of this Section 22 shall take precedence over any requirements of API Standard 688.

22.2.2 Required Studies and Analyses

Purchaser shall specify the pulsation, mechanical vibration and piping flexibility studies that are required to be performed by the packager.

NOTE: In some cases, the purchaser or a third-party engineering company, rather than the packager, may have direct responsibility for all or some studies. In all cases, it is important that pulsation and mechanical vibration studies are completed for the package and connected system.

Purchaser shall specify the Design Approach (i.e., either Design Approach 2 or 3) according to the requirements of Table 1 in 5.1.4 of API Standard 688.

Packager’s proposal shall include separate line items for each study specified by purchaser and any additional studies recommended by packager.

22.2.3 Preliminary Sizing of Pulsation Suppression Devices

Packager's proposal shall specify preliminary pulsation suppression devices, including as a minimum, the outside diameter, seam-to-seam length, and MAWP of each device. The preliminary sizing shall be determined using one of the following methods: Preliminary analysis by a pulsation study supplier, or the GMRC Preliminary Field Gas Compressor Bottle Sizing Procedure (see Annex F), or packager's proprietary method that is identified and described with the proposal, or other method specified by the purchaser.

NOTE 1: Preliminary sizing of pulsation suppression devices is completed in the compressor package proposal stage, prior to the pulsation study, to provide a basis for costing and evaluation of the proposal. Actual final designs will be based on the final pulsation study results and may be different than the preliminary sizing.

NOTE 2: Compressors operating at speeds of 900 rpm or higher may require the use of properly designed low-pass acoustic filters as discussed in API Standard 688.

Inlet scrubbers utilized as one of the volumes in the suction acoustic filter, shall consider the effect of the internal gas volume variation as the liquid volume changes.

NOTE 3: The volume requirements of 5.1.1.2 of API Standard 688 typically result in bottles that are too large for use on packaged high-speed reciprocating compressors, resulting in excessive weight that lowers mechanical natural frequencies.

22.2.4 Pre-study

When a pre-study is performed according to 5.1.5.4 of API Standard 688 without definition of the on-skid and/or off-skid connected piping, the maximum allowable pressure pulsation level at the pulsation suppression device line-side nozzle flange shall not exceed 50% of the allowable value defined in 5.1.7.4 of API Standard 688.

NOTE 1: The pre-study is typically performed as the first step of the pulsation analysis.

NOTE 2: Experience has shown that, when the connected piping system is not included in the study, a more conservative pulsation control approach is needed. This is especially important for high-speed compressors, which also frequently operate on common headers with multiple units in parallel.

22.2.5 Mechanical Natural Frequency Analysis of the Compressor System and Piping System

For the mechanical natural frequency analysis (Step 3a) specified in 5.1.6.2.1 of API Standard 688, the Finite Element Method (FEM) shall be used for calculating piping system mechanical natural frequencies to determine whether or not the separation margin guidelines are met.

NOTE 1: Experience has shown that the finite element method with appropriate boundary conditions is required for designing frequency avoidance in high-speed compressor systems.

NOTE 2: The mechanical natural frequency analysis of the piping is best done concurrently with the thermal flexibility analysis, with both analyses conducted by the same supplier.

22.2.6 Maximum Allowable Pressure Pulsation at Compressor Cylinder Valves

Unless otherwise specified by the purchaser of the pulsation study, the requirements for maximum allowable pressure pulsation at the compressor cylinder valves in 5.1.7.3 of API Standard 688 shall not apply.

NOTE The accuracy of predicted pulsations at the compressor cylinder valves is limited by the simplified model that is typically used to represent the complex compressor cylinder gas passages between the flanges and the valves. For low (e.g., <1.5) pressure ratio applications where valve losses have a greater influence on performance, a best practice is for the packager to review the performance predictions of the pulsation analysis with the compressor and/or valve manufacturer.

22.2.7 Separation Margins

22.2.7.1

If the separation margin requirements of 5.1.8.2 of API Standard 688 cannot be met in a particular mode shape predicted in the vibration response of the packaged compressor system, including the compressor, pulsation suppression devices, scrubbers or piping systems, then with agreement of the purchaser of the study and the packager, the alternative criteria of this Section may be applied.

NOTE 1: The term “X” refers to multiples of the running speed, e.g., 1X is the fundamental frequency of running speed, 2X is 2 times the fundamental frequency of running speed, etc.

NOTE 2: 5.1.8.2 of API Standard 688 requires that the minimum natural frequency of any compressor or piping system element be greater than 2.4X, and that predicted natural frequencies be separated from significant excitation frequencies by at least 20%. This is often difficult to achieve for high-speed compressors. Several other guidelines have been found to be reliable for application without requiring a forced response analysis.

22.2.7.2

When the separation margin requirements of API Standard 688 cannot be met for a pulsation suppression bottle, scrubber or piping for a fixed speed compressor, the predicted mechanical natural frequency shall be located between 1.2X and 1.6X the fixed speed.

22.2.7.3

When the separation margin requirements of API Standard 688 cannot be met for a pulsation suppression bottle, scrubber or piping for a variable speed compressor using less than 100 horsepower/throw at running speeds ≥1400 rpm, the minimum predicted mechanical natural frequency shall be at least 1.2X the maximum rated speed.

22.2.7.4

When the requirements of 22.2.7.2 or 22.2.7.3 and the requirements of 5.1.8.2 of API Standard 688 cannot be met for the compressor system, a forced mechanical response analysis (Step 3b1) per 5.1.6.3 of API Standard 688 shall be performed.

22.2.7.5

When the requirements of 22.2.7.2 or 22.2.7.3 and the requirements of 5.1.8.2 of API Standard 688 cannot be met for the piping system, a forced mechanical response analysis (Step 3b2) per 5.1.6.4 of API Standard 688 shall be performed.

22.2.7.6

If, during the design analysis phase, it is not reasonably possible or practical to design all the package components with predicted mechanical natural frequencies that are compatible with operation over the package’s specified speed range, the following requirements apply:

a) The study supplier shall promptly advise the study purchaser of this limitation during the design phase.

b) The study purchaser and the study supplier should consider the implications of the limitation and agree on necessary configuration or operational changes.

c) The study purchaser should inform and recommend to the package purchaser that before the package begins continuous operation, the package purchaser should conduct field testing of the package to determine whether vibrations will be acceptable. Where vibration is not acceptable and reasonable changes cannot be implemented to reduce vibration to acceptable levels, control methods, e.g., blocked out speed ranges or avoided load steps, should be used to prevent continuous operation within such speed range(s) where vibration is unacceptable.

NOTE: The design of a high-speed compressor package to avoid all package component mechanical natural frequencies over wide speed ranges is difficult to achieve, and it requires a detailed analysis of the entire package. An ideal practice is to complete the basic package design and a sufficient level of analysis to confirm that the packaged system can be operated with acceptable predicted vibration levels throughout the intended speed range and with all necessary load steps, prior to package order placement. When this practice is not followed, there is a risk that the analysis will predict that it is not possible or practical to design the packaged system to operate within vibration guidelines at all intended speeds and load steps. As soon as such predictions are known, after the study supplier has explored reasonable design alternatives with the packager, it is important for all stake holders, including the study supplier, the study purchaser, the packager and ideally, the end user, to be promptly brought into a discussion of the implications and to agree on possible solutions.

22.2.7.7

When the forced mechanical response analysis of the piping system (step 3b2) predicts vibration limits that exceed the limits specified in 5.1.6.4.1 of API Standard 688, the approval of the packager and the purchaser of the study shall be required for use of the cyclic stress limits of 5.1.7.7 of API Standard 688 as the acceptance criteria.

NOTE 1: Since vibration is often a basis for end user acceptance of compressor packages and piping, whenever Step 3b2 predicts vibrations that are higher than the specified limits, it is important that the packager, the study purchaser, and ultimately, the package purchaser and end user, are alerted of the situation and that they approve the use of cyclic stress acceptance criteria for Step 3b2.

NOTE 2: Small bore piping and attached instrumentation are not typically included in the analysis model. If the cyclic stresses are predicted to be acceptable, there is still an increased risk of elevated vibration and stress in those attached components. Best practice is for those components to be examined carefully during the analysis phase, to ensure that they will not be adversely affected by allowing vibration beyond the limits of API standard 688 5.1.6.4.1.

22.3 Acoustic Simulation

Time-domain acoustic simulations including non-linear fluid dynamics and time-varying boundary conditions should be used for packaged compressors applied at 900 rpm or higher. Frequency-domain acoustic simulations may also be used if they are performed by a pulsation study supplier having successful experience applying them to compressor systems with comparable speed, power and operating pressure.

22.4 Skid Dynamic Analysis

If specified by the purchaser of the study, a dynamic analysis of the compressor package skid shall be conducted and shall include:

a) A finite element model of the compressor, driver, skid structure and major skid-mounted components, including, where applicable, pulsation suppression devices, scrubbers and coolers.

NOTE 1: There are several methods of generating a finite element model of the compressor, e.g., a full detailed model of the compressor or a more simplified model with beam/spring elements. When a simplified model is used, accurate flexibility of the distance pieces and their connection points to the frame are critical to achieving good results.

NOTE 2: Skid-mounted coolers are normally modeled as a point mass on the skid.

b) Consideration in the model of the specific foundation specified by the Purchaser, e.g. reinforced concrete, caliche pad, driven piles, etc., that the package is to be used on, including the foundation dynamic properties.

NOTE 3: If, in the pulsation study supplier's judgement, the foundation is determined to be very stiff, compared to the skid, simple boundary conditions may be applied at the skid/foundation interface. If the foundation is flexible compared to the skid, such as in driven pile foundations, it is important to include a finite element model of the foundation, based on measured soil properties or proven proprietary methods.

c) Application of dynamic loads due to unbalanced inertia forces and couples, engine roll torque, vertical crosshead forces and gas rod loads (acting on cylinders causing "stretch").

NOTE 4: Pulsation-induced forces are often omitted from consideration in the skid flexibility analysis, as they are frequently negligible compared to the other dynamic loads. However, best practice is to include pulsation-induced forces (e.g., cylinder vertical, pulsation bottle and scrubber) if they are available at the time of the skid dynamic analysis.

d) Predicted (i.e., not field measured) skid analysis vibration acceptance criteria:
    1) the specified limits of the compressor and engine manufacturers,
    2) Pedestal limit of 8 mm/sec (0.3 in/sec) [0-to-peak], and
    3) Main skid limit of 5 mm/sec (0.2 in/sec) [0-to-peak] for mounting on concrete foundations, or
    4) Main skid limit of 8 mm/sec (0.3 in/sec) [0-to-peak] for mounting on piles and gravel pads.

(e) If required for controlling vibration, the study supplier should provide recommendations to the packager for structural stiffening of the skid.

NOTE 5: Pedestal and main skid vibration limits are for any individual direction and at any individual frequency.

NOTE 6: Field vibration acceptance criteria are typically higher than acceptance criteria for predicted vibration.

23 Torsional Vibration Analysis and Control

23.1 General

The objective of this Section 23 is to define the appropriate practices for preventing excessive torsional vibration and dynamic stresses in direct-drive configurations of packaged reciprocating compressor systems. Equipment configurations that employ gearboxes require specialized analytical procedures that are outside of the scope of this document.

NOTE 1: Reciprocating compressors inherently produce large torque amplitude fluctuations. These dynamic torques cause dynamic angular deflection and dynamic angular velocity superimposed on the steady rotational motion of the machine. If the torque variation is excessive, and/or if a harmonic (frequency) of the torque variation is near a torsional natural frequency, excessive torsional vibrations can result in fatigue failure of major driveline components (driver, coupling and compressor) and/or unacceptably high levels of vibration in and around the equipment installation. The risk of a torsionally-induced failure is exacerbated by the fact that high torsional vibrations and stresses are typically only revealed by specialized testing in the field.

NOTE 2: A best practice is to conduct a preliminary torsional review of the selected compressor and driver using "rule of thumb" sizing of coupling and stub shaft dimensions. This can highlight potential torsional problems associated with equipment selection and the intended operating speed range early in the design process.

NOTE 3: It is important to recognize that large speed ranges increase the likelihood of encountering prominent resonances that may require component modifications or restricting operation to a subset of speed ranges.

23.2 Requirements for the Torsional Vibration Analysis

23.2.1

A torsional vibration analysis (TVA) shall be performed for all driver/reciprocating compressor combinations, including duplicates of previously analyzed combinations if they are to be operated with cylinder unloading schemes or operating conditions that are different than previously analyzed.

The purchaser of the TVA shall ensure that the final operating conditions, equipment configuration and load steps are provided to the TVA provider for analysis.

23.2.2

The torsional vibration analysis shall include the following requirements:

a) Modeling of the mass-elastic characteristics of all the individual drive train components from the driver through the compressor.

NOTE 1: The compressor, coupling, and driver properties are integrated into a "system" torsional shaft model. Torsional responses, shaft stresses and safety factors, coupling torques, etc. are calculated for all critical elements at steady state operating speeds and conditions.

b) System components (compressor, motor or engine driver, and coupling) modeled and analyzed in multiple discrete elements as shown in Figure 11, using mass-elastic data provided by the component manufacturer(s) or calculated from detailed drawings and other information provided by the manufacturer(s). Unless specified by the purchaser of the TVA, cooler fan drives are not typically included in a torsional analysis.

   Mass-elastic elements should be created at significant changes in diameter, where significant inertia is added and where significant forces occur (such as at each compressor throw).

NOTE 2: Combining all elements of a component into a single lumped element is generally not a good practice as potential problems within the component can be missed in the analysis. The exception would be a synchronous motor wheel, which could be lumped as a single element. The exciter is modeled separately.

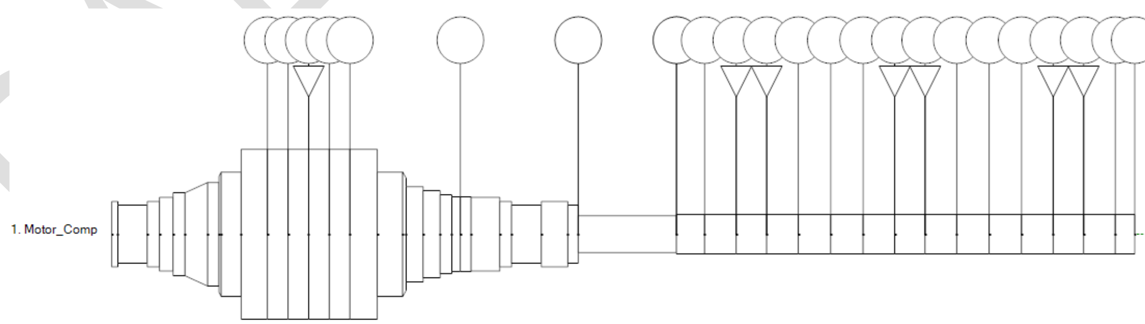


Figure 11 - Example of a torsional model with multiple discrete sections.

c) Evaluation of the torsional response relative to appropriate criteria.

d) Torsional natural frequencies coincident with 1X and 2X electrical line frequency should be avoided in motor driven systems, as large torques can be generated at these frequencies during start-up or due to current faults.

e) A forced response analysis with appropriate damping factors to ensure that torsional shaft stresses and design factors are acceptable.

NOTE 3: A direct-drive system without a damper and/or elastomeric coupling might have modal damping of 0.5% to 1.5%. However, torsional modes could be well damped for systems with engine dampers, compressor dampers, elastomeric couplings, etc.

f) Evaluation of response at anticipated machine operating conditions over the full speed range for the requirements of Table 9 and any other reasonably common or anticipated upset conditions.

Table 9 - Requirements for Torsional Vibration Analysis

Parameter	To Be Evaluated in Torsional Analysis
Speed	− Define operating speed range (RPM) − Analyze across full speed range (at appropriate increments so as not to miss any resonances).
Load Steps	− Define Load Step Sequence − As a minimum, evaluate at fully loaded and maximum unloaded cases. − Evaluate all load steps with single-acting cylinders. − Additional points to be evaluated if complex cylinder capacity control systems are employed, e.g., automatic variable clearance volume or valve control.
Upset Conditions	− Unless otherwise specified, compressor valve failures resulting in unintentional single-acting operation, will not be evaluated. − Engine misfire.
Resonant Speeds	− For variable speed applications, resonant points across the specified loaded speed range.
Transient Conditions	When specified by the TVA purchaser: − Synchronous motor start-up transients, if across-the-line. − Electrical faults, including short circuit. NOTE 5: A time transient analysis may not be required for a synchronous motor using soft starter.

g) Unless otherwise specified, an evaluation of synchronous motor driver transient torsional analysis for across the line starts, including low-cycle fatigue failure analysis, is not required.

h) Prompt notification of the Purchaser and/or packager if the TVA indicates potential torsional design issues that require changes such as larger couplings, torsionally soft couplings, flywheels, torsional dampers, detuners, limited operating speed range, etc. that are likely to affect the package cost, lead time, physical layout or operational flexibility.

i) Purchaser and/or packager approval of any changes required by torsional design issues referenced in item h).

NOTE 4: *GMRC Guideline and Recommended Practice for Control of Torsional Vibrations in Direct-Driven Separable Reciprocating Compressors*[38] provides additional detailed guidance for torsional vibration analysis.

23.3 Data Requirements for Torsional Vibration Analysis

Each component manufacturer shall promptly provide the accurate data required for the torsional analysis. Annexes E.1.1 through E1.4 list the reciprocating compressor, main drive coupling, reciprocating engine and electric motor driver data, respectively, required for a torsional analysis. Annex E1.5 lists the additional data required when the driver is an electric motor with a variable frequency drive.

23.4 Torsional Analysis Report

A torsional analysis report shall be provided that includes, as a minimum, a description of the analysis procedure, the mass-elastic model, the specific conditions and ranges of operating conditions considered in the analysis, interference plots, torque-effort data, computed stresses and design factors, and recommendations. When justified by a high level of uncertainty and/or risk indicated by the TVA, the report should recommend torsional vibration testing of the installed system.

NOTE: *GMRC Guideline and Recommended Practice for Control of Torsional Vibrations in Direct-Driven Separable Reciprocating Compressors*[38] provides additional detailed guidance for torsional vibration report content.

23.5 Torsional/Lateral Interaction

The TVA provider should consider torsional/lateral interaction.

NOTE: Annex E.3 provides additional explanation and guidelines for controlling torsional/lateral interaction.

23.6 Torsional Vibration Testing

Unless otherwise specified, the Purchaser shall be responsible for the implementation and cost of any torsional vibration testing.

NOTE 1: Annex E.2 provides guidelines for torsional testing.

NOTE 2: An on-site vibration and torsional startup survey during commissioning is a best practice to confirm that all recommendations to control vibration have been properly implemented, to identify any differences between the intended design and the as-built configuration, and to provide a baseline for reference in maintenance and troubleshooting.

24 Inspection and Testing

24.1 General

24.1.1 Inspection and Test Plan

The packager shall provide an inspection and test plan to the purchaser.

24.1.2 Notice to Vendors

The packager shall be responsible for notifying all vendors of the purchaser's inspection and testing requirements.

24.1.3 Purchaser Participation

The purchaser shall specify the extent of their participation in the inspection and testing program during the bidding phase and confirm prior to any fabrication.

24.1.4 Hold Points
The purchaser shall specify hold points on the inspection and test plan.

24.1.5 Witness Points
The purchaser shall specify witness points on the inspection and test plan.

NOTE: Witness points in the inspection and test plan means that the purchaser shall be notified of the timing of the inspection or test; however, the inspection or test shall be performed as scheduled, and if the purchaser or his representative is not present, the packager shall proceed to the next step.

24.1.6 Required Equipment
Equipment and consumables required for specified inspections or tests shall be provided by the packager.

24.2 Inspection

24.2.1 Historical Data
The packager shall keep quality control documentation at a minimum through the warranty period.

24.2.2 Types of Inspection
The purchaser and packager shall agree on the inspection and test plan.

24.2.3 Quality Control
Unless otherwise specified, it is not required for the purchaser's representative to have access to the packager's quality control program for review prior to the start of fabrication.

24.2.4 Cleaning
During fabrication and assembly of the system each component and all piping and appurtenances shall be cleaned to remove foreign materials, corrosion products, and mill scale. After cleaning, open ends of piping and vessels shall be suitably covered to prevent contamination.

24.3 Testing

24.3.1 Hydrostatic and Pressure Tests

24.3.1.1 Hydrotest of Packager Fabricated Components
The gas piping, pressure vessels and other welded pressure retaining components shall be hydrotested separately with water or solvent by the packager in accordance with an applicable code or at 150% of the maximum allowable working pressure, but not less than 345 kPa (50 psig).

24.3.1.2 Assembled Package Leak Test
Unless otherwise specified, it is not required for the assembled package to be tested for piping leaks. If required, air at approximately 689 kPa (100 psig) shall be used. Details of this test shall be as mutually agreed between purchaser and packager.

24.3.1.3 Test Period
Unless otherwise specified by the purchaser, the hydrostatic tests shall be satisfactory when no leaks are observed for a period of 30 minutes or a period as required by code.

24.3.2 Mechanical Running Tests

24.3.2.1 Compressor and Prime Movers

All compressors and prime movers shall be given the manufacturer's standard shop tests.

24.3.2.2 Engine-Driven Package Units

The engine-driven packaged unit, including all auxiliaries, shall receive the packager's standard shop running test prior to shipment. The test shall prove mechanical operation of the compressor, engine, mechanical accessory equipment, instruments, control system and skid-mounted cooler as a complete unit. The compressor does not have to be pressure-loaded for this test.

24.3.2.3 Motor-Driven Package Units

Details of motor-driven package unit mechanical running tests will be as mutually agreed upon between the purchaser and the packager.

24.4 Preparation for Shipment

24.4.1 Preparation

Equipment shall be suitably prepared for the type of shipment or storage as specified by the purchaser. If a storage period is specified, the purchaser will consult with the packager regarding recommended procedures to be followed. Proper storage of the unit is the responsibility of the purchaser.

24.4.2 Crating

Unless otherwise specified, it is not required that the equipment be crated for export shipment. Lifting, load-out, and handling instructions shall be securely attached to the exterior of the largest package in a well-marked weatherproof container. Unless otherwise specified, special lifting devices and rigging are not required to be supplied with the unit. Upright position, lifting points, weight and dimensions shall be clearly marked on each package.

24.4.3 Equipment Fluid Drainage

All equipment (including compressor, engine, cooler, etc.) shall be drained of coolant and oil prior to any shipment preparation unless otherwise specified by the purchaser.

24.4.4 Prior to Shipment

24.4.4.1 General

Preparation for shipment shall be made after all testing and inspection of the equipment has been accomplished and approved by the purchaser if required. The preparation shall include that specified in 25.4.4.2 through 25.4.4.5 as a minimum.

24.4.4.2 Exterior Surfaces

Unpainted or machined exterior surfaces shall be coated with a rust preventative.

24.4.4.3 Flanged Openings

All flanged openings shall be provided with appropriate closures.

24.4.4.4 Threaded Openings

All threaded openings shall be provided with appropriate closures.

24.4.4.5 Bevelled Openings

All openings that have been beveled for welding shall be provided with closures designed to prevent entrance of foreign material and damage to the bevel.

24.4.5 Data Book

Unless otherwise specified and noted in the VDDR (See Annex D), one copy of the packager's standard installation data book is not required to be packed and shipped with the package.

24.4.6 Loose Parts

Component parts, loose parts, and spare parts associated with a specific major item of equipment shall be clearly identified and appropriately packaged to avoid damage during shipment.

24.4.7 Temporary Closures and Plugs

Temporary closures and plugs shall be identified by tagging or bright color coding.

25 Vendor Data

25.1 Proposals

25.1.1 Scope

The proposal should include as a minimum, a detailed scope of supply that fully describes all equipment included, or not included, in the quoted price. The commercial section of the proposal should include Packager (or Vendor) Terms and Conditions. A list of comments and exceptions, if any, to API 11P and the purchaser's specifications or RFQ requirements should be provided in the proposal.

25.1.2 Technical Data

The following data should be included in the proposal:

a) Data sheets and literature or specifications for the major components to fully describe details of the offering(s). Major components are: compressor, driver, heat exchangers, vessels, pressure safety valves, control valves and the unit control system.
b) Compressor manufacturer's calculated design performance at the purchaser's specified operating conditions. Any specific limitations such as available power, rod load, process temperature or pressure, should be clearly stated in the proposal.
c) The manufacturers' predicted noise emission data for the major sources, and rated attenuation of any included silencers.
d) Environmental emissions data.
e) A schedule for shipment of the equipment in weeks after receipt of the order.
f) Details of any shipped loose or off-skid components that require field assembly by the Purchaser.
g) Details of lubrication and cooling systems including tank capacities, filters and pumps, and any special requirements.
h) Technical data related to any included compressor package building
i) Technical data of any included electrical system.
j) Statement of applicable piping and pressure vessel codes, materials of construction and MAWP of all piping systems
k) Inspection and test plan.
l) If requested, a list of recommended spare parts and any special tools required for commissioning and routine maintenance.
m) If requested, a reference list of similar machines built by the Packager, installed and operating under similar conditions.

n) A copy of the VDDR form (see Annex D for general description) indicating the schedule according to which the vendor agrees to furnish the data requested by the purchaser (see 26.2.3).
o) Details of any preservation or long term storage requirements.
p) Details of preparation for shipment.
q) Details of the shipping terms.

25.2 Contract Data

25.2.1 Vendor Drawing and Data Requirements (VDDR)

The purchaser and packager shall agree on Vendor Drawing and Data Requirements (VDDR, see Annex D for general description). The VDDR should list each of the expected deliverables in sufficient detail to inform the parties of the necessary content for drawings, documents, manuals, etc. This form prescribes the schedule for submission as agreed to at the time of order, as well as the number and type of copies required by the Purchaser. The time allowed for the Purchaser's review of drawings and data shall be specified in the VDDR.

25.2.2 Drawings

The drawings shall contain sufficient engineering information and detail necessary for safe and efficient installation and integration of the equipment by the Purchaser. Unless otherwise specified, drawings are not required to be certified by a professional engineer. Drawings shall be submitted in a format as agreed by the packager and purchaser.

25.2.3 Project Schedule

After receipt of the order, the Packager shall provide a project schedule that includes engineering and design time, manufacturing of sub-assemblies, and package assembly and testing. The schedule sets out the following details:

a) Purchase order dates and expected receipt of major components
b) Identifies all key work milestones and duration
c) Identifies all critical paths
d) Sets out dates for model reviews, other design reviews, HAZOPS, etc.
e) Identifies any witness tests, hold points, or inspections
f) Identifies final completion, packing and delivery or transfer of custody to the purchaser

The schedule should contain sufficient information and detail to enable the Purchaser to monitor progress and arrange witness of specified tests or hold points, if any. The Packager and Purchaser shall agree on project schedule reporting frequency and progress monitoring. When required, material expediting or manufacturing progress reports shall be specified on the VDDR.

25.2.4 Coordination Meeting

The Packager and Purchaser should jointly agree on an agenda and schedule for a post-award coordination meeting. The meeting should include a review of the following topics:

a) Packager's proposal and purchaser's purchase order, scope of supply and sub-vendor items.
b) Review of applicable specifications and any subsequent clarifications or exceptions.
c) Equipment datasheets.
d) Compressor performance (including operating limitations).
e) Schematics and bills of material for major items.
f) Preliminary arrangement of the equipment, this is often a 30% model review if available.
g) Instrumentation and controls, ESD for isolation, capacity control system operation, venting, or any other functional requirements.
h) Emissions, vents, consumables, cooling or lubricant fill volumes, disposal and supply access.
i) Scope and detail of planned engineering studies, piping stress, pulsation and vibration, and torsional analysis.
j) Packager's quality control program and the agreed ITP (Inspection and Test Plan) for the package.

k) Details of functional testing of the package or major components.
l) Other technical items, and review of Project Schedule.
m) Installation, start-up planning and training, spare parts if required.

Annex A
(Informative)

Project Management Responsibilities

A.1 General

The importance of good project management for the specification, design, construction and application of a reciprocating compressor package is emphasized in 4.5 of this specification. This Annex provides recommended project management responsibilities for the successful design and fabrication of reciprocating compressor packages. Sections 2.1, 2.2 and 2.3 of the *GMRC High-Speed Compressor Guideline For Field Gas Applications*[40] are acknowledged as the primary reference for this Annex.

There are many challenges involved in the specification, design, construction and application of a reciprocating gas compressor package. Good management is fundamental to any successful project, and this is especially true for complex and/or versatile compression applications. The minimum primary roles required for successful project management are a project manager, one or more inspectors, and an installation and commissioning coordinator.

A.2 Project Manager

It is important for the purchaser to assign a capable project manager, either an experienced employee or a qualified, experienced compression system consultant hired directly by the purchaser. It is also important for the purchaser to be engaged and involved in the project from planning through implementation, especially for key meetings that establish scope, kick-off the project, and review analysis findings and recommendations.

Best practice for purchased compressor packages (i.e., packages that are not rented or leased from compression rental fleets) is for the project manager and other purchaser representative(s) to be involved in regular reviews during the package design, analysis and fabrication processes. The project manager normally has the responsibility of reviewing the results of the pulsation and vibration analyses as they progress, to ensure that results are acceptable and that, where necessary, appropriate trade-off decisions are made between efficiency, reliability and cost.

A.3 Inspector

It is important for the purchaser to assign a knowledgeable inspector for the compressor fabrication phase at the packager's plant. The inspector normally verifies that the specified scope is provided, specifications are complied with, and any deviations are timely resolved. The inspector helps ensure that the packager stays focused on maintaining quality throughout the fabrication and assembly of the package.

A.4 Installation and Commissioning Coordinator

Best practice is for the purchaser to assign an experienced coordinator or supervisor for the compressor package on-site installation from the time of foundation preparation through the completion of start-up and commissioning. Annexes N, P and Q provide guidance for site preparation, package installation and package start-up and commissioning, respectively.

Annex B
(Informative)

Project Sequence and Schedule

B.1 General

The importance of a project plan and schedule for the specification, design, construction and application of a reciprocating compressor package is emphasized in 4.5 of this specification. This Annex provides recommendations and best practices related to the project sequence and schedule for the successful design and fabrication of a reciprocating compressor package. Section 2.4 and Appendix A-2.1 of the *GMRC High-Speed Compressor Guideline For Field Gas Applications*[40] are acknowledged as the primary references for this Annex.

B.2 Project Sequence and Schedule

In field gas applications, compressor packages may be owned or leased by end users. The project management recommendations or best practices outlined in this annex are primarily directed to end users that are purchasing new packages. However, many of the practices can be useful to rental fleet operators that are fabricating or purchasing packages for their fleets.

The schedule is dictated by many factors, including component and material lead times, labor availability, commercial requirements and environmental permitting. It is very important to plan the project steps in an appropriate sequence to ensure that design details are available in a timely manner for important analyses, key decisions to be made and hand offs to progress smoothly as the project proceeds.

A recommended project sequence and schedule are provided in Figure B.1. The sequence is based on typical best practices. The periods are not necessarily meant to correspond to weekly periods, but rather meant to be an indication of relative timing and interdependency of project steps. It is important for the purchaser to carefully plan the schedule in detail, in collaboration with the packager, end user, engineering firm(s), installation contractors and all other stake holders.

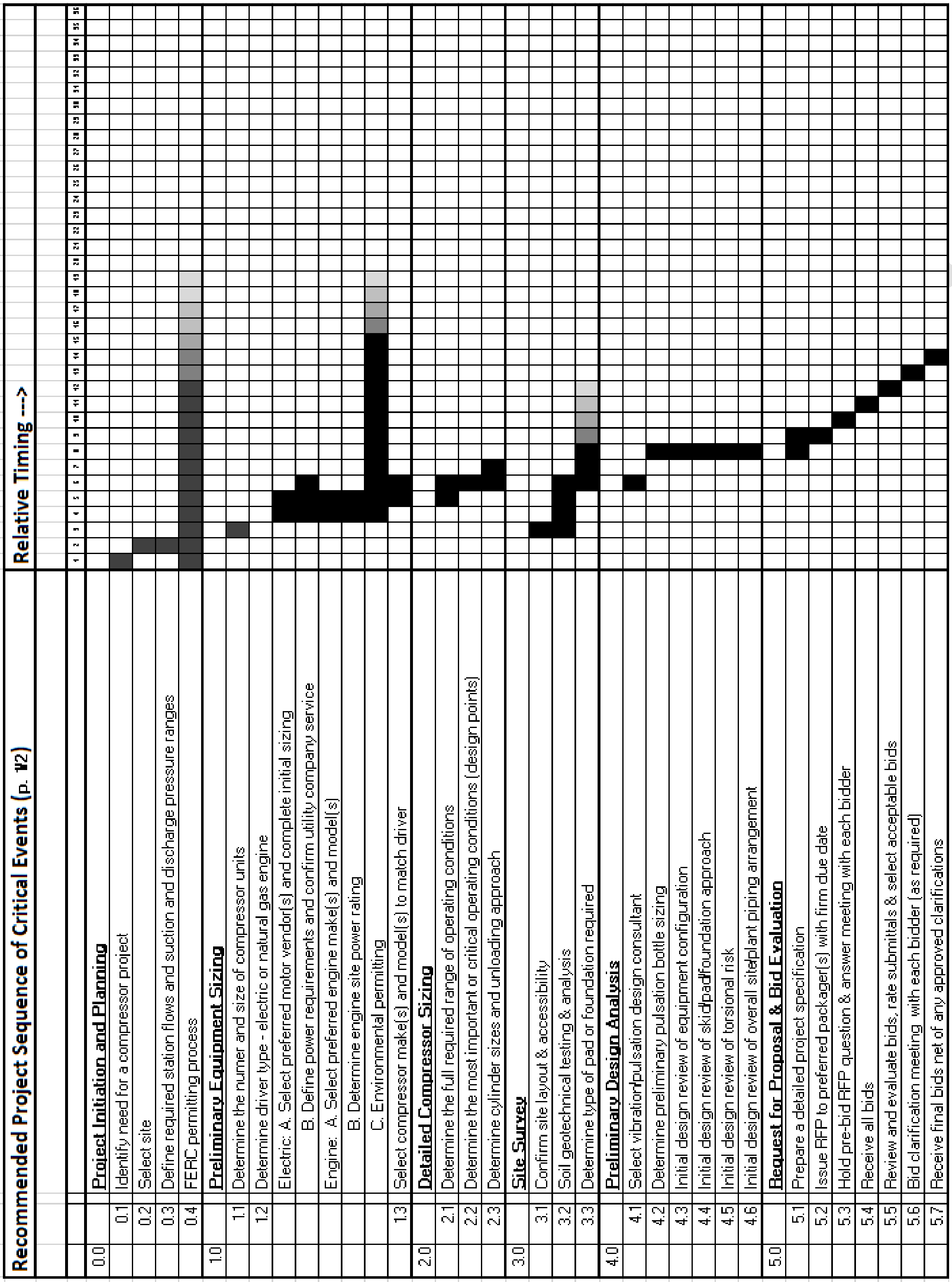


Figure B.1: Example Compressor Package Project Sequence and Schedule (1/2)

Recommended Project Sequence of Critical Events (p. 2/2)			Relative Timing --->
6.0		**Packager & Contractor Selections**	
	6.1	Select packager and issue PO with complete scope & all supporting specifications	
	6.2	Order driver and compressor (by packager or occasionally other)	
	6.3	Select site/plant/building engineering consultant	
	6.4	Select site/building contractor	
7.0		**System Design**	
	7.1	Reconfirm operating conditions	
	7.2	Size and order coolers	
	7.3	Fnalize unloading scheme and control requirements	
	7.4	Complete torsional analysis	
	7.4	Complete coupling selection, final (electric) driver shaft details, flywheel requirements	
	7.5	Complete package & skid design layout for review	
	7.6	Complete preliminary site/plant piping layout	
	7.7	Finalize pulsation bottle sizing	
	7.8	Review equipment accessibility**	
	7.9	Complete pulsation study, mechanical analyses, skid dynamics analysis	
	7.9	Review pulsation/vibration study and affects on system performance**	
	7.10	Complete piping flexibility analysis	
	7.11	Complete building layout, stairs, platforms, crane access, etc.	
	7.12	Complete final plant design	
	7.13	Update off-skid pulsation and piping analysis with final design details	
8.0		**Fabrication/Construction**	
	8.1	Fabricate package	
	8.2	Inspect package and conduct small bore piping MNF testing	
	8.3	Package control system and sequencing testing	
	8.4	Test package	
	8.5	Install foundation	
	8.6	Fabricate building	
	8.7	Install package	
	8.8	Complete process and utility piping	
	8.9	Align package	
9.0		**Start-up & Commissioning**	
	9.1	Cleaning, flushing and preparation for start-up	
	9.2	Final inspection & checklist completion prior to start-up	
	9.3	Conduct initial vibration screening & remediation if necessary	
	9.4	Torsional Testing	
	9.5	Performance Testing	
		** Consider any trade-offs before plant construction & completion of package fabrication.	

Figure B.1: Example Compressor Package Project Sequence and Schedule (2/2)

Annex C
(Informative)

Guidelines for Bid Evaluation

C.1 General

As introduced in 4.5 of this specification, this Annex C provides recommendations and best practices for the objective comparison of multiple bids vs. the purchaser's technical specifications and commercial requirements for a compressor package. Section 2.5 and Appendix A-2.2 of the *GMRC High-Speed Compressor Guideline For Field Gas Applications*[40] are acknowledged as the primary references for this Annex.

C.2 Bid Completeness and Validity vs. Specification

As bids are received, it is important that they are promptly reviewed for completeness and validity versus the specification. A spreadsheet is a preferred way to evaluate bids for completeness and objective comparison. Typically, there are many items on the spreadsheet, and it is organized to follow specific item numbers in the purchaser's specification, with columns provided for documenting each bidder's offerings. Some specification requirements may be non-negotiable and it is important for the purchaser to stipulate that any such mandatory requirements be met for a bid to be valid. For comparison of bids, a weighting process may be useful based on which parameters have the highest to the least importance to the purchaser. Table C.1 is an excerpt from a sample bid evaluation spreadsheet, provided for reference only. A complete version of *API-11P 3rd Edition Sample Bid Evaluation Spreadsheet.xlsx* is available with this specification. The purchaser may utilize such a worksheet or develop its own spreadsheet, adapted to suit the purchaser's specific requirements.

C.3 Performance Comparison

Comparison of the performance offered by various bidders will often require a further detailed engineering analysis by the purchaser or an experienced consultant. Best practice is to request that the compressor manufacturer's performance model or run file be provided for each compressor bid package. It is important to generate and review complete sets of curves and operating maps to evaluate performance and safe operating ranges for the suction and discharge conditions of significance. Best practice is to review curves for maximum, minimum and several intermediate operating speeds at all potential load steps to ensure that rod load, pin reversal, and other parameters are within manufacturers' limits. In addition, a review of the speed range from zero to minimum operating speed for a range of suction and discharge pressures is useful for determining safe loading steps for starting the unit. Detailed performance evaluations for each bid package can compare flow capabilities and efficiencies, as well as the operating range coverage and relative "robustness" of each compressor selection and unloading scheme.

C.4 Bid Clarification Meetings

One or more bid packages may be preferred based upon the performance reports and other evaluation criteria. It is important for the purchaser to arrange a bid clarification meeting with the preferred bidder(s) to resolve any exceptions, clarifications or other open issues. Prior to making a final decision and placing an order, best practice is for the purchaser to obtain a final bid from its preferred bidder(s) that, if necessary, addresses any and all open issues from the bid clarification meeting.

C.5 Purchase Order

To establish complete expectations for the package, best practice is for the purchase order to include all supporting specifications (or references to them), to reference the packager's final bid, and to document any exceptions to the purchase specification that the purchaser has accepted.

Table C.1: Sample Compressor Package Bid Evaluation Spreadsheet

**COMPRESSION BID TAB								
		†† Spec. No.	Spec. Requirements	Max. Score	Vendor A	Score	Vendor B	Score
TECHNICAL	**General**							
	Engine	†		**100**				
	Compressor Frame	†		**100**				
	Compressor Cylinders	†		**50**				
	Ambient	†		**50**				
	Altitude	†		**50**				
	Painting	†		**50**				
	Inspection	†		**50**				
	Engine							
	Engine Emissions	†		**100**				
	Engine Starter			**10**				
	Fuel Gas	†		**50**				
	Air Intake	†		**50**				
	Intake Silencer			**10**				
	Exhaust System	†		**50**				
	Exhaust Silencer			**10**				
	Exhaust Stack			**10**				
	Exhaust Line Sample Ports			**10**				
	Jacket Water Surge Tank			**10**				
	Pre-Start Jacket Water Heater			**10**				
	Lube Oil System	†		**50**				
	Pre / Post Lube Pump			**10**				
	Pre-Start Engine Oil Heater			**10**				
	Engine Barring Device			**10**				
	Motor							
	Power	†		**100**				
	Controls	†		**50**				

Annex D
(Informative)

Vendor Data and Drawing Requirements

This Annex D provides a list of typical vendor data and drawing requirements for use in specifying and managing the design and fabrication of a reciprocating compressor package. Typical requirements are shown in Table D.1. The complete Vendor Data and Drawing Requirements (VDDR) list is available in *API-11P 3rd Edition VDDR Spreadsheet.xlsx*.

TABLE D.1 (1/6)
TYPICAL
VENDOR DRAWING AND DATA REQUIREMENTS

JOB NO. ____ ITEM NO. ____
PURCHASE ORDER NO. ____ DATE ____
REQUISITION NO. ____ DATE ____
ENQUIRY NO. ____ DATE ____
PAGE 1 OF 6 BY ____

FOR ____
SITE ____
SERVICE ____

REVISION A ____
UNIT ____
NO. REQUIRED ____

Approval [a] Vendor shall furnish an electronic copy of data for all items indicated by an X.

Review [b] Vendor shall furnish an electronic copy of drawings and data indicated.

Final [c] Vendor shall furnish an electronic copy and __ paper copies of drawings and data indicated.
Vendor shall furnish an electronic copy and __ paper copies of operating and maintenance manuals.

Distribution record

Final—Received from vendor
Due from vendor [c]
Review—Returned from vendor
Review—Received from vendor
Review—Due from vendor [c]

Approval	Review	Final	DESCRIPTION	Review—Due from vendor	Review—Received from vendor	Review—Returned from vendor	Due from vendor	Final—Received from vendor
			A - GENERAL PACKAGE					
			A1. Mechanical & Process Flow Drawings (P&ID)					
			A2. General Arrangement Drawings (Package and All Shipped Loose Items)					
			A3. Line List					
			A4. Delivery / Fabrication Schedule					
			A5. Utility Consumption List (incl. Instrument Air and Electricity, UPS, Heating or Cooling Medium etc.)					
			A6. Piping Specifications					
			A7. Enclosure Plans, Sections, Detailed Drawings with Bills of Materials					
			A8. List of Connections by Purchaser (Piping, Seal Flush, Testing, Electrical, Instrumentation, etc.)					
			A9. Structural Steel Drawings (Skid, Pipe Supports, Platforms, ladders, etc.)					
			A10. Supports or Foundation Load Diagram / Anchor Location Details					
			A11. Shipping Weights and Dimensions					
			A12. Lifting Diagram/Instructions (Including Center of Gravity for Each Lift)					
			A13. Certified Compressor Configuration Performance Data and/or Curves					
			A14. Facsimile of Nameplate Stamping					
			A15. Datasheet for Major Equipment					
			A16. Dynamic Load Information (Vibration Analysis)					
			A17. Coupling assembly drawings and BOM					
			A18. Pipe Support Drawing/Details of each Terminal Point					
			A19. Seal flush flow diagrams, if applicable					
			A20. Mechanical Seal Piston rod packing assembly and cross section Drawings					
			A21. Cooler, Heat Exchanger energy and efficiency curves					
			A22. Automated Valve List Datasheets					
			A23. Manual Valve List					
			A24. PSV Datasheets Register					

			A25. Vessel Drawings					
			A26. Heat Exchanger Datasheets					
			A27. List of Known Unsafe Operating Speeds					
			A28. Mechanical Study					
			A29. Pulsation/Acoustical Report					
			A30. Torsional Report					
			A31. Package Bill of Material					

TABLE D.1 (2/6)

TYPICAL
VENDOR DRAWING AND DATA REQUIREMENTS

JOB NO. ____ ITEM NO. ____
PURCHASE ORDER NO. ____ DATE __
REQUISITION NO. ____ DATE __
ENQUIRY NO. ____ DATE __

PAGE 2 OF 6 BY ____

FOR ____
SITE ____
SERVICE ____

REVISION A
UNIT ____
NO. REQUIRED ____

Approval [a] Vendor shall furnish an electronic copy of data for all items indicated by an X.

Review [b] Vendor shall furnish an electronic copy of drawings and data indicated.

Final [c] Vendor shall furnish an electronic copy and __ paper copies of drawings and data indicated.
Vendor shall furnish an electronic copy and __ paper copies of operating and maintenance manuals.

Distribution record

Final—Received from vendor
Due from vendor [c]
Review—Returned from vendor
Review—Received from vendor
Review—Due from vendor [c]

Approval	Review	Final	DESCRIPTION	Review—Due from vendor	Review—Received from vendor	Review—Returned from vendor	Due from vendor	Final—Received from vendor
			B - ELECTRICAL					
			B1. Compressor Drive Motor facsimile of Nameplate Stamping					
			B2. Compressor Drive Motor Outline					
			B3. Compressor Drive Motor Performance Characteristics					
			B4. Speed Torque Curve of Driven Equipment and Motor at 100% & 80%Voltage					
			B5. Compressor Drive Motor Time Current and Thermal Limit Curves					
			B6. Compressor Drive Motor Datasheet for Each Item					
			B7. Compressor Drive Motor Starting Calculation and Torque Curve					
			B8. Unit Control Panel Layout Drawing Details					
			B9. Instrument / Fire and Gas Detection Location Plans					
			B10. Alarm Trip/Setpoint List					
			B11. Electrical Single Line Diagrams					
			B12. Functional Design Specifications Electrical Specifications					
			B13. Electrical Load List					
			B14. Cable and Conduit Schedules					
			B15. Electrical Equipment Vendor Drawings					
			B16. Equipment Vendor Catalogue Sheets					
			B17. Electrical Power Wiring Diagram					
			B18. Electrical Schematic Control Wiring Diagram (Power, Rtd's, Vib, etc.)					
			B19. Junction Box Layouts					
			B20. Junction Box Wiring Diagrams / Termination Drawings					
			B21. Control Panel Layouts					
			B22. Control Panel Wiring Diagrams / Termination Drawings					
			B23. Loop Diagrams					

			B24. Electric Heat Tracing (EHT) Calculations and Isometrics					
			B25. Local Authority Having Jurisdiction Certificate of Package Electrical Installation Per Specified Area Classification					

TABLE D.1 (3/6)

TYPICAL
VENDOR DRAWING AND DATA REQUIREMENTS

JOB NO. ____________ ITEM NO. ____________
PURCHASE ORDER NO. ____________ DATE ____________
REQUISITION NO. ____________ DATE ____________
ENQUIRY NO. ____________ DATE ____________

PAGE 3 OF 6 BY ____________

FOR ____________
SITE ____________
SERVICE ____________

REVISION A
UNIT ____________
NO. REQUIRED ____________

Approval [a] Vendor shall furnish an electronic copy of data for all items indicated by an X.

Review [b] Vendor shall furnish an electronic copy of drawings and data indicated.

Final [c] Vendor shall furnish an electronic copy and __ paper copies of drawings and data indicated.
Vendor shall furnish an electronic copy and __ paper copies of operating and maintenance manuals.

Distribution record

Final—Received from vendor
Due from vendor [c]
Review—Returned from vendor
Review—Received from vendor
Review—Due from vendor [c]

Approval	Review	Final	DESCRIPTION	Review—Due from vendor	Review—Received from vendor	Review—Returned from vendor	Due from vendor	Final—Received from vendor
			C - INSTRUMENTATION					
			C1. Cause and Effect Diagram					
			C2. Wiring Diagrams					
			C3. ISA Datasheet for each item					
			C4. Detailed Control Narrative & Functional Specification					
			C5. PCS Control System Factory Acceptance Test Records (DCS, SIS, F&G, BMS, PLC, etc.)					
			C6. PCS Config Docs. (incl. DCS, SIS, SCADA, PLC, F&G Displays, Alarms, etc.)					
			C7. Instrument Calibration Test Records					
			C8. Shutdown Key or Alarm Trip/Setpoint List					
			C9. Instrument List					

TABLE D.1 (4/6)

TYPICAL
VENDOR DRAWING AND DATA REQUIREMENTS

JOB NO. ____________ ITEM NO. ____________
PURCHASE ORDER NO. ________ DATE ________
REQUISITION NO. ________ DATE ________
ENQUIRY NO. ________ DATE ________

PAGE __4__ OF __6__ BY ____________

FOR ____________
SITE ____________
SERVICE ____________

REVISION A____________
UNIT ____________
NO. REQUIRED ____________

Approval [a] Vendor shall furnish an electronic copy of data for all items indicated by an X.

Review [b] Vendor shall furnish an electronic copy of drawings and data indicated.

Final [c] Vendor shall furnish an electronic copy and __ paper copies of drawings and data indicated.
Vendor shall furnish an electronic copy and __ paper copies of operating and maintenance manuals.

Distribution record

Final—Received from vendor
Due from vendor [c]
Review—Returned from vendor
Review—Received from vendor
Review—Due from vendor [c]

Approval	Review	Final	DESCRIPTION	Review—Due from vendor	Review—Received from vendor	Review—Returned from vendor	Due from vendor	Final—Received from vendor
			D - CALCULATIONS					
			D1. Vessel Mechanical Design (Including Nozzle Repad, Vessel Support, and Local Stress Calculations)					
			D2. Piping Surge Analysis					
			D3. Allowable Nozzle Loads at Piping Tie-Ins					
			D4. Vibration Analysis					
			D5. PSV Sizing Basis and Calculation (Incl. Rupture Disks If Applicable)					
			D6. Control Valve Sizing					
			D7. Process Design Calculations (Process simulation)					
			D8. Hydraulic Calculations					
			D9. Relief Load Calculations					
			D10. Steam/Water Side Pressure Drop					
			D11. Dryer Moisture Load and Regen Cycle Time Calculation					
			D12. Expected Max Heat Rejection into Building Due to Convection & Radiation Including Calculation					
			D13. Thermowell Stress and Wake Frequency Calculation					
			D14. Equipment Performance Curves (Software Output Files)					

TABLE D.1 (5/6)

TYPICAL
VENDOR DRAWING AND DATA REQUIREMENTS

JOB NO. ____________ ITEM NO. ____________
PURCHASE ORDER NO. ____________ DATE ____________
REQUISITION NO. ____________ DATE ____________
ENQUIRY NO. ____________ DATE ____________

PAGE 5 OF 6 BY ____________

FOR ____________ REVISION A ____________
SITE ____________ UNIT ____________
SERVICE ____________ NO. REQUIRED ____________

Approval [a] Vendor shall furnish an electronic copy of data for all items indicated by an X.

Review [b] Vendor shall furnish an electronic copy of drawings and data indicated.

Final [c] Vendor shall furnish an electronic copy and __ paper copies of drawings and data indicated.
Vendor shall furnish an electronic copy and __ paper copies of operating and maintenance manuals.

Distribution record

Final—Received from vendor
Due from vendor [c]
Review—Returned from vendor
Review—Received from vendor
Review—Due from vendor [c]

Approval	Review	Final	DESCRIPTION	Review—Due from vendor	Review—Received from vendor	Review—Returned from vendor	Due from vendor	Final—Received from vendor
			E - QUALITY ASSURANCE / QUALITY CONTROL					
			E1. Hydro-test Certificates					
			E2. Hydro-test Chart					
			E3. PWHT Certificate					
			E4. PWHT Chart					
			E5. Radiography Reports					
			E6. Magnetic Particle Inspection Reports					
			E7. Liquid Penetrate Inspection Reports					
			E8. Hardness Testing Report					
			E9. Impact Testing Report					
			E10. Ultrasonic Testing Report					
			E11. Weld Maps					
			E12. Certified Welding Procedure Specifications (WPS)					
			E13. Mill Test Reports (MTR)					
			E14. Function Test Report					
			E15. Code Registration Certificate					
			E16. Hydrostatic Testing Procedure					
			E17. Copy of Quality Program					
			E18. Inspection and Test Plan (incl. Sign-off Record)					
			E19. Pre-Commissioning, Commissioning and Site Acceptance Test Procedures					
			E20. Factory Acceptance Test Procedure					
			E21. Certified Engine Drive Package Mechanical Run Test Data (Incl. Vibration)					
			E22. Procedures for Mechanical, Performance & Optional Tests					
			E23. Weld Procedure Qualification Record (WPQR) and Certificates					

			E24. Weld Repair Procedure					
			E25. Contractor Packager Quality Certifications (for example ISO 9001, ASME Sect. VIII Div I, II and/or III, etc.)					
			E26. Pressure & Fired Equipment Manufacturer Data Reports and Data Books					
			E27. Cable Megger Test					
			E28. Equipment Bolt Torque Checklist					
			E29. PSV Shop Pop and Blowdown Test Records inspection and test certificate					
			E30. Non-conformance (NCR) Reports					
			E31. Internal and External Coating System, Surface prep, Installation , Holiday and DFT Inspection Reports					
			E32. Heat Treating Procedures					

TABLE D.1 (6/6)

TYPICAL
VENDOR DRAWING AND DATA REQUIREMENTS

JOB NO. ____________ ITEM NO. ____________
PURCHASE ORDER NO. ____________ DATE ____________
REQUISITION NO. ____________ DATE ____________
ENQUIRY NO. ____________ DATE ____________

PAGE 6 OF 6 BY ____________

FOR ____________
SITE ____________
SERVICE ____________

REVISION A____________
UNIT ____________
NO. REQUIRED ____________

Approval [a] — Vendor shall furnish an electronic copy of data for all items indicated by an X.

Review [b] — Vendor shall furnish an electronic copy of drawings and data indicated.

Final [c] — Vendor shall furnish an electronic copy and __ paper copies of drawings and data indicated.
Vendor shall furnish an electronic copy and __ paper copies of operating and maintenance manuals.

Distribution record

Final—Received from vendor
Due from vendor [c]
Review—Returned from vendor
Review—Received from vendor
Review—Due from vendor [c]

Approval	Review	Final	DESCRIPTION	Review—Due from vendor	Review—Received from vendor	Review—Returned from vendor	Due from vendor	Final—Received from vendor
			F – ADDITIONAL DOCUMENTS					
			F1. Noise Data					
			F2. Parts Lists with Exploded Views for major components					
			F3. Recommended Spare Parts with Prices for Start-up and/or Operation					
			F4. Recommended Spare Parts with Prices for First Year Operation					
			F5. Preservation and Storage Procedures					
			F6. Equipment Storage & Preservation Records					
			F7. First Fill and Operating Fluid Schedule					
			F8. Installation, Operation & Maintenance Manuals					
			F9. Databook					
			F10. Vendor Catalog Data					
			F11. Approval Agency Documents, Certificates & Labels as Applicable					
			F12. NACE Certificate of Compliance					
			F13. Drawing / Document Submission List					
			F14. Shipping & Packing Documents incl. Packing and ship-loose list, lifting diagram					
			F15. Insulation and Jacketing Report					
			F16. Release for Shipping Certificate					
			F17. Deficiency List					
			F18. Progress Reports					
			F19. Country of Origin Certificate					
			F20. Emissions Data (Driver, Vents, Etc)					
			F21. Shaft Coupling Assembly Drawing and Bill of Materials					

Send all drawings and data to ____

____

All drawings and data shall show project, appropriation, purchase order, and item numbers in addition to the plant location and unit. In addition to the copies specified above, one set of the drawings/instructions necessary for field installation shall be forwarded with the shipment.

Nomenclature:

_______ S—number of weeks prior to shipment.

_______ F—number of weeks after firm order.

_______ D—number of weeks after receipt of approved drawings.

Vendor ____

Date ____________ Vendor reference ___________________________

Signature

Annex E
(Informative)

Torsional Vibration Analysis Data and Testing Guidelines

Section 23 of this specification provides the requirements for torsional vibration analysis and control. This Annex E provides additional guidelines for torsional vibration analysis data and testing. The *GMRC Guideline and Recommended Practice for Control of Torsional Vibrations In Direct-Driven Separable Reciprocating Compressors*[38] is acknowledged as the primary reference for this Annex.

E.1 Equipment Data Required for Torsional Vibration Analysis (TVA)

It is important that complete and accurate equipment data is provided in electronic or hard copy form to the packager (or alternatively directly to the organization performing the torsional analysis) at the earliest possible date after it is requested. It is essential that the information is accurate and complete. If circumstances require that some data provided for analysis is preliminary, it is important that it be clearly identified with a schedule for updating it.

E.1.1 Reciprocating Compressor Data

The following data is typically required from the compressor manufacturer for the TVA:

a) Crank geometry information including bore for each cylinder (inside diameter), stroke or crank radius, connecting rod length, throw phasing and throw position diagram, number of cylinders and number of stages.
b) Compressor crank-throw reciprocating weights (including piston, piston rod, piston rod nut, small non-rotating end of connecting rod, crosshead, crosshead pin and tail-rod, where relevant).
c) Compressor rotating inertias (crank pins, webs, spreaders, counterweight and large rotating end of connecting rod).
d) Torsional stiffness of each compressor crankshaft section, accounting for each main journal, crank web, crank pin and spreader sections.
e) Details of how the inertia and stiffness of shafting between coupling and adjacent compressor throw were computed.
f) Drive end crankshaft details (diameter, length, and if present, taper diameter, width and fillet radii of any undercuts and keyways, etc.).
g) Inertia and stiffness of auxiliaries and their drive (belt or chain) – optional.
h) Compressor crankshaft damping (relative and absolute), if available.
i) Inertia and detail of any internal or external compressor flywheels or donuts (detuners).
j) Damping, inertia and interconnecting torsional stiffness of any damping devices attached to the compressor.
k) Station/location (mass-elastic) diagram including a sketch of the crankshaft showing locations of inertias and reference lengths used for stiffness values.
l) Crankshaft material properties if available. Properties may not be required if applicable stress or torque limits are given.
m) Torque effort curves or Fourier coefficients for representative load conditions and speeds, specifying whether torque effort is for gas compression only or whether it includes the influence of the reciprocating masses.

NOTE: If not provided by the manufacturer, the analyst typically calculates the torque effort using operating conditions such as pressures, temperatures, gas composition, manufacturer-provided cylinder clearances, etc.

n) Applicable allowable vibration limits which may include crankshaft maximum stress or torque, crankshaft vibratory stress or torque, crank free end vibratory amplitude or angular velocity to protect auxiliary driven equipment, limit torsional/lateral vibration forces, and limit power loss for viscous damper, if present.

The following data is typically required from the compressor packager for the TVA:

o) Specified operating speed or range, load steps, capacity control, etc.

E.1.2 Coupling Data

The following data is typically required from the coupling manufacturer for the TVA:

a) Drawing of the coupling assembly to include:
   1) Inertia of the entire coupling assembly and individual inertia of each significant coupling component.
   2) Coupling assembly torsional stiffness, noting whether the torsional stiffness value accounts for shaft/hub penetration effects and the assumed penetration length.
b) For elastomeric couplings and mechanical spring couplings with friction or hydrodynamic damping:
   1)Torsional stiffness vs. torque
   2)Torsional stiffness vs. temperature
   3)Torsional stiffness and damping tolerances due to uncertainties in material properties
   4)Durometer and damping value of elastomeric element(s)
   5)Damping characteristics for mechanical spring couplings
c) Applicable allowable limits, which may include maximum torque, vibratory torque, and (for elastomeric and mechanical spring couplings) power loss.
d) For elastomeric couplings: Torque rating and power loss based on frequency

NOTE: Ambient air temperatures affect the stiffness and allowable limits of elastomeric couplings. Best practice is for the coupling supplier to provide elastomeric coupling data at temperature points that will cover the expected range of ambient air temperatures. At least two temperature points are required for temperature dependent torsional analysis results. It is also important that the coupling guard be designed to allow for proper ventilation.

E.1.3 Reciprocating Engine Data

If the driver is a reciprocating engine, the following data is typically required from the engine manufacturer for the TVA:

a) Engine geometry including, bore (cylinder diameter), stroke or crank radius, connecting rod length, cylinder phase angles (firing order), and bank angle (angle between left and right banks in a vee engine).
b) Engine crank throw reciprocating masses (piston, piston pin and small non-rotating portion of connecting rod).
c) Engine rotating inertias (crank-throw, counterweight, large rotating end of connecting rod, and internal or external flywheel).
d) Torsional stiffness of the engine crankshaft, accounting for each main journal, crank web and crank pin.
e) Engine crankshaft damping (relative and/or absolute)
f) Gas pressure excitation forces (harmonic coefficients of tangential pressure) vs. BMEP.
g) Number of dampers. For each damper, provided data to include damper housing inertia, ring inertia, interconnecting torsional stiffness and damping values vs. frequency of any viscous, mechanical, or elastomeric dampers.
h) Station/location (mass-elastic) diagram showing positions of inertias and stiffness.
i) Crankshaft material properties, if available. Properties may not be required if applicable stress or torque limits are given.
j) Primary end and auxiliary drive end crankshaft details (diameter, length, and if present, taper, diameter, width and fillet radii of any undercuts and keyways, etc.).

k) Applicable allowable limits which may include: crankshaft maximum stress or torque, crankshaft vibratory stress or torque, front crank vibratory angular displacement amplitude, power loss limit for viscous or elastomeric damper, or other limits.
l) Cooling fan drive shaft(s) inertia and stiffness (optional).

The following data is typically required from the compressor packager for the TVA:
m) Jack shaft inertia and stiffness (optional and where applicable).
n) Cooling fan drive pulley inertia, drive belt stiffness and speed ratio of cooling fan(s) (optional).

E.1.4 Electric Motor Data

If the driver is an electric motor, the following data is typically required from the motor manufacturer for the TVA:
a) Motor shaft drawing showing sufficient detail for the analyst to independently calculate the stiffness, showing the location of a detailed list of inertias no less than listed below, and clearly identifying the units of measure for mass and inertia values.
b) Motor shaft material properties, including elastic modulus, shear modulus, ultimate tensile and yield strength.
c) Motor shaft inertia.
d) Motor rotor core inertia.

NOTE: The motor rotor magnetic core is comprised of laminated plates, and on an induction motor the core includes air gaps along the length, so that it has negligible torsional stiffness. The core inertia is preferably divided into multiple sections, typically five, and attached to the shaft at the midpoint of each section along the core length.

e) Inertia of exciter, if present.
f) Inertia of any cooling fan(s), if present.
g) Motor shaft stiffness.
h) Motor electrical supply frequency, number of poles, rated torque, slip speed, breakdown torque power factor, and efficiency.
i) Pulsating torque information for synchronous motors.
j) If couplings with low torsional stiffness are used in the coupled system, motor magnetic stiffness or information (to include electrical supply frequency, number of poles, rated torque, slip speed, and breakdown torque) for use in estimating the approximate magnetic stiffness with the simplified method described in Appendix B.7 of *GMRC Guideline and Recommended Practice for Control of Torsional Vibrations in Direct-Driven Separable Reciprocating Compressors*[38].

NOTE: Induction motors will often include a welded rib spider design. When applicable, the stiffening influence of the welded rib spider is typically calculated using FEA, B.I.C.E.R.A, Ker Wilson[43] or by the method described in Appendix B.3 of *GMRC Guideline and Recommended Practice for Control of Torsional Vibrations in Direct-Driven Separable Reciprocating Compressors*[38].

E.1.5 Variable Frequency Drive Data

If the electric motor is controlled by a variable frequency drive (VFD), the following data is typically required from the VFD manufacturer for the TVA:
a) operating speed range and torque.

NOTE: See API 684-1 Section 4.10 for additional guidance on VFD influence on torsional behavior.

E.2 Torsional Vibration Testing

Best practice for a torsional vibration test includes the following characteristics:

a) Testing is conducted through the entire design speed range as well as a sweep from zero to full rated speed during start-up, unloaded normal shut-down, and loaded emergency shut-down (ESD).
b) Torsional response is measured at all anticipated compressor load steps. Measurements may be taken using strain gage telemetry system, shaft encoder, torsional laser vibrometer, torsiograph, motor current, etc.
c) Torsional response is correlated with compressor frame and cylinder vibration data. (see paragraph E.3).
d) Test data is compared to the theoretical analysis results in the TVA report. Any discrepancies are noted and investigated. Cylinder pressure vs. time data, noting the engine to compressor phasing, may be collected to calibrate the torque effort curves. The original TVA model is revised to correlate with the measured data.
e) If excessive torsional response is measured, a theoretical model is used to assess whether changes can be made to mitigate the problem. Common remedial changes may include flywheel additions or modifications, coupling stiffness changes or coupling damping changes. In extreme cases, operating speeds zones may have to be restricted to avoid troublesome load conditions until modifications can be made to the system.

NOTE: *GMRC Guideline and Recommended Practice for Control of Torsional Vibrations in Direct-Driven Separable Reciprocating Compressors*[38] provides additional guidance for torsional testing.

E.3 Angular Velocity and Torsional/Lateral Interaction

Excessive fluctuations in compressor speed (angular velocity) due to torsional vibrations can couple to lateral frame vibration through the bearings and crossheads. Because of the slider/crank kinematics, the bearings experience forces primarily at +/- one order of the torsional oscillation frequency. Crosshead forces occur primarily at the torsional oscillation frequency and +/- two orders of the torsional oscillation frequency. The forces are proportional to the rotating and reciprocating masses, and to the frequency of the speed oscillation squared, so large forces at high frequencies can occur on some machinery.

In addition to causing torsional to lateral vibration coupling, excessive compressor speed fluctuations due to torsional vibrations can cause reliability issues due to auxiliary driven equipment (e.g., frame oil pump and cylinder lubrication pump) failure.

The guidelines shown in Figure E.1 may be used for minimizing vibration forces and providing an awareness of torsional/lateral interaction during the analysis process. These are not rigid requirements, as it may be difficult and costly to achieve the low levels dictated by Figure E.1, and some machines may operate safely above these limits.

a) If it is not possible to make the angular velocity amplitudes fall within the guidelines in Figure E.1, then kinematic algorithms, inclusive of the angular accelerations due to torsional oscillations, can be used to quantify the bearing and crosshead forces. The forces can then be analyzed in traditional mechanical studies to determine the vibratory effects on the skid, frame, cylinders and manifolds. Such a mechanical study is not part of a standard torsional analysis; it is therefore an incremental study that the purchaser may specify, when warranted, to explore the potential severity of this issue in more depth. It is best practice for such mechanical studies to evaluate the high frequencies associated with torsional-lateral interactions, which are beyond the frequencies typically analyzed in mechanical studies.

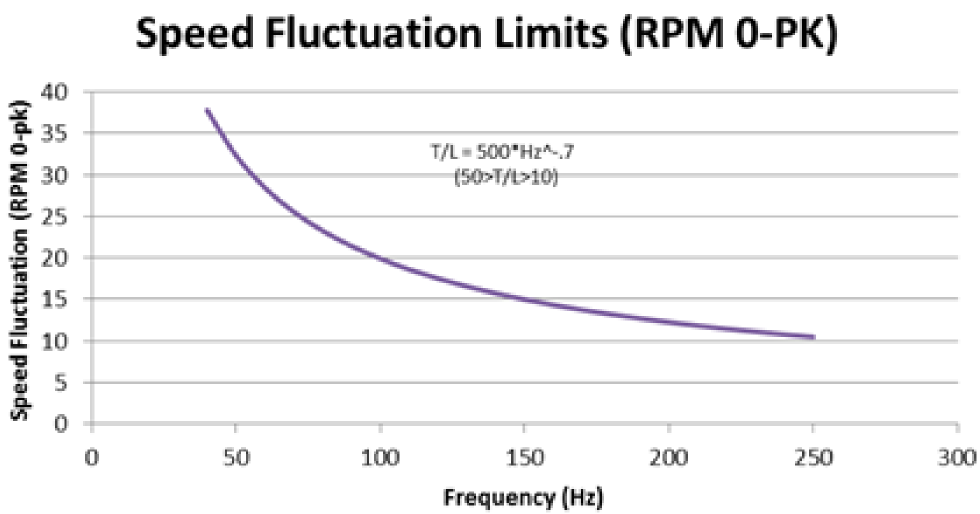


Figure E.1: Guideline for minimizing mechanical vibration forces caused by torsional vibration[38]

b) As an alternative to Figure E.1, the following torsional vibration guidelines may be followed:
   1) Limit of 2% velocity amplitude overall (zero-to-peak), based on full load rated speed, anywhere in the compressor shafting (typically would be the free end). For the class of compressors covered by this specification, this limit will reduce the risk of lateral vibration problems caused by torsional-lateral vibration coupling.
   2) Limit of 0.75% velocity amplitude overall (zero-to-peak), based on full load rated speed, in an induction motor, to avoid problems with current pulsation.
   3) Current pulsation may be measured in the field and compared to API and NEMA limits. In all cases, the best practice is to consult the compressor manufacturer for current technical guidance and acceptable limits.

NOTE: This phenomenon continues to be explored and better guidelines may evolve as more research is done. Further information and background on this phenomenon is provided in a 2012 GMRC paper[41].

Annex F
(Informative)

Guidelines for Preliminary Pulsation Suppression Bottle Sizing

This Annex F provides guidelines for preliminary sizing of field gas compressor pulsation suppression bottles. Section 3.3.3 and Appendix B-9.1 of the *GMRC High-Speed Compressor Package Guideline For Field Gas* Applications[40] are acknowledged as the primary reference for this Annex.

F.1 Best Practices For Pulsation Bottle Sizing in the Bidding Phase

As specified in 22.2.3, the Packager's proposal is to include preliminary pulsation suppression devices (aka bottles), including as a minimum, the outside diameter, seam-to-seam length, and MAWP of each device. It requires that the preliminary sizing is determined using one of the following methods:

a) Preliminary analysis by a pulsation study supplier, or
b) The GMRC Preliminary Field Gas Compressor Bottle Sizing Procedure (Annex F), or
c) Packager's proprietary method that is identified and described with the proposal, or
d) Other method specified by the Purchaser.

Preliminary sizing of pulsation suppression devices is completed in the compressor package proposal stage, prior to the pulsation study, to provide a basis for costing and evaluation of the proposal. Actual final designs are based on the final pulsation study results and may be different than the preliminary sizing. Compressors operating at speeds of 900 rpm or higher may require the use of properly designed low-pass acoustic filters as discussed in Annex A.10 of API Standard 688. The volume requirements of paragraph 5.1.1.3 of API Standard 688 typically result in bottles that are too large for use on packaged high-speed reciprocating compressors, resulting in excessive weight that lowers mechanical natural frequencies and increases the risk of high vibration levels.

This Annex F describes the preliminary field gas compressor bottle sizing procedure provided in Appendix B-9.1 of the *GMRC High-Speed Compressor Package Guideline For Field Gas Applications*[40], which is one of the defined alternatives specified in 22.2.3.

F.2 Overview of Preliminary Pulsation Control Design

The preliminary field gas compressor bottle sizing procedure is available as an Excel spreadsheet, *API-11P 3rd Edition Pulsation Bottle Preliminary Sizing.xlsx* . Its use is intended to ensure that the compressor package skid allows enough space for the suction and discharge pulsation bottles to achieve adequate pulsation control. It also reduces the risk that significant cost and lead time adders are needed for larger bottles as the detailed pulsation study progresses during the package design process. This spreadsheet in no way negates the need for a pulsation study by a qualified analysis company or consultant per Section 22.

Except for small compressors less than about 149 kW (200 hp), it is generally considered best practice to use acoustic filtering techniques when sizing pulsation bottles for high-speed (900 rpm or higher) compressors. An acoustic filter is a volume-choke-volume assembly that, for simple single-cylinder systems, can be comprised of two separate bottles with an interconnecting pipe (choke tube) or a single bottle with a baffle separating the cylinder chamber from the line chamber and a choke tube between the two chambers. When the filter frequency defined by the volume-choke-volume arrangement is properly placed below the calculated filter cutoff frequency, pulsations in the attached piping networks will be effectively attenuated. The use of acoustic filtering techniques significantly reduces the risk of pulsation-induced vibration. Orifices may also be required to minimize pulsations associated with the gas passage-nozzle responses and with pulsations in the adjacent piping that are not filtered adequately or at all. A best practice is for the preliminary compressor package design to include full-throat spacer plates at all inlet and outlet nozzle flange connections on all bottles so that orifices can more easily be accommodated if needed.

For field gas compressor packages, each stage of compression will typically have an inlet scrubber located on the compressor skid immediately upstream of the suction bottle. The suction side cylinder bottle serves as the primary volume in the volume-choke-volume acoustic filter arrangement, while the inlet scrubber serves as the secondary volume. For a compression stage with only one cylinder, the suction cylinder bottle is typically centered over the cylinder to minimize unbalanced forces within the bottle and an external choke tube connects the two volumes.

Where two or more cylinders share a common suction bottle, an internal baffle is typically located in the bottle between each cylinder pair to reduce unbalanced shaking forces. Each cylinder connection is centered within its own bottle chamber. Choke tubes or a simple penetration in each baffle allow the gas to pass between the chambers, and the inlet scrubber still serves as the secondary volume. An external choke tube connects the bottle and the inlet scrubber.

When an inlet scrubber is used as a secondary volume for pulsation control, it is best practice to consider the effectiveness of the acoustic filtering as the scrubber internal gas volume changes due to liquid level fluctuation from minimum to maximum levels.

Designing acoustic filters on the discharge side is a little more complicated, since there is no inlet scrubber to act as a secondary volume. Where space is available, a single bottle acoustic filter can be developed by lengthening the discharge bottle. In many cases, the bottle can only be lengthened in the direction opposite the inlet scrubber due to space constraints imposed by the inlet scrubber. For a simple single-cylinder bottle, an internal baffle is located between the cylinder nozzle and the line nozzle to create two separate volumes, a primary volume (cylinder) chamber and a secondary volume (line) chamber. An internal choke tube connects the two volumes. The cylinder is centered in the cylinder chamber to minimize unbalanced forces within the bottle. For many multi-stage compressors, it may not be possible to develop a single-bottle acoustic filter on the discharge of each stage. In these cases, it may be necessary to maximize the size of the cylinder bottle and add a line side orifice. Although not the best approach for pulsation control, sometimes this is the best available approach unless routing the piping and/or secondary bottle volume off skid is a viable option.
Where two or more cylinders share a common discharge bottle, an internal baffle is located between each cylinder pair to reduce unbalanced shaking forces. Each cylinder connection is centered within its own bottle chamber. If the bottle can be lengthened sufficiently to add a secondary (line) chamber for acoustic filtering, an additional baffle is located between the line chamber and the closest cylinder chamber. Choke tubes or a simple penetration in each baffle allow the gas to pass between the chambers. If the bottle cannot be lengthened sufficiently to provide acoustic filtering, it may be necessary to maximize the size of the cylinder bottle and add a line side orifice. Baffles are still used to minimize unbalanced shaking forces and cylinder interaction.

It's again important to emphasize that the procedures described in this Annex F are only intended for preliminary sizing to reduce the risk of improper bottle sizing at the bid stage of a project. A recommended best practice is for a qualified pulsation analyst to assist with preliminary bottle sizing and, at a minimum, to finalize the pulsation bottle design and the rest of the pulsation control system.

Bottle sizing spreadsheets *API-11P 3rd Edition Pulsation Bottle Preliminary Sizing.xlsx* are provided for single-cylinder bottle designs and for multi-cylinder bottle designs. The spreadsheets are only available in USC units. An overview of the required steps is provided in F.3 and F.4, respectively. Actual steps are to be completed on the relevant spreadsheet for each stage of compression. The sizing spreadsheets represent an effort to provide acoustic filtering for the attached piping system for optimized pulsation control. A best practice is to try to use the inlet scrubber as a secondary volume to create an acoustic filter. However, because there is no inherent secondary bottle on the discharge side and there is often limited space for extending the bottle, it is not always possible to create an acoustic filter on the discharge side. Where acoustic filtering is not feasible, the default recommendation is to install a bottle with a minimum size determined according to the graph published by the Gas Processors

Suppliers Association (GPSA)[41]. The GPSA graph, shown in Figure F.2, determines suction and discharge pulsation bottle volumes as a multiple of cylinder piston displacement based on the pressure level. However, the best practice in this case is to have a pulsation specialist determine the preliminary bottle dimensions.

API does not guarantee the accuracy of the spreadsheets *API-11P 3rd Edition Pulsation Bottle Preliminary Sizing.xlsx*, and it accepts no responsibility or liability for their use or any results that the user may apply for any purpose whatsoever. The user accepts all risk for their use. It is important that final bottle designs are completed by a qualified pulsation analysis company or consultant.

F.3 Preliminary Field Gas Compressor Bottle Sizing Procedure For A Single-Cylinder

F.3.1 Bottle Arrangement

This subsection explains the API-11P preliminary pulsation bottle sizing procedure for a single-cylinder arrangement. Figure F.1 is a conceptual layout of this arrangement.

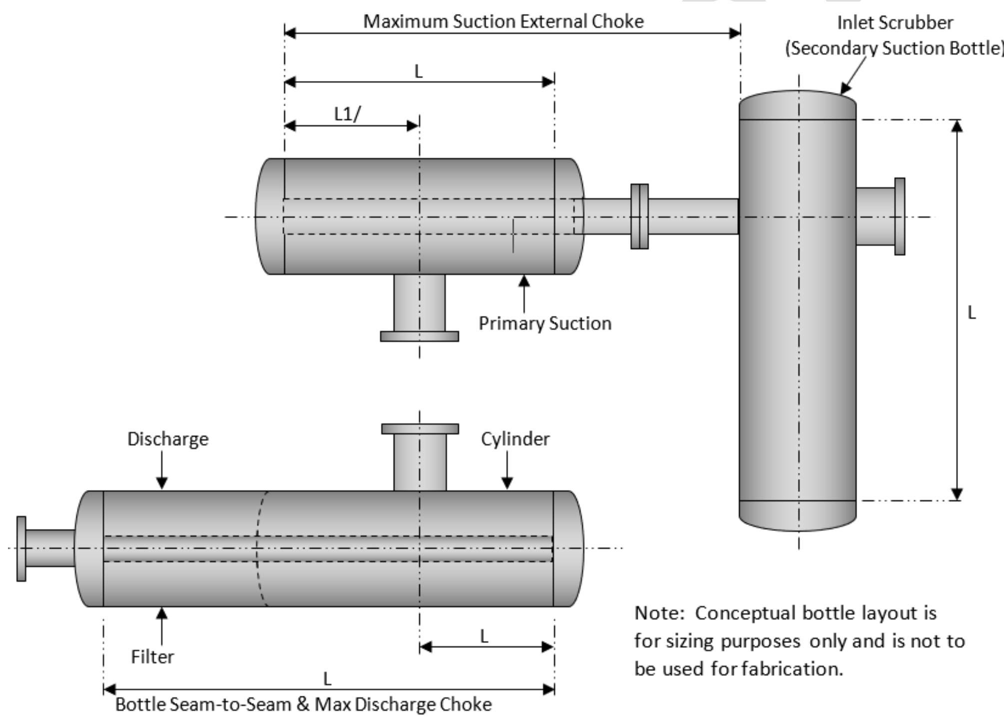


Figure F.1: Conceptual bottle layout for single-cylinder bottle sizing.

F.3.2 Step 1 – Identification of Compressor Parameters

The compressor speed and cylinder parameters are input into the sizing spreadsheet as shown in Table F-1 to determine the piston displacement and the filter cutoff frequency for optimizing the pulsation control. The spreadsheet assumes that the cylinder is double-acting. Table F-1 is an example shown for reference only.

Table F.1: Example of input parameters for determining piston displacement and filter cutoff frequency.

INPUT	
750	Compressor Min Speed (RPM)
1000	Compressor Max Speed (RPM)
3	Cylinder Nozzle Nominal Diameter (in)
11.250	Cylinder Bore (in)
6.000	Stroke (in)
2.500	Rod Diameter (in)
CALCULATED	
1163.4	Piston Displacement (cu in)
12.5	Minimum Operating Frequency (Hz)
8.8	ff, Ideal Filter Frequency (Hz)

F.3.3 Step 2 - Definition and Analysis of Operating Conditions

The compressor operating conditions and gas properties are input into the sizing spreadsheet as shown in Table F.2 to determine the speeds of sound of the gas. Table F.2 is an example shown for reference only.

Preferably, the compressibility and speed of sound are calculated for each operating pressure and temperature associated with each gas composition to establish the range. If not available on the compressor package performance sheets, the gas compressibility and ratio of specific heats can be obtained using gas property tables or from software available from various sources. It is important that this be done for all gas compositions, but at a minimum, it can be done only for the gas compositions with the lowest and highest molecular weights with reasonable results.

The maximum calculated speed of sound for the suction and discharge operating conditions is evaluated in Table F.2 and is used later in the calculation of the filter frequency. The maximum speed of sound is typically associated with the highest operating temperature for a given gas composition. Using the maximum speed of sound for each system will generate the highest anticipated filter frequency and will ensure that the filter sizing is adequate across the anticipated operating range.

Table F.2: Example of input parameters for determining speed of sound for important operating conditions.

INPUT						
Gas Composition 1			**Gas Composition 2**			
Design	**Min Flow**	**Max Flow**	**Design**	**Min Flow**	**Max Flow**	
4.65	3.87	6.53	4.65	3.87	6.53	Flow (mmscfd)
308.37	322.92	404.93	308.37	322.92	404.93	Suction Pressure (psig)
120.00	120.00	120.00	120.00	120.00	120.00	Suction Temperature (°F)
656.62	808.12	656.62	656.62	808.12	656.62	Discharge Pressure (psig)
224.12	248.47	186.34	224.12	248.47	186.34	Discharge Temperature (°F)
0.971	0.970	0.963	0.971	0.970	0.963	Suction Compressibility
0.974	0.975	0.965	0.974	0.975	0.965	Discharge Compressibility
0.590	0.580	0.590	0.590	0.590	0.590	Specific Gravity
1.300	1.300	1.300	1.300	1.300	1.300	K (Cp/Cv)
CALCULATED						
1460	1471	1453	1460	1459	1453	Suction Speed of Sound (ft/s)
					1471	Max Suction Speed of Sound (ft/s)
1588	1630	1536	1588	1617	1536	Discharge Speed of Sound (ft/s)
					1630	Max Discharge Speed of Sound (ft/s)

F.3.4 Step 3 – Sizing the Suction Bottle

Optimizing the bottle sizes is an iterative process. A good practice is to start with a suction bottle nominal diameter of three to four times the cylinder nozzle nominal diameter. The maximum diameter is generally limited to four times the cylinder nozzle nominal diameter to minimize the risk of high vibration levels. The length of a single-cylinder suction bottle will be limited by the proximity to the vertical on-skid inlet scrubber and any other suction bottles that are part of the skid package. In some multi-stage cases, a single-cylinder suction bottle might be rotated 90 degrees to avoid interference with other bottles. In any case, locating the midpoint of the bottle at the cylinder nozzle centerline will minimize unbalanced shaking forces. On the suction side, the volume-choke-volume acoustic filter is developed using the on-skid inlet scrubber as a secondary volume.

The calculated volume-choke-volume filter frequency can be lowered by:

a) increasing the bottle diameter and/or length
b) increasing the filter separator or scrubber diameter and/or length
c) increasing the choke tube length
d) increasing the choke tube wall thickness
e) decreasing the choke tube diameter

The proposed suction bottle and inlet scrubber dimensions, as well as the proposed choke tube dimensions, are input into the sizing spreadsheet as shown in Table F.3 to determine the filter frequency and the choke velocity. Table F.3 is an example shown for reference only. It is common practice to start with a choke tube length equal to the distance from the shell of the inlet scrubber to the cylinder centerline. The maximum possible choke tube length is the distance from the shell of the inlet scrubber to the weld seam at the rear of the primary bottle. The choke velocity is typically kept below 30 m/s (100 ft/s) to minimize pressure drop; however, velocities up to 1/10th of the speed of sound are not unusual. Ideally, the filter frequency is below the optimum filter frequency calculated in Step 1; however, placing the filter frequency 10 to 20 percent below 1X minimum operating speed is often sufficient.

Table F.3: Determination of Suction Bottle Dimensions

INPUT		
12.750	Primary Bottle OD (in.)	
0.500	Primary Bottle WT (in.)	
36.000	L1, Primary Bottle Seam-to-Seam Length (in.)	
20.000	Inlet Scrubber OD (in.)	
0.500	Inlet Scrubber WT (in.)	
60.000	L2, Inlet Scrubber Seam-to-Seam Length (in.)	
60.000	Choke Length (in.)	
2.375	Choke OD (in.)	
0.218	Choke WT (in.)	
CALCULATED		
10.1	Filter Frequency (Hz)	Ideal filter frequency (ff) is ≤ 8.8
139	Max Choke Velocity (ft/s)	Max ff typically 10.0 to ≤ 11.3

When an inlet scrubber is used as a secondary volume for pulsation control, it is important to consider the effectiveness of the acoustic filtering as the scrubber internal gas volume changes with liquid level fluctuation between minimum and maximum levels.

F.3.5 Step 4 – Sizing the Discharge Bottle

Optimizing the discharge bottle size is an iterative process. A good practice is to start with a discharge bottle nominal diameter approximately two to three times the cylinder nozzle nominal diameter. The maximum diameter of the bottle will be limited by its proximity to the compressor pedestal and by the distance between the cylinder discharge flange and the top of the skid. Other space considerations are the likely need to install shim blocks under the bottle and to accommodate a cylinder nozzle length of not less than one pipe diameter. The bottle length will be limited by its proximity to any other vessels on the skid (including inlet scrubbers or other cylinder bottles). The bottle is divided into two chambers by a baffle. The cylinder chamber serves as the primary volume in the acoustic filter and is center-fed by the cylinder nozzle, while the line chamber serves as the secondary volume. An internal choke tube moves the gas between the two chambers. The maximum choke tube length is equal to the bottle seam-to-seam length. The choke velocity is typically kept below 30 m/s (100 ft/s) to minimize pressure drop; however, velocities up to 1/10th of the speed of sound are not unusual. Ideally, the filter frequency is below the optimum filter frequency calculated in Step 1; however, placing the filter frequency 10 to 20 percent below 1X minimum operating speed is often sufficient.

The proposed discharge bottle dimensions, as well as the proposed choke tube dimensions, are input into the sizing spreadsheet as shown in Table F.4 to determine the filter frequency and the choke velocity. Table F.4 is an example shown for reference only.

Table F.4: Determination of Discharge Bottle Dimensions

INPUT		
12.750	Bottle OD (in.)	
0.500	Bottle WT (in.)	
96.000	L3, Bottle Seam-to-Seam Length (in.)	
24.000	L4, Bottle Seam-to-Cylinder Centerline Length (in.), cylinder chamber	
84.000	Choke Length (in.)	
2.375	Choke OD (in.)	
0.344	Choke WT (in.)	
CALCULATED		
9.6	Filter Frequency (Hz)	Ideal filter frequency (ff) is ≤ 8.8
128	Max Choke Velocity (ft/s)	Maximum ff is typically 10.0 to as much as 11.3

If the discharge bottle length cannot be extended sufficiently to create an acoustic filter, the bottle has to be sized such that the weld seams are equidistant from the cylinder nozzle centerline. The nominal bottle diameter must be maximized to the extent possible, in any case, being at least three times the cylinder nozzle nominal diameter. The volume of the empty bottle is a multiple of piston displacement, increasing with pressure level, per the GPSA[41] published graph that is shown in Figure F.2. However, in such a case, the preliminary bottle sizing is best determined by a pulsation analyst. An unfiltered pulsation bottle will generally result in a higher potential for damaging vibrations. The bottle length may have to be adjusted by the pulsation analyst to minimize the potential for vibration at frequencies corresponding to the acoustic length resonance of the unfiltered bottle.

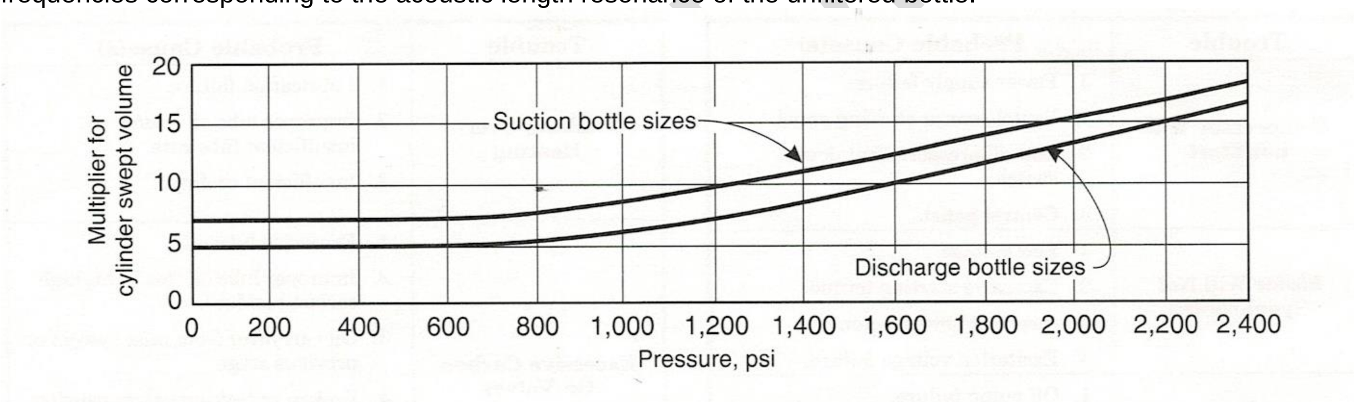


Figure F.2: GPSA Pulsation Bottle Sizing Graph[41]

The GPSA volume multiplier and the proposed discharge bottle dimensions are input into the sizing spreadsheet as shown in Table F.5 to determine the estimated volume and length. Table F.5 is an example shown for reference only.

Table F.5: Determination of Alternative GPSA Sizing Method Bottle Volume and Length

INPUT	
12.750	Bottle OD (in.)
0.500	Bottle WT (in.)
5.0	GPSA Volume Multiplier
CALCULATED	
5816.9	GPSA Estimated Empty Bottle Volume (in^3)
46.0	L5, Empty Bottle Seam-to-Seam Length (in.)

The relevant bottle dimensions are shown in Figure F.3.

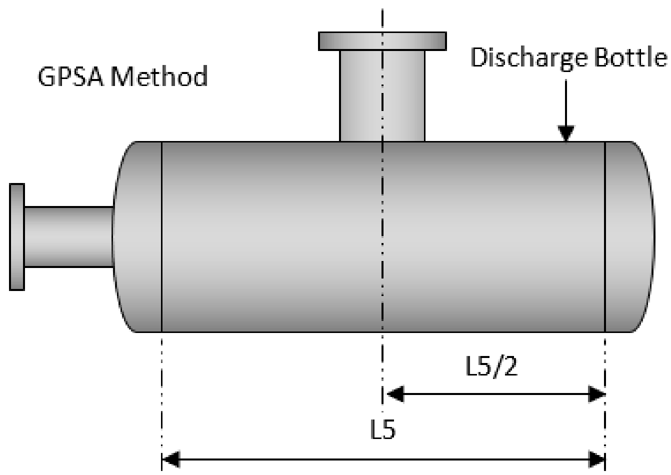


Figure F.3: Layout for GPSA single-cylinder, single-bottle sizing.

F.4 Preliminary Field Gas Compressor Bottle Sizing Procedure For Multiple Cylinders

F.4.1 Bottle Arrangement

This subsection explains the API-11P preliminary pulsation bottle sizing procedure for a mutiple-cylinder arrangement. Figure F.4 is a conceptual layout of this arrangement for two cylinders and Figure F.5 is the layout for three cylinders.

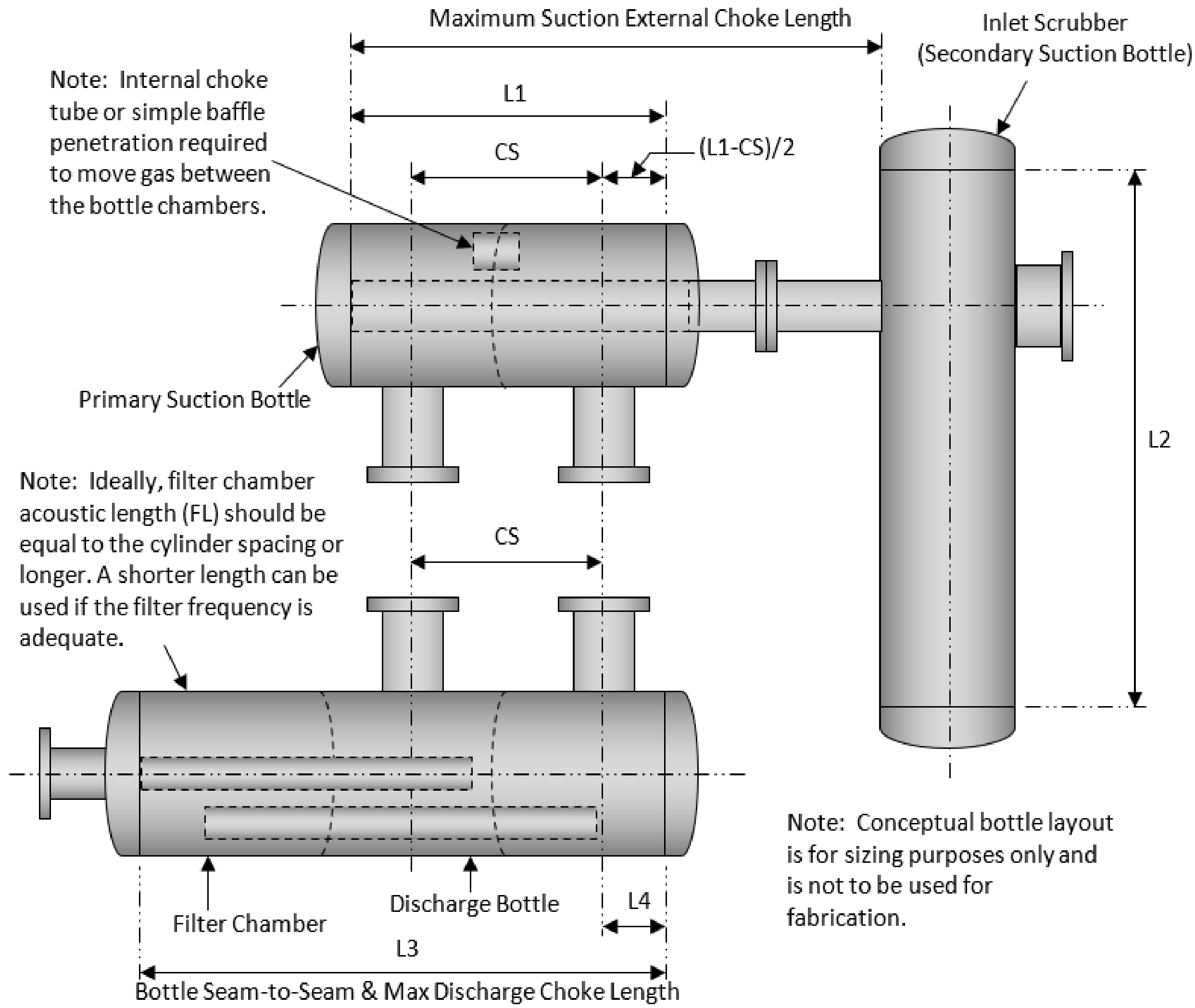


Figure F.4: Conceptual bottle layout for two-cylinder bottle sizing.

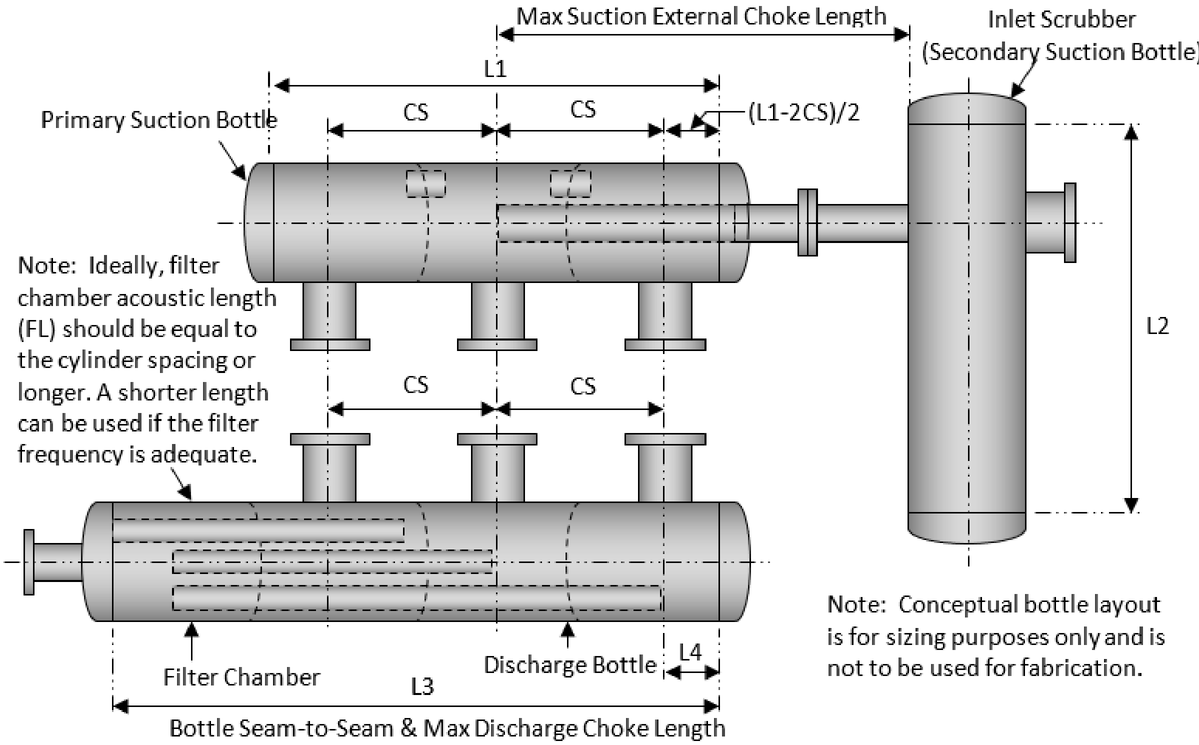


Figure F.5: Conceptual bottle layout for three-cylinder bottle sizing.

F.4.2 Step 1 – Identification of Compressor Parameters

The compressor speed and cylinder parameters are input into the sizing spreadsheet as shown in Table F.6 to determine the piston displacement and the filter cutoff frequency for optimizing pulsation control. The spreadsheet assumes that the cylinders are double-acting. Table F.6 is an example shown for reference only.

Table F.6: Example of input parameters for determining piston displacement and filter cutoff frequency.

INPUT	
1200	Compressor Min Speed (RPM)
1500	Compressor Max Speed (RPM)
2	Number of Cylinders
6	Cylinder Nozzle Nominal Diameter (in.)
42.000	CS, Spacing Between Adjacent Cylinders (in.)
9.250	Cylinder Bore (in.)
4.500	Stroke (in.)
2.000	Rod Diameter (in.)
CALCULATED	
590.7	Piston Displacement (in^3)
20.0	Minimum Operating Frequency (Hz)
14.1	Optimum Filter Frequency (Hz)

F.4.3 Step 2 - Definition and Analysis of Operating Conditions

The compressor operating conditions and gas properties are input into the sizing spreadsheet as shown in Table F.7 to determine speeds of sound of the gas. Table F.7 is an example shown for reference only.

Preferably, the compressibility and speed of sound are calculated for each operating pressure and temperature associated with each gas composition to establish the range. If not available on the compressor package performance sheets, the gas compressibility and ratio of specific heats can be obtained using gas property tables or from software available from various sources. It is important that this be done for all gas compositions, but at a minimum, it can be done only for the gas compositions with the lowest and highest molecular weights with reasonable results.

The maximum calculated speed of sound for the suction and discharge operating conditions is evaluated in Table F.7 and is used later in the calculation of the filter frequency. The maximum speed of sound is typically associated with the highest operating temperature for a given gas composition. Using the maximum speed of sound for each system will generate the highest anticipated filter frequency and will ensure the filter sizing is adequate across the anticipated operating range.

Table F.7: Example of input parameters for determining speed of sound for important operating conditions.

INPUT						
Gas Composition 1			**Gas Composition 2**			
Design	**Min Flow**	**Max Flow**	**Design**	**Min Flow**	**Max Flow**	
97.00			97.00			Flow (mmscfd)
750.00			750.00			Suction Pressure (psig)
82.00			82.00			Suction Temperature (°F)
1050.00			1050.00			Discharge Pressure (psig)
124.00			124.00			Discharge Temperature (°F)
0.845			0.918			Suction Compressibility
0.844			0.924			Discharge Compressibility
0.590			0.590			Specific Gravity
1.300			1.300			K (Cp/Cv)
CALCULATED						
1316			1372			Suction Speed of Sound (ft/s)
					1372	Max Suction Speed of Sound (ft/s)
1366			1429			Discharge Speed of Sound (ft/s)
					1429	Max Discharge Speed of Sound (ft/s)

F.4.4 Step 3 – Sizing the Suction Bottle

Optimizing the bottle sizes is an iterative process. A good practice is to start with a suction bottle nominal diameter of approximately three to four times the cylinder nozzle nominal diameter. The maximum diameter is generally limited to four times the cylinder nozzle nominal diameter to minimize the risk of high vibration. An internal choke tube or a simple penetration in the baffle(s), neither of which are addressed by this spreadsheet, will be required to move the gas between bottle chambers. The intent of this spreadsheet is to help ensure proper bottle sizing, and best practice is for a qualified pulsation analysis company or consultant to be employed to complete the design. The length of a bottle with two or more cylinders will typically be determined by the cylinder spacing and is calculated by this spreadsheet. On the suction side, the volume-choke-volume acoustic filter is developed using the on-skid inlet scrubber as a secondary volume.

The calculated volume-choke-volume filter frequency can be lowered by:

a) increasing the bottle diameter and/or length
b) increasing the filter separator or scrubber diameter and/or length
c) increasing the choke tube length
d) increasing the choke tube wall thickness
e) decreasing the choke tube diameter

The proposed suction bottle and inlet scrubber dimensions, as well as the proposed choke tube dimensions, are input into the sizing spreadsheet as shown in Table F.8 to determine the filter frequency and the choke velocity. Table F.8 is an example shown for reference only. It is common practice to start with a choke tube length equal to the distance from the shell of the inlet scrubber to the cylinder centerline. The maximum possible choke tube length would be the distance from the shell of the inlet scrubber to the weld seam at the rear of the primary bottle. For a three-cylinder bottle, the maximum choke length would typically be the distance from the shell of the inlet scrubber to the centerline of the middle cylinder. The choke velocity is typically kept below 30 m/s (100 ft/s) to minimize pressure drop; however, velocities up to 1/10th of the speed of sound are not unusual. Ideally, the filter frequency must be below the optimum filter frequency calculated in Step 1; however, placing the filter frequency 10 to 20 percent below 1X minimum operating speed is often sufficient.

Table F.8: Determination of Suction Bottle Dimensions

INPUT		
20.000	Primary Bottle OD (in.)	
0.750	Primary Bottle WT (in.)	
30.000	Inlet Scrubber OD (in.)	
0.875	Inlet Scrubber WT (in.)	
72.000	L2, Inlet Scrubber Seam-to-Seam Length (in.)	
114.000	Choke Length (in.)	
8.625	Choke OD (in.)	
0.875	Choke WT (in.)	
CALCULATED		
74.000	L1, Primary Bottle Seam-to-Seam Length (in.)	
15.5	Filter Frequency (Hz)	Ideal filter frequency (ff) is < 14.1
80.3	Max Choke Velocity (ft/s)	Maximum ff is typically 16.0 to as much as 18.0

When an inlet scrubber is used as a secondary volume for pulsation control, it is important to consider the effectiveness of the acoustic filtering as the scrubber internal gas volume changes with liquid level fluctuation between minimum and maximum levels.

F.4.5 Step 4 – Sizing the Discharge Bottle

Optimizing the discharge bottle size is an iterative process. A good practice is to start with a discharge bottle nominal diameter approximately two to three times the cylinder nozzle nominal diameter. The maximum diameter of the bottle will be limited by its proximity to the compressor pedestal and by the distance between the cylinder flange and the top of the skid. Other space considerations are the likely need to install shim blocks under the bottle and to accommodate a cylinder nozzle length of not less than one pipe diameter. The bottle length will be limited by its proximity to any other vessels on the skid (including inlet scrubbers or other cylinder bottles). A baffle would be located between each cylinder pair to minimize bottle unbalanced shaking forces and an additional baffle would separate the line chamber from the nearest cylinder. Each cylinder chamber would serve as a primary volume in the acoustic filter and would be center-fed by its respective cylinder nozzle, while the line chamber would serve as the secondary volume. An individual choke tube would independently connect each cylinder chamber to the line chamber. For the purpose of sizing the bottles, it is only necessary to consider the shortest choke tube, which would connect the line chamber to the nearest cylinder chamber. The maximum length of the shortest choke tube is calculated by the spreadsheet and is used to estimate the filter frequency. The choke velocity is typically kept below 30 m/s (100 ft/s) to minimize pressure drop; however, velocities up to 1/10th of the speed of sound are not unusual. Ideally, the filter frequency is placed below the optimum filter frequency calculated in Step 1; however, placing the filter frequency 10 to 20 percent below 1X minimum operating speed is often sufficient.

Table F.9: Determination of Discharge Bottle Dimensions

INPUT		
20.000	Bottle OD (in.)	
0.750	Bottle WT (in.)	
42.000	FL, Filter Chamber Acoustic Length (in.)	Start with filter chamber length equal to cylinder spacing (CS).
4.500	Choke OD (in.)	
0.337	Choke WT (in.)	
CALCULATED		
116.000	L3, Bottle Seam-to-Seam Length (in.)	
16.000	L4, Bottle Seam-to-Cylinder Centerline Length (in.), end cylinder chamber	
67.000	Maximum Length of Shortest Choke (in.)	
15.0	Filter Frequency (Hz)	Ideal filter frequency (ff) is < 14.1
101.0	Max Choke Velocity (ft/s)	Maximum ff is typically 16.0 to as much as 18.0

The proposed discharge bottle dimensions, as well as the proposed choke tube dimensions, are input into the sizing spreadsheet as shown in Table F.9 to determine the filter frequency and the choke velocity. It is necessary to input an acoustic length for the filter chamber, which is typically equal to or greater than the cylinder spacing, although it is possible that the filter chamber would need to be shorter due to space constraints. The seam-to-seam bottle length will be calculated and must be checked to ensure it will fit in the available space. Table F.9 is an example shown for reference only.

If the discharge bottle length cannot be extended sufficiently to create an acoustic filter, the bottle has to be sized such that the weld seams are equidistant from the cylinder nozzle centerline. The nominal bottle diameter must be maximized to the extent possible, in any case, being at least three times the cylinder nozzle nominal diameter. The volume of the empty bottle would be a multiple of piston displacement, increasing with pressure level, per the GPSA[41] published graph in Figure F.2. In such a case, the preliminary bottle sizing is best determined by a pulsation analyst. An unfiltered pulsation bottle will generally result in a higher potential for damaging vibrations. The bottle length may have to be adjusted by the pulsation analyst to minimize the potential for vibration at frequencies corresponding to the acoustic length resonance of the unfiltered bottle. The pulsation analyst may also determine that baffles are required to control unbalanced shaking forces within the bottle.

The GPSA volume multiplier and the proposed discharge bottle dimensions are input into the sizing spreadsheet as shown in Table F.10 to determine the estimated volume and length. Table F.10 is an example shown for reference only.

Table F.10: Determination of Alternative GPSA Sizing Method Bottle Volume and Length

INPUT	
5.0	GPSA Volume Multiplier
CALCULATED	
5906.7	GPSA Estimated Empty Bottle Volume (in^3)
10	Minimum Nominal Bottle Diameter (in.)
77.0	L5, Empty Bottle Seam-to-Seam Length (in.)
17.5	L6, Bottle Seam-to-Cylinder Centerline Length (in.)

The relevant bottle dimensions are shown in Figure F.6 for a two-cylinder arrangement and Figure F.7 for a three-cylinder arrangement.

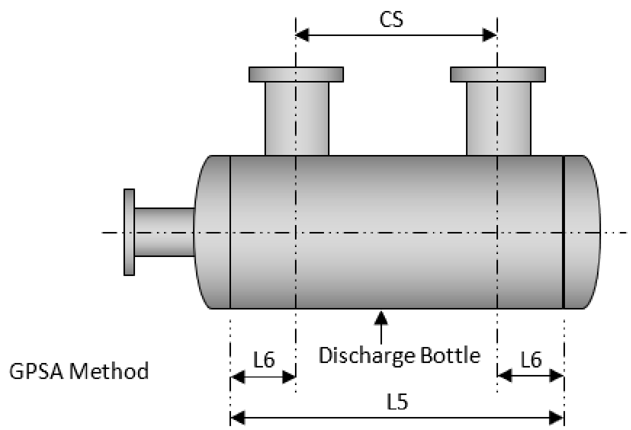


Figure F.6: Layout for GPSA two-cylinder, single-bottle sizing.

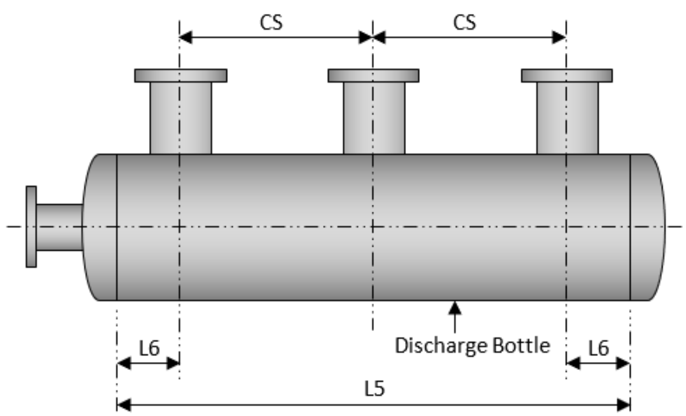


Figure F.7: Layout for GPSA three-cylinder, single-bottle sizing.

F.5 Preliminary Bottle Sizing For Small Compressors

Small compressors less than about 149 kW (200 hp) may not require the use of acoustic filtering. In that case, the GPSA graph in Figure F.2 may be used for preliminary sizing of the suction and discharge bottles as functions of cylinder displacement (swept volume) and pressure rating. Nevertheless, a recommended best practice is for a qualified pulsation analyst to assist with preliminary bottle sizing.

Annex G
(Informative)

Guidelines for Compressor Package Vibration Screening and Baseline Testing

This Annex G provides guidelines for compressor package vibration screening and baseline testing. These guidelines are not mandatory requirements, and it is important to emphasize that they are useful only for initial screening of vibration to identify potential areas of concern. Section 13.4.2 of the *GMRC High-Speed Compressor Package Guideline For Field Gas Applications*[40] is acknowledged as the primary reference for this Annex.

G.1 Vibration Assessment

The main objective of a vibration and pulsation survey is to identify potential problem areas based on high vibration levels anywhere on the compressor package, with primary focus on the compressor driver, compressor frame and cylinders, pulsation bottles, inlet scrubbers, process piping, PSVs, small bore connections and the fuel gas system. Pulsation readings in the suction and discharge systems of each compressor stage are useful in identifying whether the high vibration peaks are driven by pulsation induced shaking forces or by mechanical sources. Impact (bump) tests are useful for confirming the mechanical natural frequencies of relatively low mass components such as cylinders, bottles, scrubbers and piping.

Recommended practice is to conduct a field startup test on each newly installed package include measurement of vibration, pressure pulsations and mechanical natural frequencies.

The following list identifies the waveform descriptors that have generally been used to measure vibration. It is very important that the actual waveform descriptor be clearly identified on data and reports. Most data collectors in current use will provide data in one or more of these formats.

a) RMS (root-mean-squared at individual frequencies)
b) RMS OA (root-mean-squared overall)
c) pPk OA (pseudo Peak Overall) = RMS OA x √2
d) tPk OA (true Peak Overall) = RMS x Crest Factor

NOTE 1: The crest factor of a waveform is the ratio of the peak value of the waveform to the RMS value of the wave form. It is also sometimes called the “peak-to-RMS-ratio”.

e) P-P (peak-to-peak)
f) Peak Overall

NOTE 2: Peak Overall is derived from the square root sum of squares of the amplitude of the 20 highest peaks from a vibration spectrum. This provides a single value that is helpful for general trending, however, it is not as useful in troubleshooting and determining the root cause of a vibration problem.

g) tP-P OA (true peak-to-peak from a waveform)

NOTE 3: True peak-to-peak overall cannot be derived from a spectrum.

At a minimum, vibration and pressure pulsation measurements are recorded in a frequency spectrum format. Although overall vibrations are often used as a preliminary screening tool, such an approach is not foolproof and, therefore has to be applied with caution. In extreme cases, problems could be missed, and in other cases, problems could be falsely indicated. At best, overall vibration provides a simplified initial screening tool. If the screening indicates a problem, spectral information is required to evaluate the problem. The preferred vibration units by most North American sources are velocity (inches per second, IPS, 0-to-peak), because velocity amplitudes are less dependent (than displacement and acceleration) on variation in frequencies.

Dynamic pressure pulsations are measured in pressure units (typically psi, peak-to-peak), or as a percentage of line absolute pressure, at individual frequencies on the line side of the inlet scrubber and the discharge pulsation bottle, and at both overall and individual frequencies in the nozzles between the cylinders and the bottles. Pulsation guidelines are usually specified in terms of either individual frequency or true peak-to-peak overall.

Equivalent metric units with the same waveform descriptor can be used for vibration and pressure measurements, depending on the end user's preference.

The compressor and driver manufacturers typically require that their commissioning procedures, inspections and recommended measurements are completed and documented for future reference. If not required by a manufacturer, this is still a recommended practice. A baseline vibration survey is then recommended to establish that there are no fundamental vibration issues and for use in comparison with future surveys. If not documented, common vibration problems may occur in the future from loose components, soft feet and/or shaft misalignment and be mis-judged as design or installation problems.

Prior to initial startup, it is important that all bottle wedges and all pipe supports are inspected for proper design and fit-up. It is important to document any missing supports to the owner for remedy and to ensure that any gaps under piping at support pedestals and sleepers are shimmed.

NOTE 4: (If there is no gap under the pipe, the pipe could be in strain because the pipe support is too high. This situation is best dealt with in the manufacturing stage by always putting a shim pack or "packer" on top of the sleeper that can be removed to check for vertical pipe strain situations. Alternative methods include prying the pipe up to see how much force is required to create a gap.)

Prior to tightening, pipe clamps normally have a clamp gap at the bottom to allow proper tightening. Unless previously checked and documented at the time of installation, recommended practice is to disconnect piping connections at compressor inlet scrubbers, bottles and coolers and measure flange alignments for proper piping tolerances, both lateral offset and angularity. Piping that has large static pipe strain will generate higher vibration.

This practice is especially important on hot discharge systems. Cylinder crossheads and, if present, head end cylinder supports are generally pre-shimmed for hot operation and discharge bottle support wedges are set in a hot condition.

NOTE 5: There are various opinions about the use of wedge supports under discharge bottles. One recommended practice is to measure vibration with the wedges loose or removed to determine whether they are necessary. If testing confirms that they are not necessary, they can be left loose or removed entirely. In such a case, best practice is to confirm with the compressor manufacture that the compressor frame and distance piece can support the cantilevered weight of the bottles on the cylinders.

Vibration and pulsation measurements are best taken at expected operating conditions (if attainable) and at the load step as close as possible to the guaranteed performance. Ideally, the test condition will utilize at least 80% of the driver rated power. For capacity control systems utilizing unloaders and multiple load steps, representative readings are recommended throughout the speed range (every 50 to 100 rpm) with all cylinders in double-acting mode, all cylinders in single-acting mode (if required to operate single-acting in normal service) and a combination of single- and double-acting cylinders (consistent with the planned unloading scheme). This sequence will provide acoustical pulsations and shaking forces at various combinations of 1X, 2X and other multiples of the operating speeds. During such data acquisition, it is important for the vibration specialist to note high vibration areas and record the predominant vibration frequencies of such vibration.

NOTE 6: A lot of the compressor vibration in the direction of piston motion is due to “cylinder assembly stretching forces” (or gas rod loads). It is sometimes easier, prior to testing, to model the gas forces at all of the operating conditions and load steps on the compressor and identify the worst-case force at each order (up to 10 to 20 or more times running speed). This analysis may greatly reduce the number of tests required. The analysis can also be used to estimate the worst-case vibrations over the range of operation based on one vibration test at one load step and one operating condition. Pulsation-induced shaking forces will also change with operating conditions and load steps, but with good pulsation control, these changes will be minor compared to the gas rod load forces. Often, the Acoustical Design Report will provide useful details for prioritizing vibration test conditions.

G.2 Vibration Screening Guidelines [based on EFRC (and ISO 20816-8) Guidelines]

A common and practical approach to vibration screening, in addition to meeting the equipment manufacturer’s guidelines, is to measure overall vibrations across the entire operating speed range and apply a screening guideline such as the ones described in this subsection. Vibrations are measured in three perpendicular directions and the levels in each direction compared with limits in the screening guideline. If vibration levels exceed the screening limits provided in this guideline, more detailed investigation is recommended using frequency-based data.

As pointed out in the previous subsection, overall vibrations are often used for preliminary screening, however such an approach is not foolproof and it is very important to apply such screening guidelines with caution. In extreme cases, problems could be missed with this approach and in other cases, indication of problems could be false. At best, it provides a simplified initial screening tool. If the screening indicates a problem, spectral information is required to evaluate the problem. Proper assessment requires that vibration measurements are recorded in a frequency spectrum format, not as overall vibrations.

Some compressor, engine and motor manufacturers specify allowable vibration levels that are higher than the screening vibration guideline mentioned above. Normally, manufacturer’s vibration limits indicate “maximum allowable values”, which are not to be exceeded or machinery damage may occur. Normally, operation above the manufacturer’s values may void their warranty.

The *EFRC (European Forum for Reciprocating Compressors) Guidelines for Reciprocating Compressor* Packages[35], which were adopted in ISO-20816-8, are the basis for the screening values shown in Figure G-1. The guidelines are somewhat conservative as they were developed for rigidly mounted (i.e., block mounted) compressors. For reliable application to skid-mounted packages, it is necessary for the skid to be appropriately stiff and mounted directly to a concrete foundation. Therefore, the guidelines in Figure G.1 are not best practice for compressor packages that are not mounted on concrete foundations.

There are different screening guidelines for different elements (e.g., piping, cylinder, frame, etc.) of the compressor package or system. The vibration scale is inch per second pseudo-Peak Overall velocity. The green region (Zone A) is representative of design limits for avoiding the risk of failure from vibration. The yellow region (Zone B) represents the acceptable and preferred limits for field measured vibration. The tan region (Zone C) represents the area where vibration is marginal and likely requires some remediation, but as a minimum requires further testing and review. The red region (Zone D) represents vibration that should be avoided unless further testing and review confirms that resulting component stresses are acceptable.

Once again, it is also important to emphasize that these are screening guidelines and not mandatory limits. Operating above the overall vibration values in Zones C and D of Figure G.1 may not necessarily mean that failures will occur. However, vibration levels above these guidelines typically warrant a further investigation into the probable sources of the vibration and whether or not they will likely lead to component failures. If measured vibration levels exceed the screening limits provided in this guideline, recommended practice is to conduct a more detailed investigation using frequency-based data and further analysis to determine whether the vibration level is acceptable or whether it requires corrective action.

Often, additional stiffening or damping, through the addition of braces or supports, or detuning by changing the stiffness and/or the mass, is required to eliminate a potential failure risk from excessive vibration levels.

Most vibration specialists utilize more sophisticated techniques based on frequency spectrum analysis (see G.4). The advantage of the frequency spectrum analysis is that the vibration specialist can collect screening data and perform advanced troubleshooting analysis in one step. Vibration guidelines by individual frequency spectrum are illustrated in Figure G.2 in G.4.

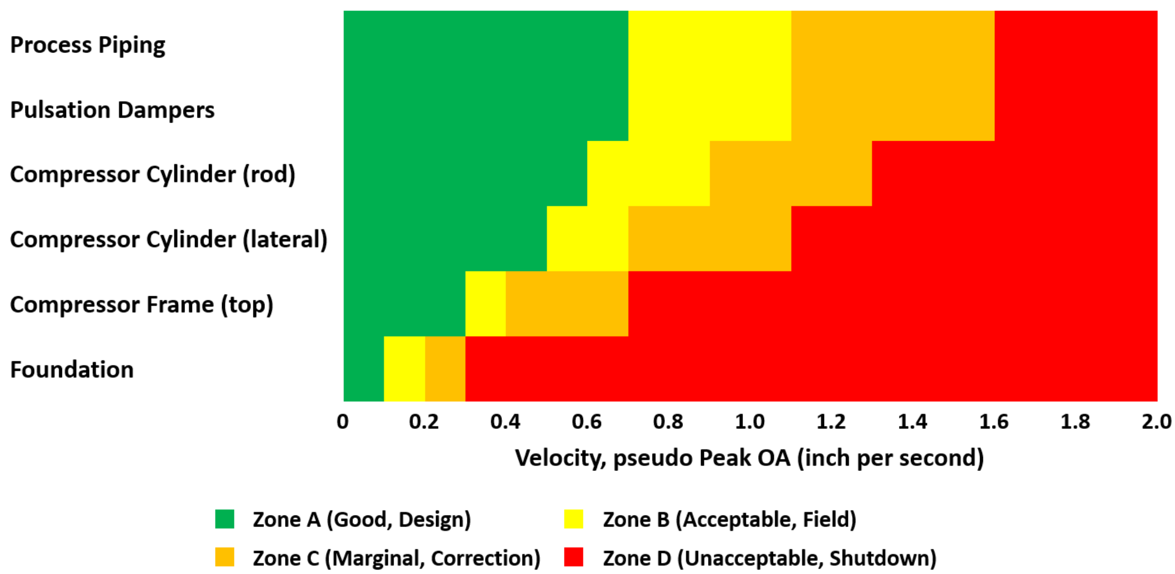


Figure G.1: EFRC Vibration Screening Guidelines for Reciprocating Compressor Packages, Converted to pPk OA

G.3 Small Bore Piping Vibration Screening Guidelines

Small bore vibration tends to be the largest source of vibration related piping failures, however, small bore piping and relief valves are not included in the EFRC Guidelines. Generally speaking, small bore piping refers to a pipe appendage with a lumped mass attached to it, such as a pressure safety valve (PSV) on a pipe nipple. Many vibration consultants use a screening guideline of 1.00 IPS tPk OA for all small bore piping. Typically, the guideline requires that the small bore appendage vibration is less than a 1.00 IPS tPK OA differential between the “top” (read at the middle of the lumped mass, such as a PSV or a pressure transmitter) and the “base” (such as a header pipe or pressure vessel) to which the small bore is attached.

Recommended practice is to measure the vibration at each point in three perpendicular directions and the differential levels in each direction compared with the screening limit. Advanced vibration and stress analysis is recommended when vibration exceeds this guideline. Another practice that can be used is to take operating deflection shape (ODS) measurements that can be used to cancel out base translations and rotations.

G.4 Advanced Vibration Screening, Analysis & Troubleshooting Guidelines

Some vibration consultants have developed frequency-based guidelines for use in screening and troubleshooting. Typically, these guidelines have been developed through extensive field testing and validated by a significant amount of successful experience. One such example of a commonly used screening tool is shown in Figure G.2, which is from the GMRC High-Speed Compressor Package Guideline For Field Gas Applications[40].

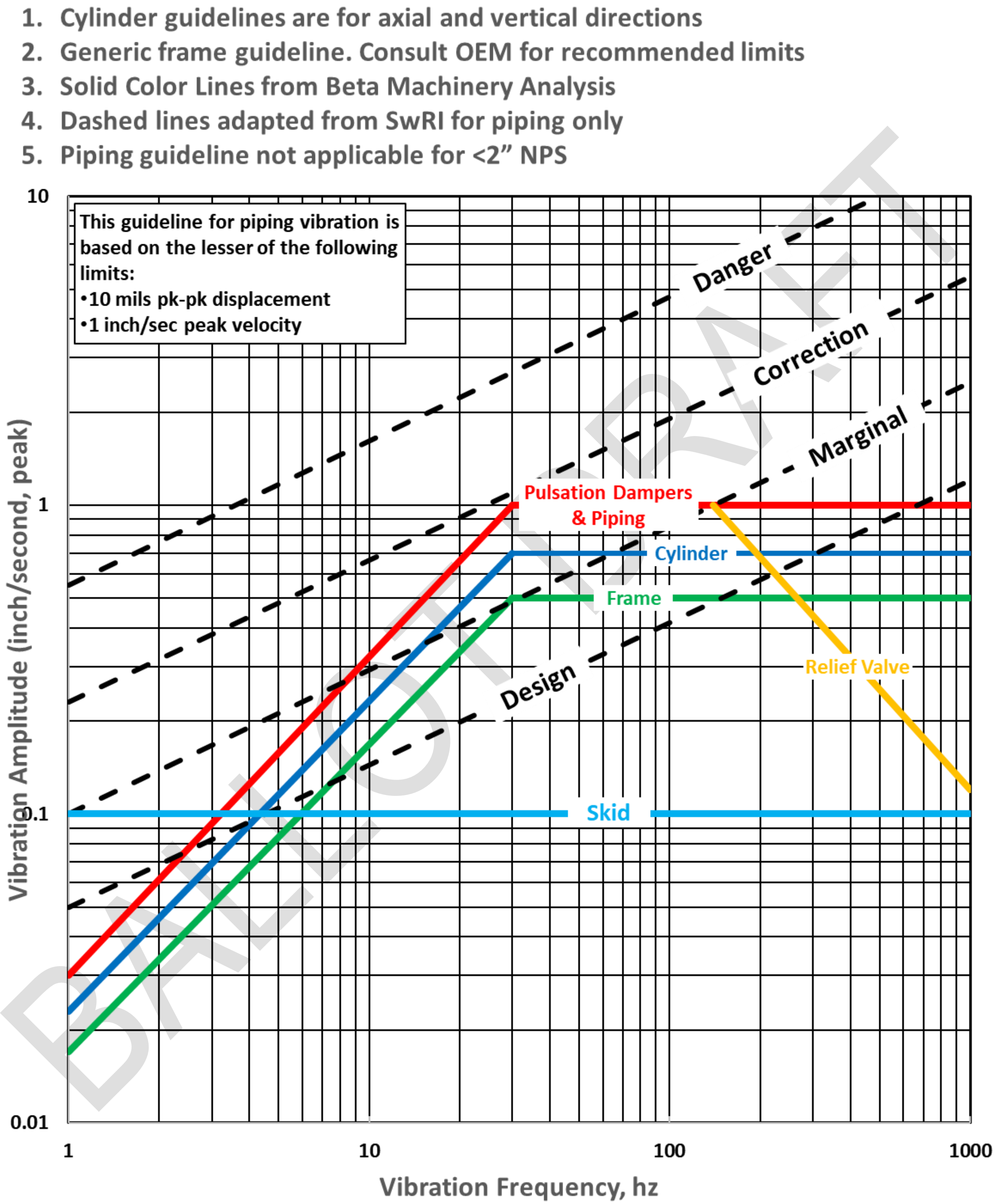


Figure G.2: Vibration Screening Guidelines for Reciprocating Compressors (≤1800 rpm)

The dashed lines in Figure G.2 are for the piping system only. The colored lines are the different limits for various elements of a reciprocating compressor package or system (e.g., bottles, piping, cylinder, frame, etc.). These lines are equivalent to the zone B to zone C boundary in the EFRC system on Figure G.1, which is the transition from acceptable to marginal vibration. Typically, vibration amplitudes at 100 to 150% of the colored lines represent marginal vibration levels for the various components. Amplitude above 150% of the colored lines is equivalent to EFRC zone D, which is generally considered to be unacceptable vibration.

The screening guideline in Figure G.2 is for reference only and is not intended to exclude the use of other guidelines that have been validated by the vibration consultant that is applying them. It is important to recognize that these are screening guidelines, not mandatory limits. Operating above the overall vibration values of Figure G.2 does necessarily mean that failures will occur. However, vibration levels above these guidelines typically warrant a further investigation into the probable sources of the vibration and whether or not they will likely lead to component failures. If measured vibration levels exceed the screening limits provided in this guideline, recommended practice is to conduct a more detailed investigation using frequency-based data and further analysis to determine whether the vibration level is acceptable or whether it requires corrective action. Whether a particular measured vibration is acceptable or not ultimately depends on the vibratory strain and stress that result from the vibration. In this case, the velocity and the frequency are converted to a displacement, which is used to calculate the strain and stress. Often, additional stiffening or damping, through the addition of braces or supports, and/or detuning by changing the stiffness and/or mass, is required to eliminate a potential failure risk from excessive vibration levels.

Annex H
(Informative)

Commonly Applied Materials for Sour and Corrosive Gas Services

In addition to the requirements specified in Section 18, Annex H provides guidance and some recommended practices for materials used in reciprocating compressor packages in sour and other corrosive gas services.

H.1 Applicable Material Specifications

The consequences of sudden failures of metallic components used for oil and gas production associated with their exposure to sour and corrosive fluids led to the development of NACE MR0175. NACE MR0175/ISO 15156-1 and ISO 15156-2 were developed using those sources to provide requirements and recommendations for materials qualification and selection for application in environments containing wet hydrogen sulfide (H_2S) in oil and gas production systems. Carbon and low-alloy steels selected using ISO 15156-2 are resistant to cracking in defined environments in oil and gas production, but they are not necessarily immune to cracking under all service conditions. Different service conditions might necessitate the alternative testing that is dealt with in ISO 15156-2:2003 Annex B, which specifies requirements for qualifying carbon and low-alloy steels for sour and corrosive service by laboratory testing. Several current standards cover similar content, and it is not the intent of this Annex to supersede them, but to consolidate and tailor them to the scope of API 11P.

Additional guidance for common items may be found in:

a) API 5L, Annex H – PSL 2 Pipe Ordered for Sour Service
b) ASME Boiler and Pressure Vessel Code, Section II, Part D, Appendix A – Metallurgical Phenomena
c) NACE MR0175, ISO 15156 – Materials for use in H2S-containing environments in oil and gas production

H.2 Material Review

It is very important for the packager and equipment manufacturers to select carbon and low-alloy steels suitable for the intended service. It is also important for the purchaser to review and approve the specified materials.

In many applications, small amounts of wet H_2S are sufficient to require materials resistant to sulfide stress corrosion cracking. When there are trace quantities of wet H_2S known to be present or if there is any uncertainty about the amount of wet H_2S that may be present, it is important for the purchaser to specify by notation on the data sheets the requirement for materials resistant to sulfide stress corrosion cracking.

H.3 Copper and Copper Alloys

Copper and copper alloys are known to be susceptible to corrosion in the presence of H_2S and are generally not acceptable for parts of compressors or auxiliaries that are in contact with corrosive (H_2S) gas.

However, where mutually agreed by the vendor and purchaser, copper-containing materials may be used for piston rod packing on lubricated compressors, as the lubricating oil may act as a protective barrier from the corrosive gas.

CAUTION – Certain gases and corrosive fluids (e.g., acetylene and hydrogen peroxide) in contact with copper alloys have been known to form explosive compounds.

Some nickel-copper alloys (UNS N04400 Monel or its equivalent) are generally acceptable for corrosive gas.

H.4 Bearing Materials

Bearings containing copper or babbitt materials are acceptable if they are isolated from exposure to corrosive process gas. This can be accomplished with a two-compartment compressor distance piece and an intermediate piston rod packing, often with use of a buffer gas.

H.5 Other Considerations

There are a number of other considerations and recommended practices for systems in the presence of corrosive gases.

a) External parts that are subject to rotary or sliding motions (such as control linkage joints and adjustment mechanisms) are constructed of corrosion-resistant materials suitable for the site environment.
b) Minor parts such as nuts, springs, washers, gaskets, and keys have corrosion resistance at least equal to that of specified parts to which they are attached in the same environment.
c) When justified by the manufacturer’s experience, hardness requirements for valve seats and piston rod surfaces may be in excess of NACE provisions. Similar exceptions may be made for valve plates, springs, and unloader components, where greater hardness has been proven necessary for wear resistance and durability. In such cases, it is important for the packager to specify the materials of the affected components and for the purchaser to review and approve the proposed materials and material properties.
d) Exposure of austenitic stainless steel parts to conditions that may promote intergranular corrosion is avoided. Low-carbon steel is preferred, especially where parts are to be fabricated, hard faced, overlaid or repaired by welding.
e) A buffer layer that is not sensitive to intergranular corrosion is applied beneath overlays or hard surfaces that contain more than 0.10% carbon applied to low-carbon and stabilized grades of austenitic stainless steel to avoid sensitizing the base metals to intergranular corrosion.

H.6 Common Materials Used for Corrosive Gas Services

Tables H.1, H.2 and H.3 provide examples of materials that are commonly used for corrosive gas services. They are for general guidance and not intended to supersede requirements specified in Section 18 or more quantitative requirements listed in this document or in the documents referenced herein.

Following are definitions of the abbreviations used in the tables, with examples stated in parenthesis, unless stated otherwise:

a) CS - Carbon Steel (API 5L, ASTM A106, ASTM A350)
b) CA - Corrosion Allowance [Wall thickness +1.6 mm (1/16 in.), +3.2 mm (1/8 in.)]
c) CR - Corrosion Resistant
d) CRSG - CR Soft Goods (PTFE, RTFE, PEEK)
e) DI - Ductile Iron (ASTM A395, ASTM A536)
f) EDCP - Explosive Decompression Proof (EPDM, Viton, Nylon, Teflon / PTFE)
g) FS - Forged Steel (AISI 4340)
h) FSS - FS Softened / Heat Treated
i) LS - Low SMYS [0.24 kN/mm^2 (35 ksi) < 0.36 kN/mm^2 (52 ksi)]
j) GI - Gray Iron (ASTM A278)
k) HS - High SMYS [>0.36 kN/mm^2 (52 ksi)]
l) SMYS – Specified minimum yield strength
m) SS - Stainless Steel (AISI 304SS, 316SS, 410SS, 416SS)
n) SS+ - Duplex Stainless Steel (2205) or other high alloy SS (2210, 17-4PH, Hastelloy, Inconel)

Table H.1 compares the relative corrosion risk of carbon steel (CS) with two levels of corrosion allowance (CA), stainless steel and duplex or high alloy stainless steel with various gas applications.

NOTE: The Chart in Table H.1 is presented with a subjective scale of 1 to 10 (10 = most corrosion potential, 1 = least corrosion potential).

Table H.2 provides general materials that are typically used for various components with various gas applications.

Table H.3 lists specific material specifications that are commonly used in sour (H_2S) wet CO_2 and dry CO_2 gas applications.

Table H.1: Corrosion Risk Ranking Matrix

	Category				
Application	CS	CS with 1/16 in. CA	CS with 1/8 in. CA	SS	SS+
Pipeline Gas	**1**	**1**	**1**	1	1
Wet Gas	**3**	**2**	**1**	1	1
Heavy Hydrocarbons	**4**	**3**	**2**	1	1
Ethane	**4**	**3**	**2**	1	1
Propane	**4**	**3**	**2**	1	1
Sour Gas	**5**	**4**	**3**	2	1
High H_2S Sour Gas	**9**	**8**	**7**	2	1
Air	**1**	**1**	**1**	1	1
Nitrogen	**1**	**1**	**1**	1	1
CO_2 (DRY)	3	2	1	1	1
CO_2 (WET)	9	8	7	2	1

Table H.2: Material Selection (General)

Application	Piping	Pressure Vessels	Cylinder Bodies	Rods	Valves	Fasteners	Non-Wetted Parts	Wetted Parts	Wear Surfaces	Soft Goods
Pipeline Gas	CS	CS	DI / GI	CSHS	CS	CSHS	CS	CS	13CR	EDCP
Wet Gas	CSCA / CSLS / SS	CSCA / CSLS / SS	FS / FSS / SS	SSHS	SS	SSHS	CSCA / CSLS / SS	SS	SSHS	CRSG
Heavy Hydrocarbons	CSCA / CSLS / SS	CSCA / CSLS / SS	FS / FSS / SS	SSHS	SS	SSHS	CSCA / CSLS / SS	SS	SSHS	CRSG
Ethane	CSCA / CSLS / SS	CSCA / CSLS / SS	FS / FSS / SS	SSHS	SS	SSHS	CSCA / CSLS / SS	SS	SSHS	CRSG
Propane	CSCA / CSLS / SS	CSCA / CSLS / SS	FS / FSS / SS	SSHS	SS	SSHS	CSCA / CSLS / SS	SS	SSHS	CRSG
Sour Gas	CSCA / CSLS / SS	CSCA / CSLS / SS	FS / FSS / SS	SSHS	SS	SSHS	CSCA / CSLS / SS	SS	SSHS	CRSG
Air	CS	CS	DI / GI	CSHS	CS	CSHS	CS	CS	13CR	EDCP
Nitrogen	CS	CS	DI / GI	CSHS	CS	CSHS	CS	CS	13CR	EDCP
CO_2 (DRY)	CS	CS	DI / GI	CSHS	CS	CSHS	CS	CS	13CR	EDCP
CO_2 (WET)	CSCA / CSLS / SS	CSCA / CSLS / SS	FS / FSS / SS	SSHS	SS	SSHS	CSCA / CSLS / SS	SS	SSHS	CRSG

Table H.3: Material Selection (Application Specific)

Application	Sour (H_2S) Gas	CO_2 (DRY)	CO_2 (WET)
Notes ->	CONSIDER CS with 3.2mm (1/8 in.) CA		
Trim	AISI 316; STELLITE; MONEL; ALLOY 20	AISI 410, 316 or 310	AISI 316; STELLITE; MONEL; ALLOY 20
Fasteners	ASTM A193-B7, 194-2H, A193 or A194 B8M SS	ASTM A193-B7 or 194-2H	ASTM A193 or A194 B8M SS
Pressure Vessels	AISI 316L or 304L; ASTM A516, A738 or A333	AISI 316L or 304L; ASTM A516, A738 or A333	AISI 316L or 304L
Piping	AISI 316L or 304L; ASTM A106, A105, A234 or A333; ANSI/API 5L	ASTM A106, A105 or A234; ANSI/API 5L	AISI 316L or 304L

Annex I
(Informative)

Guidelines and Best Practices for Enclosed Cold Weather Packages

In addition to the requirements specified in Section 21, Annex I provides guidelines and what are typically considered to be best practices related to compressor packages that are enclosed and intended to operate in cold weather. Cold weather packages are typically considered when the unit is expected to be subjected to temperatures below 4˚C (40˚F) for sustained periods or when there is a risk of freezing. Below these temperatures, there is risk of freezing water or ice formation in unprotected equipment, impaired flow of lubricants, or inability to restart cold equipment. Section N.4 of Annex N provides many cold temperature considerations for compressor packages. The best practices contained in Annex I are more specifically aimed at enclosed cold weather packages for ambient temperatures down to -40˚C (-40˚F). While the recommendations are still relevant below -40˚C (-40˚F), more robust measures are typically need for colder ambient temperatures or locations with extreme windchill.

Packaging compressors for operation in cold weather presents several unique challenges. The primary reasons to enclose a package are to maintain process and equipment temperatures at appropriate levels for starting and operation. The enclosed package also provides space within it for operation and maintenance.

The primary challenges arise generally from enclosing the package and the resulting effects on package design and layout. This Annex outlines the best practices to achieve a reliable cold weather package. There are too many applications and variations for this list to be exhaustive and some of the following suggestions may be mutually exclusive depending on how they are implemented and the process requirements. There are additional requirements that arise from enclosing a package that may have to be considered.

I.1 Site Data

It is important for the purchaser to specify the low and high ambient temperatures that the package will be expected to experience. The package is then designed for safe operation through the range of specified ambient temperatures.

Additional information may be required by local building codes such as wind, seismic and snow loads.

I.2 Package Heating Philosophy

Enclosed cold weather packages generally utilize a heated building to keep the overall package sufficiently warm for starting and operating. There are some specific instances that will be discussed further where building heaters may need to be supplemented with additional heaters or heat tracing.

The type of building heaters depends greatly on the utilities present at site. These can be gas fired catalytic heaters, electric forced air heaters or they may utilize other heat medium if available.

One critical consequence of enclosing a unit to retain heat is that the cooling of the unit in hot ambient conditions becomes much more of a challenge. It is not uncommon for units in some climates to be subjected to 78˚C (140˚F) difference between the minimum ambient design temperatures and the maximum ambient design temperature. The building needs to be provided with enough ventilation to meet electrical area classification requirements, retain sufficient heat for process and equipment reliability in the cold months and be able reject sufficient heat in the warm months to prevent overheating of equipment and or personnel.

Typically, three cases dominate when sizing the heating and cooling systems:

a) Winter Shutdown – This is the worst case for the heaters as there is no heat rejection by the process or equipment.
b) Summer Operating – This is the worst case for the ventilation / cooling system.
c) Winter Operating – This case is used to determine any extra heaters or fans that may be required to balance the heating and cooling loads with the heat rejection of the equipment.

Fresh air intake louvers are typically required year-round to maintain area classifications. This means that cold outside air is drawn into the building. During the coldest months, cold air may pool in pockets in the skid. It is important to review the air flow through the package to limit the ability of stagnant air to pool. Some systems (discussed later) may need additional heating and/or insulation when placed in these areas.

I.3 Process Piping

It is important that process piping is designed for the minimum ambient temperatures, including meeting all code requirements. Design temperatures below -29˚C (-20˚F) will require special materials and welding procedures. Charpy impact testing may be required, depending on the material selected. If heat is provided by the building envelope as opposed to heat tracing, low temperature piping is generally carried inside the package some distance to ensure that the piping is sufficiently removed from the outside and can be heated by the building prior to transitioning to regular temperature material. Often the transition is made at the first break flange inside the package.

It is important that pockets where liquid may collect in process piping are avoided, especially in sections that may be subject to freezing.

I.4 Hydrocarbon Drain Lines

Drainage lines are typically made larger to facilitate drainage of higher viscosity fluids resulting from low temperatures. Scrubber bridles and drains may have to be heat traced and insulated.

If the scrubber drains are heat traced and insulated, the heat tracing typically extends to the waste tank to prevent freezing.

I.5 Lube Oil Supply

Increased viscosity of lubricating oils subjected to cold temperatures may require design modifications to maintain approved lubricating qualities.

Lube oil make-up tanks are heat traced, or otherwise heated, and insulated for operation in ambient temperatures below 4˚C (40˚F). Often in enclosed packages, oil make-up tanks are incorporated into overhead crane rails, which brings them into the heated envelope and eliminates the need for separate heating and insulation.

If the building is designed to adequately maintain internal temperature, lube oil lines can be run without heat tracing. However, cold weather packages, even with building heaters, may have low points below the grating where cold air can pool. If the lube oil lines are congregated in these areas, they are typically sized at least 1.5 times larger diameter than lines seeing normal ambient temperatures above 4˚C (40˚F). The lines typically require heat tracing and insulation from the supply/make-up tank to the oil level controller.

I.6 Compressor Cylinder Lubrication

Compressor lubricator box supply lines and oil supply tank are to be heat traced and insulated to ensure a continuous supply of oil to the lubricator pumps for ambient temperatures below 4˚C (40˚F). However, if the cylinder lubricators are fed from the compressor sump, this requirement may not be necessary.

I.7 Engine and Compressor Frame Lubrication

Lube oil for engines and compressors needs to meet manufacturers' specified viscosity requirements prior to start. The oil viscosity is controlled by maintaining the oil at a sufficient temperature to start the equipment. Even in a heated building it could take a significant amount of time to sufficiently heat soak the compressor or engine enough to start. A dedicated oil heat source is recommended for ambient temperatures below 4˚C (40˚F). These can be immersion heaters inserted directly into the oil sump, but a preferred system is to utilize circulating oil heaters, which help ensure that the oil is evenly heated and distributed through the machine. Refer to the compressor or engine manufacturers' documentation, as they often have specific dedicated ports for this purpose.

Oil heating systems, whether immersion or circulating type, need to have temperature control and they generally engage upon a unit shut down and do not switch off unit start up is achieved.

Oil circulating heaters may be dual purposed as pre-lube pumps, provided they are sized appropriately.

Program OEM specified engine and compressor coolant and lube oil temperature minimums into the control system to prevent premature loading of a cold unit. If OEM specifications are not provided, typical start-up permissives are: compressor oil temperature of at least 10˚C (50˚F) and engine oil temperature of at least 10˚C (50˚F). Typical load permissives are: compressor oil temperature of at least 35˚C (95˚F), engine oil temperature of at least 52˚C (125˚F), engine jacket water temperature of at least 74˚C (165˚F), and engine auxiliary water temperature of at least 49˚C (120˚F).

If the compressor frame oil is cooled by an air-cooled heat exchanger (common in motor driven applications), it is necessary for the oil cooler to be positioned such that it can direct its outlet air either inside or outside the package in the winter or summer months, respectively. Oil coolers that exclusively exhaust to the outside place an increased demand on the building heaters in the winter months.

I.8 Engine Coolant

The engine coolant has to be an appropriate mixture to avoid freezing. Refer to the coolant manufacturer's recommendations to meet the design requirements of the system. It is important that the cooler manufacturer is advised of the proposed or specified coolant mixture, as it impacts the thermal design of the cooler.

In some cases, engine coolant heaters are recommended rather than, or in addition to, lube oil heaters in order for the unit to achieve a proper start.

Program the specified minimum engine coolant temperatures into the control system as a start permissive to prevent premature loading of a cold unit. Consult the engine manufacturers' specifications for guidance. If OEM specifications are not provided, typical load permissives are: jacket water temperature of at least 74˚C (165˚F) and auxiliary water temperature of at least 52˚C (120˚F).

Adhere to engine inlet air temperatures that are consistent with permissible startup and operation per OEM guidelines. Cooler louver controls and coolant temperature regulation may have to be employed to regulate the post turbocharger air temperature supplied to the engine for combustion.

I.9 Fuel Gas

Make engine fuel gas pressure cuts away from the engine. Where this is impractical, the fuel gas line may be heat traced and insulated, both before and after the pressure regulator, to prevent the formation and collection of liquid in the fuel lines.

I.10 Engine Starting Air / Gas

Size engine air start systems based on the higher torque loads required for starting a cold engine with colder oil than normal applications. Likewise, the starting air system will likely require upgrading to a larger receiver capacity and larger diameter pipe to supply sufficient flow to the starter(s).

I.11 Engine Air Intake

Size and design air inlet filters for colder ambient temperatures to prevent filter icing and snow ingestion.

If a package is installed in a building with air filters mounted outside, slope the intake air ducting downward from the engine to the filters to prevent any ice formation in the piping of an idle unit.

Snow accumulation and depth have to be considered when mounting air inlet filters outside of the enclosed package.

Engine inlet air temperatures need to be sufficient to allow startup and operation per OEM guidelines. This may require air pre-heating. Several sources of warm air pre-heat have been used. The most consistent, but most complicated and expensive, source of intake air pre-heat is a glycol pre-heater upstream of the air intake filters. This is generally only used in applications with heat medium and subject to extremely low temperatures.

Alternative sources of warm air may be achieved by passing the intake air over the exhaust silencer or using the warm air of the building itself. Either system requires a diverter valve to select the air source, either pre-heated air, or fresh ambient air.

When using building air as the warm air source, it is imperative that the building has sufficient ventilation to make up the consumed combustion air and that heaters are able to maintain the minimum building temperature when the engine is consuming that air.

I.12 Engine Exhaust

Exhaust piping may need to be insulated for units requiring catalytic converters in cold climates to keep the exhaust temperature high enough for the converter to operate properly and achieve compliance with air permit requirements.

Exhaust piping within the building may also have to be insulated to limit heat rejection into the building and for personnel protection.

I.13 Air-Cooled Heat Exchangers

Provide cooler louvers with automatic temperature control to control coolant and gas temperatures. In extreme cold ambient temperatures, a cooler exhaust air recirculation system, or variable speed fan drive may also be required.

A thermodynamic review of the gas at the various operating conditions through the compression and cooling stages throughout the system is advisable when operating in cold ambient conditions. Where there is a risk of hydrate formation, coolers are generally supplied with a methanol injection port in the gas piping upstream of the cooler coils.

Design the coolers for use with an appropriate mixture of water and glycol specified for the minimum ambient temperature.

Provide hail guards on vertical discharge coolers.

I.14 Control Panels

Control panels may require heaters. Consideration for this is based on the control system's minimum operation temperature. Many PLC-based systems cannot handle subfreezing temperatures.

Control panels and PLCs in enclosed packages that experience excessively hot temperatures may also require air conditioning.

Consult the control system manufacturer for the minimum and maximum allowable operating environment temperatures.

Annex J
(Informative)

Best Practices for Distance Piece Vents and Drains

In addition to the requirements of Section 15, this Annex J provides tutorial information and recommended practices for distance piece vents and drains.

Distance piece configurations and the associated connections vary among compressor models and manufacturers.

The Type 0 short-coupled distance piece (see Fig. 1 in 6.9.2) is used when mixing of the cylinder and crankcase lubricants is acceptable. Typically, the wiper packing is mounted on the flange of the piston rod packing case. This configuration is not suitable for sour gas service or when cooled packing is utilized.

The Type 1 single-compartment distance piece (see Fig. 2 in 6.9.2) is used for separation of the pressure and wiper piston rod packings. The separation of the wiper and pressure packing enables the use of different frame and cylinder lubricants as well as cooled packing. This distance piece, when supplied with a purged packing and wiper, is suitable for sour gas service. For nonlubricated service an oil slinger must be included.

The Type 2 short two-compartment distance piece (see Fig. 3 in 6.9.2) has two separate compartments and two or three seal sets (pressure packing, and seal/wiper seals), all of which can be purged. This distance piece option provides additional protection against flammable, hazardous, toxic and corrosive gases entering the crankcase. The Type 2 will have a distance piece long enough to utilize an oil slinger (making it a “long” distance piece).

The Type 3 long two-compartment distance piece (see Fig. 4 in 6.9.2) has two separate compartments with three seal sets (pressure packing, intermediate seal set, and a wiper/seal set), all of which can be purged. This distance piece option provides even additional protection against flammable, hazardous, toxic and corrosive gases entering the crankcase, and better separation of the frame and cylinder lubricants. Both compartments of the Type 3 are “long” (both can utilize an oil slinger).

All of these configurations have connections to allow venting of piston rod pressure packing process gas leakage and drainage of piston rod packing lubricant. It is important that these vents and drains are installed in a manner that allows the free-flow of gas or liquid to a safe location and are consistent with the equipment manufacturer’s recommendations and in compliance with applicable codes.

Packing and distance piece vents and drains merit special consideration and are vented to a safe location due to normal gas leakage during operation and when the compressor is pressurized while idle. Undersized or improperly designed vent/drain systems may also contribute to piston rod packing problems.

Traditionally, venting to atmosphere has been common with non-toxic or non-lethal gases. However, venting to atmosphere is not acceptable for toxic or lethal gases, and non-toxic or non-lethal gases are becoming increasingly restricted due to emission regulations and reduction strategies. In the future, it may be a requirement that all gas vents connect to a flare or other recovery/capture system. Whether venting to atmosphere, flare or to some other recovery system, following is a list of considerations that have been found to be helpful:

a) It is necessary to vent all distance piece compartments. Size the vent and drain lines to handle the worst-case leakage rates without causing the internal pressure of the distance piece to exceed the manufacturer’s maximum allowable pressure. Piston rod pressure packing leakage rates vary but are typically in the range of 0.14 m^3/hr to 0.28 m^3/hr (5 SCFH to 10 SCFH) per pressure packing case when packing seal rings are new, but may reach 5.1 m^3/hr (180 SCFH) or higher, when worn. Consult with and follow the compressor manufacturer's guidance on maximum potential packing leakage rates and maximum allowable distance piece pressures.

b) It is important to minimize pressure drops in the drain and vent lines. Make all compressor packing vents and drains be at least equal to the size of the distance piece connections furnished on the compressor. Connect any 6.4 mm (¼ in.) NPT packing vent/drain connections on the distance piece to 9.5 mm (3/8 in.) diameter or larger tubing.
c) Packing vent/drain lines from multiple packing cases are often connected to a common header and routed to an oil separation pot (drain tank).
d) Configure the distance piece vent connections so that gas cannot transfer from one vented distance piece compartment to another. Check valves are not ideal, as they can foul and plug with contaminants in the oil and gas mixture. A liquid check valve (or weir) in an oil separation pot or a seal trap is a very effective means of isolating vents from a common waste oil tank. If a building or enclosure is required, it is important to carefully consider and coordinate the location of the waste oil tank (on-skid or off-skid) with all parties.
e) Size the main vent line leaving the oil separation pot to be large enough to freely flow the total volume flow from the individual packing vents in a worn condition.
f) Slope drain manifolds continually toward the drain pots and the waste oil tank, avoiding low level traps where oil could pool and collect.
g) Avoid tying the packing vent/drain connection to the distance piece drain prior to entering the oil separation pot, as the packing vent flow can go back through the drain connections to vent through the top of the distance pieces. This will not allow the oil to drain properly from the distance piece.
h) Whenever two lines are manifolded together, size the combined line to be about equal to the added areas of the incoming two lines. For example, if two 19 mm (¾ in.) lines combine, a 25.4 mm (1 in.) line is appropriate after the connection. This applies to packing vents and drains as well as to distance piece vents and drains. Larger sizes may be necessary to allow proper draining for lines that can contain oil and for long runs of piping or tubing. Worn or damaged pressure packing rings can result in high vent flow rates and increased back pressure on the vent line. Size venting lines sufficiently to avoid back pressure exceeding 172 kPa (25 psi) on the distance piece compartments.
i) When vents are routed to a flare system, review flare upset conditions. Other equipment can provide a large flare pressure that causes back pressure to the distance piece compartments.
j) To avoid back pressure from a short-term flare pressure (seconds), install a check valve on the main vent between the compressor system and the flare (downstream of the drain pots).
k) Size drain lines generously to allow proper draining when adequate slopes are not possible.
l) It is necessary for lube oil to be separated from the packing vent gas.
m) Install a check (non-return) valve on the final vent line when venting to flare.
n) There are several methods for monitoring or assessing pressure packing leakage:
    1) Packing vent gas temperature out of the packing case. This method monitors the packing vent line temperature immediately outside the distance piece. Higher leakage flow rates have higher tubing temperatures. If immersing a temperature device in the vent line for vent gas temperatures, the installation should be routed in a manner that prevents any hot oil in the line from contacting the probe, as this spikes the temperature.
    2) Packing case temperature. This method involves the installation of a temperature element in the packing case itself.
    3) Purge gas to vent gas differential pressure. This method involves installing a differential pressure gauge across the purge gas and packing vent/drain line to provide a positive indication that the vent line flow is not creating more back pressure than the purge gas pressure. This method can only be used when purge gas is applied.
    4) Packing vent flow. Packing flow measurements need to consider the oil in the packing vent/drain lines. Either the oil is removed from the line prior to measurement or an appropriate flow meter is installed in a larger pipe section where oil in the line is not a concern. An RTD style mass flow meter may be used in larger line sizes.
o) Where packing leakage rates are to be monitored, one method is to pipe the vents into a single vent header terminating at the edge of the skid with valves and a flow meter. If the flow meter restricts the flow rate in

any way that would result in increasing the distance piece pressure to an excessive level, it is necessary to connect an automatic pressure relief/bypass valve in parallel around the flow meter.

p) When a purge system is utilized, a maintained level in the oil separation pot is preferred to the use of check valves (separating the packing vent/drain from each distance piece vent and drain).

q) Capacity control devices mounted on the compressor cylinders may also have vents that need to be connected to the vent/drain system. A common device used on field gas compressors is the variable volume clearance pocket (VVCP). The vent off a VVCP will typically be routed to atmosphere. Vents from pneumatically operated capacity control devices also require proper venting. It is important to closely follow the manufacturer's recommendations to ensure that proper operation and safety considerations are not compromised by the vent system(s).

Annex K
(Informative)

Guidelines for Compressor Package Safety, Accessibility & Maintainability

This Annex K provides guidelines and some typical best package design and installation practices related to package safety, accessibility and maintainability. Section 12 of the *GMRC High-Speed Compressor Package Guideline For Field Gas* Applications[40] is acknowledged as the primary foundation reference source for this Annex.

It is important that compressor packagers, rental fleet operators and end users understand and take responsibility for their role in the design, installation and operation of the field gas compressor package and accessories, including all features designed to enhance the safety, accessibility and maintainability. Early collaboration between the purchaser, packager and operators is a best practice for optimizing the package design to enhance safety, accessibility and maintainability.

In addition to the design of the package, proper training and continued awareness are critical factors for the prevention of harm to personnel and machinery. The safest compressor package is only as safe as the operator running it. It is very important that end user owners and operators make personnel aware of, and provide for their familiarization with, the operation and maintenance of the machinery and all support systems, including the potential dangers in the work areas.

K.1 Equipment Safety Considerations

In the U.S., numerous Federal Occupational Safety and Health Administration (OSHA) standards apply. Other countries may have similar agencies and standards that are applicable. Some of the most applicable and important standards pertain to fall protection, safe access and egress, and quick exit from an area in the event of an emergency. Safety starts with the design process. It is important to allow for the safest possible access to the most commonly serviced parts of the package.

A Hazard and Operability (HAZOP) analysis for the entire facility is a best practice that may also be a regulatory requirement in some locations.

K.2 Compressor Package Access

It is necessary that the installation site provided for the compressor package has adequate access and egress. This includes providing a clear, unobstructed path of escape from any location around the package in the event of an emergency.

Accessibility is an important consideration around the package. It is necessary for service trucks and/or cranes to have adequate access to the package for maintenance work. Containment walls or berms placed around a compressor package for environmental containment often block access by service trucks and inhibit access by personnel. Even though a crossover stairway can be provided as shown in Figure N.4 in Annex N to enable personnel access, the wall interferes with truck and crane access, and it requires personnel to carry heavy parts up the stairs and over the wall.

End users are encouraged to work with compressor operators during the selection of environmental protection methods to ensure that the chosen method is workable and safe for operator and maintenance technician access. For example, plastic liners placed under the compressor package can create a slippery surface when water or oil collects on them. Placing a layer of sand on top of the liner greatly improves the safety for personnel needing to walk around the compressor package as shown in Figure N.5 in Annex N.

K.3 Engine and Compressor Access

There are a number of specific best practices and recommendations relating to engine and compressor access on the package skid, many of which relate to the package layout and design. Additional information, including examples, can be found in Section 12 of the *GMRC High-Speed Compressor Package Guideline For Field Gas Applications*[40].

K.4 Service Access for Enclosed or Housed Packages

When compressor packages are placed in buildings or enclosures, it is necessary to have either (i) monorail or bridge crane hoists with adequate lifting capacity and clearance for handling the heaviest piece of removable equipment or part to be installed in the building, or (ii) suitable overhead doors for trucks to access the compressor package to load, unload and remove equipment or parts. A concrete or gravel pad under the door and immediately outside each overhead door is a recommended practice.

For enclosed or housed compressor packages, the choice of interior color is an important consideration when optimizing lighting in a work area. Avoiding dark color paints for the interior of enclosures can improve the effectiveness of lighting.

K.5 Service Access for Outdoor (Unhoused) Packages

When compressor packages are located outdoors without a building or enclosure, it is important that the package can be sufficiently accessed by service trucks and lifting booms or cranes for maintenance. Additional guidance is provided in N.1 of Annex N.

K.6 Package Arrangement Guidelines

Although the skid design has to be structurally sound, a design that keeps the engine and compressor as close to grade as practical improves maintenance access and typically results in less vibration. When ground-to-skid height exceeds 483 mm (19 in.) or is obstructed, installation of industrial stairs is recommended for accessing the compressor package skid.

It is important to avoid placing commonly serviced components in locations that are at elevated or otherwise difficult to reach locations where personnel will have to climb into a tight space that cannot be exited quickly.

In general, it is important that all instrumentation be designed and located on the compressor package for ease of observation, calibration and maintenance. The best practice is for all instrument control cases, liquid level controls, control valve assemblies, temperature and pressure indicators, gage glasses, drain valves, relief valves, and other equipment which requires observation, adjustment, or regular servicing to be conveniently accessible from grade or from an operating platform on the skid.

For on-skid control panels, best practice is to locate the panel at the edge of the skid, facing out, with adequate clearance in the back for wiring and maintenance access.

Consider lighting conditions and when possible, avoid blocking on-skid stairways and platforms with large components that cast a shadow on them.

It is important to have at least one clear skid deck entrance point on either side of the skid, preferably close to the engine. It is important for all stepping and working surfaces on compressor packages to be of a non-slip type. Sturdy metal grating is recommended for stairways and platforms. Diamond plate is a common choice for skid decking.

It is best practice to install platforms for operators and technicians to stand on while working on the engine or compressor when piping and other components are located along the skid deck. These platforms are preferably light weight and designed to be easily removed if they block access to common maintenance items such as starters.

Handrails and guardrails are typically necessary for stairs and platforms when the height exceeds that set by applicable regulations, typically 1.2 m (4 ft) or more.

K.7 Cooler Access

Falls are a leading cause of injury, and fall protection is an important consideration when it is necessary or likely for maintenance, testing or other work to be conducted on top of compressor coolers. Many field compressors are located outdoors where there is no overhead anchorage point for safe tie-off of fall arrest safety harness systems. As much as possible, use engineering controls to eliminate servicing needs on top of coolers, taking into account such needs as emission testing and maintenance of the catalyst, exhaust system, silencer and coolant tanks; PSV testing; and louver repairs. When design of the package requires operating or service personnel to work on top of a cooler, there are several best practices and recommendations for consideration. Additional information, including examples, can be found in Section 12 of the *GMRC High-Speed Compressor Package Guideline For Field Gas Applications*[40].

For work surfaces on coolers, best practices include a suitable non-slip work surface, up to and at the portions requiring access, suitable anchorage points for personal fall restraint tie-off, or a guardrail system with toe boards (if there are working areas below the cooler's work surface). A fixed ladder is also recommended, with rails extending at least 0.9 m (3 ft) above the top of the cooler platform and equipped with a self-closing safety gate.

K.8 Engine Intake and Exhaust Access

There are a number of recommended practices for engine intake and exhaust mounting to improve safe access for maintenance and to increase reliability, which reduces the need for access for maintenance. Additional information, including examples, can be found in Section 12 of the *GMRC High-Speed Compressor Package Guideline For Field Gas Applications*[40].

It is very important for air inlets to be located away from fuel tanks, flammable vapors, tank vents, chemicals, or any combustible material, as an engine backfire might ignite such material. Also, volatile fumes could be drawn into the engine, affecting the engine combustion, controllability and exhaust emissions.

Follow the engine manufacturer specifications for proper design of the supports to relieve loading and alignment stresses from engine mounted intake and exhaust connections. Use dual clamps on each end of air inlet rubber boots to reduce the risk of boot slippage and air leaks that increase the need for maintenance. On larger packages, consider designs that allow heavy duty air cleaners to be accessed from grade level. When the exhaust system is to be mounted off of the engine, seek and apply the engine manufacturer's guidance to ensure that the installation adheres to their basic recommendations for providing adequate support, clearance and vibration resistance.

Route and support engine air intake and exhaust lines so as to allow for access by a crane to lift engine heads and internal components without having to re-rig and make multiple lifts to move a single component.

Where practical, consider adding heat shields to protect personnel from significantly hot surfaces where accidental contact is likely during equipment access or servicing. Consult the engine manufacturer for availability of original equipment heat shields or guidance on how best to provide necessary personnel protection.

For packages with exhaust catalysts, it is important that there be safe and available access to the catalyst housing/silencer for catalyst maintenance and emissions testing. This can be accomplished by installing ladders, catwalks and/or platforms. When guard rails are not provided, a suitable anchorage point for fall arrest safety harness systems is an alternative that can be considered. It is important to avoid interference of exhaust systems with safe use and access to ladders or platforms.

K.9 Skid Deck and Access Covers

There are several recommended practices for decking and access covers on skids. Additional information, including examples, can be found in Section 12 of the *GMRC High-Speed Compressor Package Guideline For Field Gas Applications*[40].

Use of concrete filled skids with diamond plate decking is a common practice that provides a non-slip work surface. Best practice is to recess the deck plate to be flush with the top of all main beams to prevent the edges of the plate from being a trip hazard. To prevent accumulation of liquids on decking, drain troughs can be provided, running longitudinally down both sides of the skid, sloping toward the compressor end. A screened drain box with a NPT 2 drain connection and a perforated or expanded metal screen [0.6 mm (1/4 in) max. hole size] on the bottom side of the drain box grate is typically provided.

It is important to avoid open holes on skids that may pose a trip or fall hazard. Where inspection and access ports are provided in the skid deck, it is typical to provide covers that can be removed and reinstalled as necessary. Sturdy metal grating is a best practice for access covers.

K.10 Machine Guards

All machinery guards on compressor packages are subject to compliance with applicable regulatory requirements, e.g., OSHA 1910[45] Subpart O Machinery and Machine Guarding Design Requirements in the U.S. Flywheel, coupling, and cooler fan drive guards can present design and fabrication challenges on packages due to space provisions and the need to access the area for maintenance tasks. Access to the flywheel for barring of the engine, compressor, or the entire drive train, to the coupling for inspection and alignment, and to the cooler drive sheaves and belts for alignment and replacement makes access to and removal of the guards an important consideration. Field compressor packages that are not installed in buildings normally do not have service cranes. This also factors into the design by creating a need for the guards to be light and of a design that allows them to be disassembled for removal without a crane. Accordingly, field compressor guard sections are typically limited to weights of 22.6 kg (50 lb) or less.

Figure K.1: Example of a well-designed cooler belt-drive guard.

Figure K.1 is a good example of a cooler belt-drive guard design. The top half can be easily unbolted and, using the handle, lifted off to service the belts. A decal provides caution for energy control procedures to be followed before the guard is removed.

K.11 Protection From Hot Surfaces

It is important for the packager and the purchaser to review and agree on any requirements for personnel protection from hot surfaces. A common safety consideration for preventing personnel injury is to insulate or guard surfaces that are at or above 60°C (140°F) and located where accidental contact is likely during regular maintenance. Where practical, consider adding insulation, specialized insulating coatings or heat shields to protect personnel from significantly hot surfaces where accidental contact is likely during equipment access or servicing. It is important to consider equipment function, design and OEM requirements in the design and application of insulation or heat shields. Consult the engine manufacturer for availability of original equipment heat shields or guidance on how best to provide necessary personnel protection near the engine. Figure K.2 is an example of an insulated exhaust system being installed for use inside a skid-mounted building.

Figure K.2: Example of an insulated exhaust system installed for use inside a skid-mounted building.

K.12 Provisions for Energy and Flammable Liquid Isolation

Energy isolation during maintenance activities is a critical component of safety. Best practice is to provide lockable-type valves or switches for the suction, discharge, fuel, electrical supply, battery, air starter supply, purging and bypass systems on field compressors, as a minimum.

Fire safety valves, which fail closed when triggered by combustion temperature, are an excellent fire mitigation device when installed in oil and flammable coolant supply lines.

Annex L
(Informative)

Guidelines and Best Practices for Compressor Package Design and Fabrication

Annex L provides guidelines and what are typically considered to be best practices related to compressor package fabrication. Sections 6, 10, 12 and 14 of the *GMRC High-Speed Compressor Package Guideline For Field Gas Applications*[40] are acknowledged as the primary reference source for this Annex.

This Annex is intended to provide guidelines, best practices and tutorial information for the design and fabrication of high-speed reciprocating compressor packages that is supportive of the requirements of Section 14 of this specification. Additional guidelines and best practices for package design and fabrication are provided as part of the installation and connection guidance in Annex P.

There are many package features that are project, end user and packager specific, and some end users and packagers have their own preferred designs and standards. Recommendations and best practices must always be viewed through the lens of the particular need that the compressor package is intended to fulfill; some may not be suitable for all applications such as rental fleet packages, that, by necessity, have to be compact and portable.

Rental or contract compression fleets comprise a large percentage of the compression horsepower deployed in the worldwide marketplace for field gas applications. End users commonly use rental equipment when operating conditions and flows are expected to change over time or when the production from reservoir reserves is uncertain. Rental fleet packages are designed by the fleet operators to cover the maximum reasonable operating window to allow flexibility for a large number and range of operating conditions. Rental fleet equipment designs also retain a higher residual value in the marketplace due to the flexibility of their design over “built for purpose” packages. This approach ensures utilization of the equipment throughout its life cycle but may have lower thermodynamic efficiency at a specific operating condition. A rental fleet package may not meet exacting equipment fabrication specifications of each operator and may therefore require additional investment for modifications (to be paid for by the end user) prior to deployment.

Accordingly, the guidelines in this Annex are useful for the design of rental compression packages, but many of the detailed guidelines are more applicable to custom-engineered compressor packages that are purchased by an end user. It is important that compressor packagers, rental fleet operators and end users understand and take responsibility for their role in the design, installation and operation of the field gas compressor package and accessories, including all features designed to enhance the safety, accessibility and maintainability.

L.1 Auxiliary Systems and Piping

There are a number of specific best practices and recommendations relating to auxiliary systems and piping described in this Annex. Annex K provides additional guidance for package safety, accessibility and maintainability. Additional information, including examples, can be found in Sections 10 and 12 of the *GMRC High-Speed Compressor Package Guideline For Field Gas Applications*[40].

L.1.1 Arrangement of Systems and Piping

Packaging all the auxiliaries and piping on the skid is a common practice on smaller field compression packages, because it simplifies shipment and can reduce installation time. However, on some larger units, it may cause clutter on the skid and reduce access and workability for maintenance as shown on Figures L.1 and L.2. These are an example of a package that is very difficult to access and maintain. Too many things are on the skid and not enough consideration has been given to maintenance access to prelube pumps, starters, etc. Work on the equipment requires standing on a maze of slippery pipes and conduit.

Figure L.1: Example of a package with excessive congestion that inhibits access for maintenance.

Figure L.2: Another view of the congested packaging that makes maintenance access difficult.

When present, features such as pre-heating modules and fuel conditioning systems can obstruct access for maintenance by blocking access to other equipment. If possible, consider locating these items off the skid to allow better access to the engine, compressor and auxiliaries.

Avoid installing starting air supply piping, block valves, strainers, relief valve and exhaust piping in the way of access to the starter and any controls or accessories that require maintenance. This area can easily become too congested if not designed carefully. Suggested practice is to move the regulator off skid or further upstream away from engine components and areas that require frequent maintenance. The installation shown in Figure L.3 provides poor access to the engine starters for servicing. The relatively sharp bends in the large flexible hose are also a bad practice that is potentially unsafe. The installation shown in Figure L.4 provides much better access.

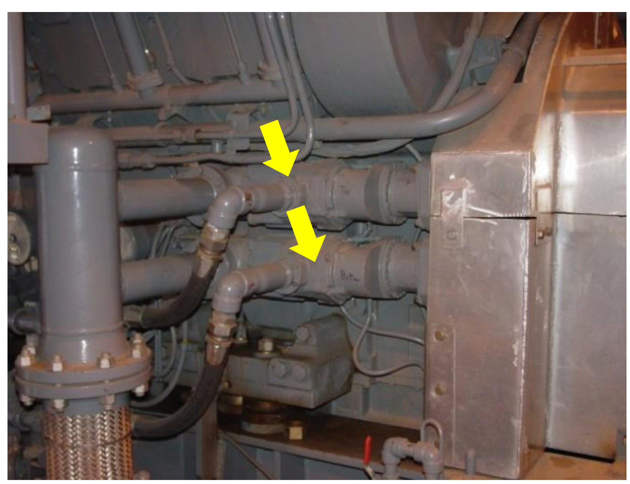


Figure L.3: Example of packaging that provides poor access to the engine starters (indicated by arrows) for servicing.

Figure L.4: Example of piping that provides good access to engine starters (indicated by arrows) for servicing.

It is important that pneumatic starters are equipped with suitable exhaust piping to vent the starting air or gas safely away from the compressor unit, personnel work areas and potential ignition sources (if gas is used).

L.1.2 Flexible Hoses

In addition to the specified requirements of 14.6, best practices for flexible hose installations include the following:

a) As specified in 14.6, it is very important that flexible hoses, when used, are suitable for the service and selected and installed according to the hose manufacturer's specified pressure, temperature and service rating and minimum bend radius limitation.
b) As much as possible, best practice is to install flex hoses in straight, or nearly straight, runs between the points to be connected.
c) Excessively long hoses and misaligned connections that require the hose to be significantly bent, or the use of a flex hose in place of an elbow fitting, are not acceptable practices.
d) Avoid installing flex hoses that are twisted, bird-caged, crushed or otherwise installed in a visibly stressed manner.
e) When steel braided hoses with solid internal liners are used, best practice is to check the integrity of the liners before installation and during routine scheduled maintenance thereafter.
f) Where practical, it is beneficial for packager-supplied flex hoses of the same diameter to be of one consistent length to ensure that spare hoses are universally interchangeable.
g) Best practice is to install any flexible hose connections required on the fuel gas line as close to the engine as possible, in the lowest pressure portion of the system.

L.1.3 Hard Piping

In addition to the requirements specified in Section 14, best practices for hard piping installations include the following:

a) It is important that on-skid hard piping is designed and arranged with sufficient anchor clamps and hold-downs to prevent excessive stresses, strains, deflections or variations of supports, and to prevent possible resonance of imposed vibration as may be caused by reciprocating equipment.
b) Where possible, design and support of on-skid piping is such that frequently-serviced equipment can be accessed without the necessity for temporary supports or dismantling piping other than spool pieces adjacent to equipment connections.
c) Because of the inherent vibration associated with reciprocating compressor packages, improperly designed or installed threaded pipe nipples are subject to breakage by fatigue. A number of detailed best practices for this common problem component include:
    1) Avoid the use of threaded pipe nipples when possible.
    2) Avoid small bore appendages unless absolutely required. Consider off-mounting small bore connected devices with flexible connections. Refer to Annex F of API Standard 688 for additional design guidance on small bore piping and appendages.
    3) Avoid the of use threaded pipe nipples in high motion or high vibration locations. Instead, design the placement of the device in a lower vibration or lower stress area and connect it with tubing or braided stainless steel hose as design specifications may allow.
    4) For carbon steel (CS) threaded pipe nipples, use schedule 160 or XXS, meeting the requirements of ASTM A733.
    5) For galvanized CS applications, utilize a hex pipe nipple with at least a 13mm (½ in.) shoulder (thread to thread distance).

6) For stainless steel applications, use a minimum of schedule 80S or higher schedule if required by the pressure design criteria.
7) Use welded fittings if threaded nipples do not meet pressure design limits.
8) If on-site threading is necessary, utilize schedule 160, XXS, A53, or A106 (CS), or schedule 80S A312 (stainless steel) piping, threaded in accordance with ANSI/ASME B1.20.1 NPT taper threads.
9) Avoid the use of threaded pipe nipples larger than NPS 1 in pressurized [potential to operate at 103 kPa (15 psig) or greater] natural gas service.
10) Avoid the use of close (i.e., all thread) pipe nipples. Utilize pipe nipples with at least a 13mm (½ in.) shoulder (thread to thread distance).
11) Without violating recommendation (x), keep pipe nipple length as short as possible, but in no case longer than 102 mm (4 in.) for NPS 1 and below and 152 mm (6 in.) for NPS 1-1/4 to NPS 2.
12) Avoid use of one-step (i.e., difference of only one pipe size) threaded bushings. For one-step size changes, use MSS SP-95 SCH 160 or XXS swaged nipples (rather than one-step bushings). Multi-step (i.e., difference of more than one pipe size) bushings are acceptable to increase or decrease piping sizes in areas with space limitations.
13) Avoid the use of Teflon thread sealing tape for instrument air or instrument gas installations or any place where there is a possibility of particles of tape getting into instruments or small orifices. An elastic-paste-type, greaseless, non-hardening pipe-thread compound, compatible with and rated for the service (contents, pressure, and temperature), is generally acceptable for all threaded connections.
14) Minimize external loading on small branch connections.

L.1.4 Gas Piping Flow Velocity

In the design of process gas piping, it is important to weigh the increased pressure losses, power and noise against the potential benefits of smaller diameter piping. Higher velocities are generally tolerable for low gas pressures. Recommended practice is to limit gas velocity within the on-skid compressor package piping to the following values:

a) 30 m/s (100 ft/s) for pressures < 345 kPa (50 psig)
b) 15 m/s (50 ft/s) for pressures from 345 kPa to 6895 kPa (50 to 1000 psig)
c) 10 m/s (33 ft/s) for pressures > 6895 kPa (1000 psig)

The above guidelines are not absolute requirements, as engineering analysis may dictate lower or permit higher gas velocities. The guidelines are for dry, single-phase gases with specific gravity of <0.9. Refer to API 14E for erosional velocity limits for two phase flow, wet gas, high molecular weight or corrosive gases.

Higher velocities can be tolerated in orifice plates and choke tubes used for pulsation control. Common practice is to limit the velocity through these pulsation control elements to a maximum of 10% of the Mach number of the gas.

For low pressure ratio compression applications, such as gas transmission, a flow velocity of 10 m/s (33 ft/s) in the main process piping is a generally accepted piping design criteria for both suction and discharge.

L.1.5 Pipe Supports and Clamping

In addition to the pipe support requirements specified in 11.15 and 14.13, it is important that piping is supported and secured in accordance with good engineering practice. Best practice is for all piping NPS 2 and larger to be mounted using band clamps or pipe straps on I-beam supports. The recommended type of pipe clamp is a steel strap that wraps around the pipe 180° with two or four hold down studs or bolts that engage via welded bolt sleeves, integrally cast bosses or welded gusseted tabs as shown in Figure P.16 in Annex P. The use of flat bar with ungusseted tabs and U-bolt style clamps for process piping, except under NPS 2, is not advisable, as they can cause damage and wear to the piping coating and the piping wall if there is piping movement from expansion or vibration. Best practice is to install vibration absorbing material between clamps and pipe to prevent paint damage, fretting and corrosion of the pipe. Another best practice is to attach clamps directly to a structural member of the skid or to directly support them by a structural member that is securely attached to the skid, the foundation or special piers as shown in the example in Figure P.15 of Annex P. Supporting piping from the skid deck plate or with uni-strut clamps is not sufficient. It is important that the piping rests securely on shims on the support and of a proper thickness such that tightening the clamp bolts does not bend or otherwise add strain to the piping. Additional guidelines for pipe support, alignment and clamps is provided in Annex P.10.

L.1.6 Pulsation Dampening Orifice Plates

Orifice plates are commonly used for attenuating pulsation. An orifice plate is typically a plate with a circular hole cut in the center. Typical installation is between two gaskets, usually in flange pairs in the piping or flanged nozzles on cylinders, pulsation control bottles or other pressure vessels, for easy removal or modification, if necessary. Normal practice is for removable orifice plates to have a welded radial-protruding tab that extends beyond the flange outer diameter with the orifice bore diameter permanently marked on the tab. Orifice plates may also be welded into the pipe, flange or nozzle rather than installing them between two gaskets in a flange set.

For existing installations, or systems where the added thickness of installing the orifice plate and an additional gasket may cause pipe strain, the orifice diameter can be incorporated as an inner ring for the gasket. If orifice plates are not required as part of the initial design, full bore orifice plates are often installed at the above-described connections to facilitate the addition of smaller diameter orifice plates (for pulsation control), if needed, at a later date. The typical minimum orifice thickness for typical pipe sizes is shown in Figure L.5. The static and dynamic forces acting on the orifice plate are typically small, so evaluation of the orifice plate stress is usually not done within the scope of a pulsation study. Orifice plates are typically fabricated from 316 stainless steel plate. The hole in the plate is usually circular and centered in the gas flow. For orifice thickness of 10 mm (0.4 in.) or less, the hole edge profile is not critical. Up to that thickness, a special tapered profile, such as is used for metering orifices, is not necessary for pulsation control, and a simple square edge (free of machining burrs) hole is acceptable for pulsation control. However, it is possible that orifice plates thicker than 10 mm (0.4 in.) can generate an unacceptable whistling noise. For that reason, the maximum length of the cylindrical part of the hole in the orifice plate is typically limited to 10 mm (0.4 in.). If thicker plates are used, a 30 to 45° bevel is applied on the downstream (back) side of the orifice to limit the cylindrical length of the hole to 10 mm (0.4 in.).

Nominal Line Size		Orifice Thickness	
in.	mm	in.	mm
½ to 8	15 to 200	⅛	3
10 to 14	250 to 350	¼	6
16 to 26	400 to 650	⅜	10
30 to 36	750 to 900	½	13
44	1100	¾	19

Figure L.5: Typical minimum orifice plate thicknesses

High pressure pulsations at the compressor valves can cause high shaking forces and vibration as well as affect compressor valve operation. An orifice plate installed in the cylinder nozzle is often used to control the "cylinder nozzle" pulsation resonance mode. Orifice plates at the cylinder connections are effective in reducing the pulsations associated with the cylinder response, but they cause pressure drop. Pressure drop increases the power loss which may also limit capacity. Due to the high dynamic flow in this part of the system, it is important to calculate and evaluate the power loss caused by the total pressure drop, that is the pressure drop from both steady and oscillating flow.

As a general rule, orifice plates for pipeline applications are normally limited to a beta ratio of 0.6 to 0.7 (diameter ratio compared to the pipe inside diameter) to limit the pressure drop and resulting power consumption. However, for high ratio field gas applications, pressure drop has less effect on power, so that orifices with beta ratios of as low as 0.4 are not uncommon. In all cases, however, it is important to evaluate the effects of the orifice pressure drop on compressor performance over the expected range of operating conditions.

The damping efficiency of a single-hole orifice plate decreases at higher frequencies, falling off significantly as frequency increases above 100 Hz. Other specialized pulsation control devices (e.g., dynamic variable orifices, nozzle inserts and virtual orifices) are also sometimes used. Dynamic variable orifices typically provide the capability to vary the beta ratio from 0.4 to 0.7 or even 0.9 while in operation.

L.2 Electrical, Conduit and Wiring Systems

The most important step in designing and installing the wiring system for a field gas compressor is establishing the area classification. If the area classification has not already been determined by the end user, then NEC/NFPA 70 Chapter 500, and API/RP 500 are good resources to help determine the correct classification. Best practice is that all field gas compressor electrical wiring systems comply with NEC/NFPA 70, at a minimum. Many end users and component manufacturers may have additional specifications, such as engine wiring requirements. Once an area classification is established and end devices have been selected, then the selection of wiring systems can be determined.

Basic safety considerations require that all electrical wiring systems be neatly routed along the pathway, protected from damage, and securely connected at all terminations. Loose, dangling wires create numerous hazards and are not acceptable, regardless of voltage or current type.

Most major components, especially gas engines, come equipped with standard OEM wiring cables and harnesses. It is important to follow the manufacturer's recommendations for electrical wiring systems on these components. Avoid any alterations to OEM provided electrical systems without consulting the manufacturer first.

Several different wiring systems exist for field gas compression. Among the most commonly used are rigid galvanized steel conduit, cable tray, plug and play cables and armored marine or shipboard cable.

In addition to the specified requirements of Section 17, there are a number of specific best practices and recommendations relating to electrical, conduit and wiring systems described in this Annex. Additional information, including examples, can be found in Sections 10 and 12 of the GMRC High-Speed Compressor Package Guideline For Field Gas Applications[40].

L.2.1 Rigid Galvanized Steel Conduit

The advantage of rigid galvanized steel conduit (RGSC) and fittings is that they provide excellent mechanical protection for wires and cables, and they are acceptable in Class 1 Division 1 and 2 hazardous areas. An example of RGSC is shown in Figure L.6.

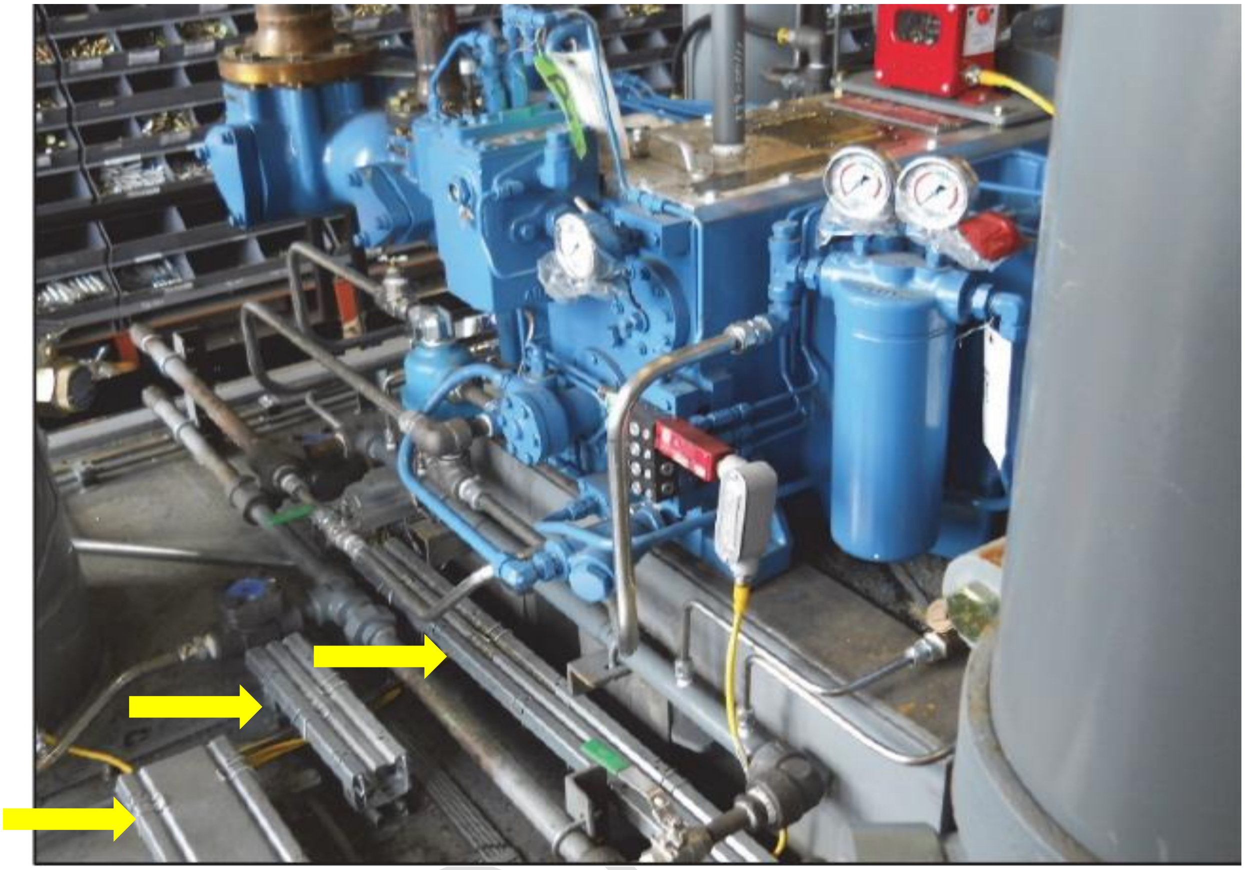
Figure L.6: Example of rigid galvanized steel conduit.

In addition to the specified requirements of 17.7, following are best practices for conduit design and installation on field gas compressor packages.

a) Any time conduit transitions from one area classification to another, it is important to install a conduit seal within 3 m (10 ft) of the transition to prevent gas from flowing from a hazardous area to a non-hazardous area or from one area classification to another.
b) Size each conduit for a maximum 80% fill or less. Include cable insulation in the capacity calculation.
c) Use appropriate lubrication, that is compatible with the insulation, when pulling wires and cables.
d) Support conduit at least every 3 m (10 ft) and securely fasten it within 1 m (3 ft) of each conduit termination.
e) When possible, avoid installing conduit directly on the skid. Conduit raised 51 mm to 76 mm (2 in. to 3 in.) above the skid surface, at least to a height above the skid drip lip, allows fluids to flow more freely toward the drain troughs.

L.2.2 Cable Trays

The advantage of using a cable tray is that it allows more flexibility in design, given that additional cables can be installed after manufacturing, and covers can be used to provide additional mechanical protection. Figure L.7 shows the use of cable tray wiring during packaging of a compressor package intended for an outdoor field gas application.



L.7: Example of cable trays (indicated by arrows) to protect wiring from being stepped on during maintenance.

In addition to the specified requirements of 17.7, following are important best practices for cable tray design and installation.

a) Oversize the cable tray to accommodate design changes or field modifications.
b) Avoid using trays to store excess cable length, as cables can be kinked, and over time, the copper strands can be broken.
c) Support cable trays at least every 1 m (10 ft) or as per the manufacturer's recommendation.
d) When possible, avoid running cable trays directly on the skid. Cable trays raised 51 mm to 76 mm (2 in. to 3 in.) above the skid surface, at least to a height above the skid drip lip, allow fluids to flow more freely toward the drain troughs.
e) Consider frequent service areas when routing cable trays, and avoid creating trip hazards or blocking frequently serviced components.

L.2.3 Plug and Play Cables

Plug and play cables (with quick disconnect ends) may be used with a cable tray system as long as the cables are rated for the service and ambient conditions and a locking device is installed over the quick disconnect to prevent accidental disconnection of the cable while in service.

L.2.4 Armored Marine or Shipboard Cable

Some packagers prefer to use armored marine or shipboard cable for compressor packages. Depending on the type used, advantages can include simplicity of use, availability and superior resistance to structural damage, fire and heat, oil and other fluids. Armored marine cable has a metal protective sleeve over insulated wires. The sleeve is typically aluminum or bronze. Once the sleeve is cut back and the wires exposed, normal wiring methods can be used for termination.

Armored marine cable is readily available in many types and configurations, whereas some other cables are not. This can reduce downtime issues when a cable has to be repaired or replaced. The flexible metal outer sheath protects the wires inside from many sources of damage, as well as keeping wiring neatly together. Cable trays are often used to help contain and route armored marine cables across the skid, as shown in Figure L.8. However, in the example shown in Figure L.9, the marine cable is partially secured in a channel mounted along the bottom of the cooler, but the loops near the battery box are unprotected and could be damaged from personnel stepping on it. Figure L.7 is an example of a reasonably good electrical system using marine cable in cable trays in areas that may require personnel to access them for maintenance. The connection loops to instruments are short and located so as to minimize the risk of damage from being stepped on.

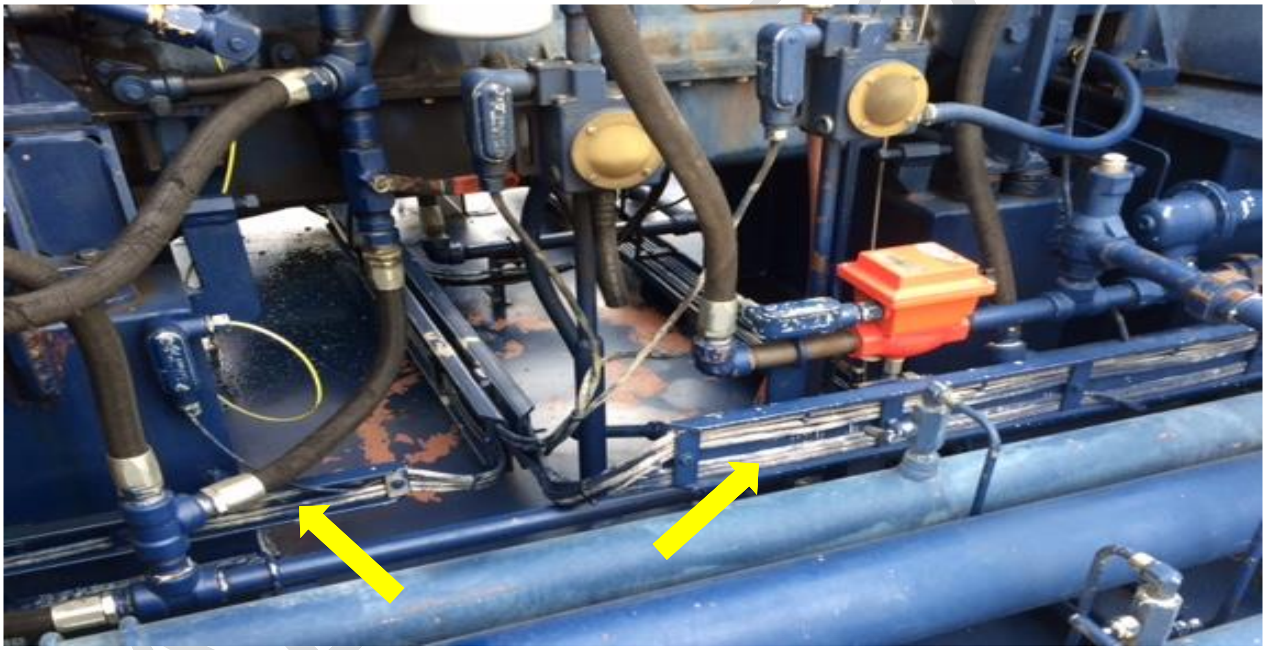


Figure L.8: Armored marine cables routed in cable trays for protection from being stepped on.

It is important that users of armored marine cable are aware that the outer sheath is conductive. This requires that necessary precautions are taken, such as, for example, trimming the armor sheath back before entry into a junction or battery box.

L.3 Batteries

Many field gas compressors utilize on-skid batteries. It is important that batteries are safely enclosed and protected in battery boxes as shown in Figure L.9. The batteries, and the box, are secured in place, in a safe location that minimizes exposure of the batteries to personnel, ignition sources, fuel sources and significant vibration.

Although sealed gel and maintenance-free batteries are better options, traditional lead acid batteries are still common for many field gas compressors. When these are used, it is important that the battery box has a cover with a sturdy and secure closure. To help prevent battery failure and possible battery explosions, it is important that fluid levels and over-charge protection, such as a voltage regulator, are maintained. It is also good practice to include a lockout/tag-out disconnect point in battery supply systems, whenever possible, to aid in energy isolation procedures. An example of a lock-out device is shown in Figure L.10.

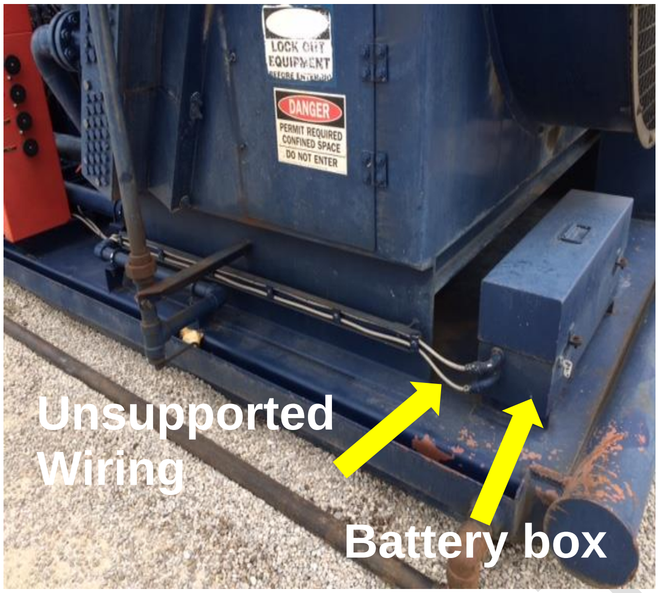


Figure L.9: Example of a battery box

Figure L.10: Example of a battery lock-out device.

L.4 Pressure Relieving Devices

The minimum requirements for compressor package pressure safety valves (PSV) are specified in 14.9. Some additional guidelines and best practices are detailed in this Annex subsection.

a) Besides proper sizing, basic safety considerations for PSV include being safely mounted and vented.
b) PSV sizing requires specific data, including, but not limited to, required set point, back pressure, vent flow velocity, vent stack sizing, maximum capacity of the compressor package, capacity of the PSV, gas analysis, inlet pressure, and inlet temperature.
c) The three most common API Standards for pressure relief devices are *API Standard 520 Parts 1 and 2*, and *API Standard 521*. These are excellent resources for complete details on PSVs.
    1) *API 520 Part 1* defines sizing of pressure-relieving devices (PSV's). It is suitable for preliminary sizing, but the final selection for pressure vessels is generally based on ASME Section VIII.
    2) API 520 Part 2 defines Methods of Installation for pressure-relief devices (PRDs) for equipment that has a maximum allowable working pressure (MAWP) of 103 kPa (15 psig) or greater.
    3) API 521 defines pressure-relieving and vapor de-pressuring systems. Although intended for use primarily in oil refineries, it is also applicable to petrochemical facilities, gas plants, liquefied natural gas (LNG) facilities, and oil and gas production facilities. The information provided is designed to aid in the selection of the system that is most appropriate for the risks and circumstances involved in various installations.
d) It is very important that all PSVs are mounted and braced securely enough that the weight of the valve and associated piping, normal vibration and forces applied during operation do not overstress a PSV's connection. During an overpressure event, the discharge of a PSV imposes a load, referred to as a reaction force. This

force creates a moment arm of leverage force. The stress caused by the reaction force is propagated into and through the relief valve, and then into the inlet piping and/or vessel nozzle, unless the system is properly supported and braced. On high-pressure PSVs, the reactive forces during relief are substantial, and external bracing is typically required. Refer to the formulas in API *520, Parts 1 and 2* for computing these forces. Refer to the GMRC PRCI *Design Guideline for Small Diameter Branch* Connections[37] for recommendations on the allowable weight and length for the PSV branch geometry.

e) Best practice is to locate PSVs (aka relief valves) on straight pipe runs away from any changes in direction and to keep the valve height at a minimum. It may be necessary to brace large PSVs to the piping as shown in Figure L.11 , which provides additional mounting recommendations.

f) It is also very important for PSVs that are not connected to a closed relief system to have vent stack piping that directs the relieving gases to a safe area away from personnel and potential ignition points. Figure L.12 is an example of a very poor design. This PSV has no vent line and it discharges at skid level, within inches of an open battery box. The aforementioned reaction forces and vibration that are typically present in a flowing PSV can also translate to the PSV vent piping. Therefore, it is important that the PSV vent lines are securely braced to control reaction forces. Vent stack piping also helps protect PSV internal components from corrosion and contamination. Weep holes are often used on vent piping to allow water to escape the vent line and prevent ice blockage, however, it is very important to ensure that weep holes do not pose a potential fire hazard by allowing gas to escape and contact a hot surface when the PSV opens.

Locate relief valves on straight pipe runs away from any changes in direction.

A. Keep valve height to a minimum. Avoid installing a block valve between the relief valve and pipe run. If a block valve is installed, a brace (C) is recommended.

Optional: (based on relief piping design, pulsation forces, and thermal growth concerns).

B. Install four 3/8" thick gussets and repad. Ensure all welds are good quality and stress relieved. Avoid welding on pressure containing pipe and within 1/2" of other welds.

If required: (based on vibration levels at startup).

C. Brace relief valve to pipe run. Either use a pipe brace with minimum diameter of 2" SCH 40 pipe or use a structural tube. Size is to be not less than two sizes smaller than the relief size.
D. Weld pipe brace to 1/4" thick steel plate and bolt to relief valve.
E. Weld pipe brace to 1/2" thick steel plate. Shim and clamp to pipe run with clamp as per Wood standard Figure CL-1.
F. Install a clamp as per Wood standard figure CL-1 near the valve.

Notes:
1. The brace should be adjusted when the system is at neutral (operating temperature) position.
2. Minimum 1/2" distance between gussets and edge of repad.

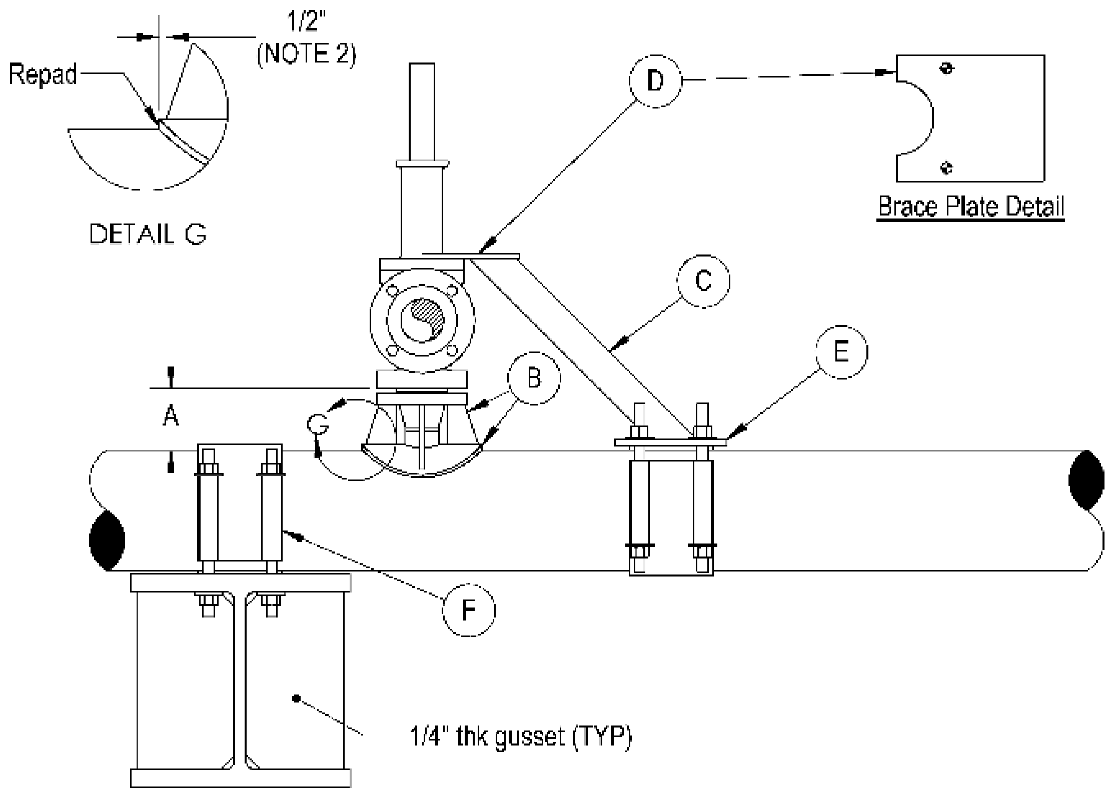


Figure L.11: Large PSV mounting recommendations.

Figure L.12: Example of a poor PSV design that relieves directly at skid level near an open battery box.

g) PSV vent lines may discharge into a common vent header as long as they are not piped together with pneumatic starter vents, unloader vents or drain lines. It is important that common vent piping headers are designed so that the backpressure does not exceed an acceptable value for any PSV in the system. To limit backpressure, PSV vent piping diameters are generally larger than the valve outlet size. Lift and set pressures of pilot-operated relief valves with the pilot vented to the atmosphere are not affected by backpressure; however, if the PSV discharge vent pressure can exceed the inlet pressure (e.g., tanks storing low-vapor-pressure material), a backflow preventer (vacuum block) is normally required. The set pressure for balanced spring-loaded relief valves will suffer reduced lift as backpressure increases; this results in a slower rate of pressure relief, which may compromise system safety.

L.5 Coolant Systems

In addition to the requirements specified in 14.25, there are several considerations and best practices for liquid coolant systems.

a) Mount expansion tanks high enough to provide specified OEM requirements for pump suction head.
b) Provide separate expansion tanks for engine jacket coolant and auxiliary coolant. Comingled systems are possible, but often problematic.
c) Unless otherwise specifically required by the engine manufacturer, size the tank with expansion capacity for typically 20% of the cooling system's total volume.
d) Mount expansion tanks on supports that are firmly attached and braced to the package skid, or on an adjacent structure that is not prone to vibration.
e) Locate the tanks where there is good visibility of the liquid level gauge and where the tank is accessible for filling the cooling system.
f) A drip pan with drainage located under the expansion tank will help maintain cleanliness during coolant fills, and if the system should overheat.
g) Units that are located in buildings may have multiple options for mounting expansion tanks, due to the building structure. However, it is important that the building structure or additional structure is adequate for supporting the expansion tank at the required height.
h) Many rental compression units that are relocated often, and/or are frequently located outside of a building, have expansion tanks mounted on top of the cooler. In those packages, utilize good design principles in placement of the expansion tank on the cooler to reduce risk to operating and service personnel, provide good level gauge visibility and provide safe accessibility for filling.
i) In cases where off-skid horizontal coolers are used, a structural support stand can be used to support the expansion tanks, either on- or off-skid, meeting the height, visibility, and accessibility requirements.
j) The suction line from the expansion tank to the coolant pump is fed from the bottom end of the tank away from the entry of the vent lines. Vent lines feed into the bottom of the expansion tank from the opposite side of the pump suction line. It is important for pump suction lines to follow OEM recommendations, typically a minimum of 25 mm (1 in.) diameter pipe to avoid cavitation of the pump. The line is fed into the main coolant inlet piping as close to the pump inlet as possible.

L.6 Fluid Supply Fill Points

It is important to consider the location of engine lubricating oil, compressor frame lubricating oil, cylinder lubricating oil and coolant fill points. In most cases with larger field units, refill is provided from larger holding tanks that are located off-skid. These tanks will have transfer pumps to pump the coolant or oil to the compressor package. In some cases, the coolant or oil will be pumped to a smaller on-skid tank, which will then feed by gravity to liquid level controls on the equipment. It is important to mount any on-skid tanks high enough to create sufficient head pressure to adequately supply the level controls.

Oil level controls can also be supplied directly from an off-skid tank with a transfer pump. In these cases, it is important to match the level control with the pressure of the supply system and to provide some adjustment capability to the level control to ensure proper operation.

In cases with smaller packages [e.g., <745 kW (1000 hp)], there may only be on-skid oil and coolant tanks. It is important that these tanks are sized such that they can meet the package's requirements for oil or coolant over a 30-day period or another period specified by the purchaser. They may be operated with a transfer pump or by gravity feed with placement on top of a vertical cooler. In these cases, it is important that the site layout can readily accommodate truck access to allow for refilling the tanks.

When storage tanks are mounted on coolers or stands, it is important to consider the safety of maintenance personnel during filling operations. Design provisions that allow filling from ground level greatly improve safety and efficiency. The trailer-mounted compressor package in Figure L.13 shows a good example of this. Gravity-feed oil supply tanks can be easily accessed from the trailer deck, and 25 mm (1 in.) diameter piping with ball valves is provided under them for refilling. A coolant supply tank is not necessary in this case. Stowed platforms and guardrails are deployed for unit servicing.

Figure L.13: Trailer-mounted compressor package with accessible oil storage tanks

It is important to clearly mark the primary liquid fill points. Quick fill systems are typically provided, normally separate from the normal system and used only for major fills of the sumps or cooling systems.

It is important to provide ports for liquid sampling, located in flowing lines, not in dead legs or low points.

L.7 Scrubber Design and Mounting Guidelines

Tutorial information and guidelines for compressor package inlet scrubber sizing can be found in various references such as Section 7 of the GMRC *High-Speed Compressor Package Guideline For Field Gas Applications*[40], the Gas Processors Suppliers Association, *Engineering Data Book*, Volume 1[41], and the European Forum for Reciprocating Compressors (EFRC), *Guidelines On How To Avoid Liquid Problems In Reciprocating Compressor System*[36].

Compressor package inlet scrubbers are typically tall pressure vessels that are mounted vertically. Proper scrubber structural design and mounting can reduce and control scrubber vibration. Typically, a stiffer scrubber base will result in higher scrubber natural frequencies and lower vibration levels. Mounting scrubbers on legs is not advisable. A best practice is to weld scrubbers directly to full depth skid beams with the beams boxed into the skid such that the beam webs are located at 85-90% of the scrubber OD, as shown in the example in Figure L.14. Additional stiffness can be achieved by adding 13 mm (½ in.) thick full depth gussets to each quadrant of the scrubber base at the scrubber centerline as shown in Figure L.15. Filling the boxed area with concrete provides beneficial damping. Large scrubbers are preferably located off the compressor skid on a separate pad.

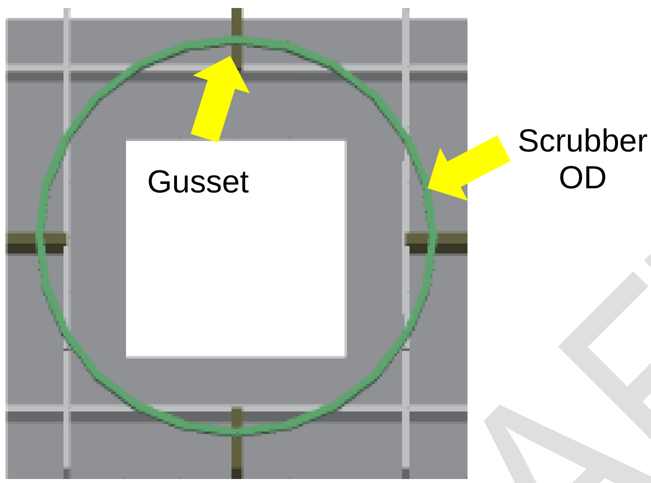


Figure L.14: Boxed-in full-depth beams with gussets to support the scrubber.

Where off-skid mounting or adequately boxing in the scrubber support are not feasible, Figure L.15 shows another preferred approach where the scrubber is welded onto a scrubber base plate located over a boxed portion of the skid which is concrete filled. The scrubber skirt is welded, rather than bolted, to the base, and it is important to make the area of base plates for vertical scrubbers as small as possible to reduce flexibility. For smaller scrubbers these plates are typically 25 mm to 38 mm (1 in. to 1-½ in.) thick. For larger scrubbers, thicknesses of 51 mm to 76 mm (2 in. to 3 in.) may be required. In all cases, it is very important that the bottom edges of the scrubber plate are welded to the beam flanges and the scrubber is welded to the scrubber plate as shown in Figure L.16.

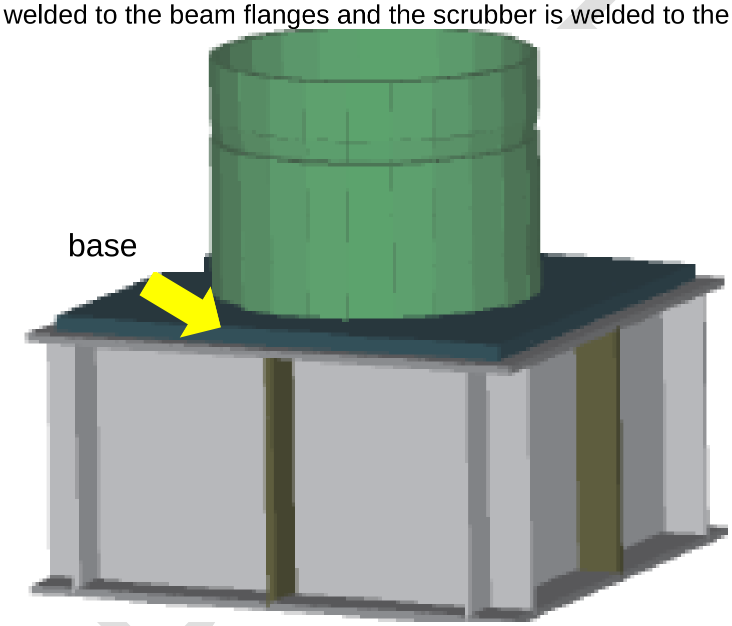


Figure L.15 : Scrubber welded to a base plate.

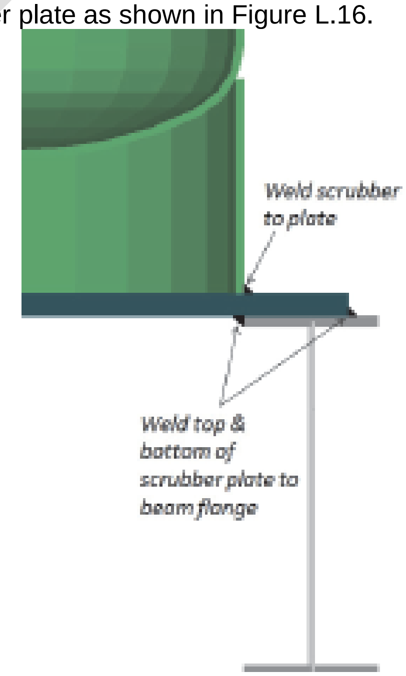


Figure L.16: Recommended base plate weld detail.

Best practice is for the compressor mechanical model to include a determination of the vibratory mode shapes of the scrubber, whether they are likely to cause excessive vibration and whether they will adversely affect equipment and connections attached to the scrubber. If modal frequencies are within 20% of significant dynamic forces, significant vibration may occur, as depicted by the exaggerated image in Figure L.17. In these cases, additional full depth skid gussets and/or scrubber skirt gussets may be required, as shown in Figure L.18, to avoid resonance. The tall scrubber mounted on the deck at the end of the compressor package in Figure L.19 had to have an angled brace added to detune a mechanical natural frequency. This emphasizes the need for a thorough compressor package mechanical model and analysis during the design phase, as well as vibration measurement and bump testing performed during the commissioning phase.

Figure L.17: Exaggerated example of scrubber vibration

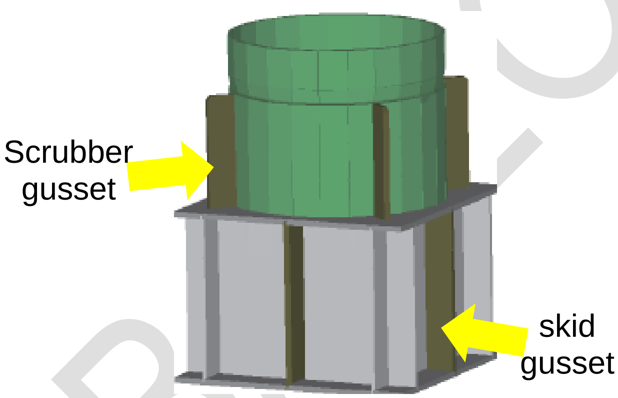


Figure L.18: Scrubber and skid gussets for the beams under the scrubber

Figure L.19: Angle brace used to detune a scrubber natural frequency.

L.8 Compressor Starting System Guidelines

In addition to the requirements specified in 7.3 and 14.17, there are additional guidelines for compressor starting systems. In the design phase, it is important to calculate the breakaway and acceleration torque vs. speed for a range from zero to minimum operating speed for a range of suction and discharge pressures. To avoid the wasteful and environmentally sensitive practice of blowing down the pressure for start-up, it is important that starters for gas engine drivers and ratings for electric motor drivers are sized and designed to start the unit with the highest anticipated equalized or settled out pressures in the piping between the suction and discharge block valves.

The breakaway torque, which is the torque required to cause the compressor and driver to begin to rotate, is a sum of mechanical friction resistance and the gas torque created by the internal static pressure acting on the piston rod area of each compressor cylinder. This information is normally available from the compressor and engine manufacturers. The torque required by the compressor as it accelerates can also be provided by the compressor manufacturer for a specified process gas pressure at startup and an assumed bypass or cylinder unloading configuration. It is important to compare these torque requirements with the available “cold” engine starter torque vs. speed, or, where an electric motor driver is used, with the motor’s starting torque vs. speed. Engine starters and electric motors may have to be oversized to accommodate the starting requirements.

The higher the gas settled-out pressure, the greater the starting torque requirements. In most cases, starting is enabled with a properly sized start-up bypass line around the compressor. It is important for the end user/purchaser to specify the maximum pressure at which starting is required and to discuss starting and unloading with the packager in the proposal phase or early in the design phase. In some cases, it may be necessary to add suction valve unloaders to the compressor cylinders to reduce the acceleration torque while the compressor is being started.

Bypass systems recirculate process gas from discharge to suction. This limits the discharge pressure and the differential pressure across the compressor. Bypass systems involve adding a process gas line, containing a flow control valve, from the compressor discharge line to the compressor suction line upstream of the inlet scrubber on the package. Connecting the line upstream of the scrubber prevents accumulation and ingestion of cylinder lubricant or other liquids that may drop out of the gas stream and be recycled in the gas stream. Bypass systems can utilize either hot discharge gas, taken upstream of the aftercooler, or cooled discharge gas, taken downstream of the aftercooler. Either hot or cold gas bypass systems can be used for start-up to reduce the load required for starting the unit. However, for capacity control under continuous loaded operation, a bypass with cooled gas (i.e., taken downstream of the aftercooler) is required. Continued use of a hot bypass system will lead to high cylinder operating temperatures after a short period of operation.

An additional method of unloading the compressor for starting is to add suction valve unloaders to some or all of the compressor cylinders for end deactivation. Suction valve unloaders do not reduce the break-away torque, but they do reduce the torque required to accelerate the compressor. The pneumatically actuated unloaders require a clean actuation air or gas supply, along with a control system with tubing, solenoids and electrical wiring. Suction valve unloaders result in internal recirculation of flow, so that the net flow to the discharge is zero. This significantly reduces the work of compression. However, the flow recirculates through the suction valves from the suction line into the cylinder and then back out of the cylinder through the suction valves into the suction line, so that there are significant parasitic losses. Nevertheless, they are commonly used for starting, actuated only long enough to get the compressor stably operating at its minimum operating speed. The compressor manufacturer can typically provide guidance on how many suction valve unloaders are required and how and under what conditions they can be safely operated. Use of end deactivation requires a predetermination that their use will not lead to insufficient pin reversal, excess rod load or torsional or pulsation problems.

L.9 Equipment Pedestals and Equipment Mounting Guidelines

In addition to the skid design and equipment mounting requirements specified in 11.5, some additional guidelines and best practices for equipment pedestals and skids include the following.

a) It is important that when pedestals are used to mount the driver and compressor, the height of the pedestals is minimized. However, in most cases, the pedestal height has to be sufficient to accommodate supports under all discharge pulsation bottles.
b) Always adhere to manufacturers' guidelines, requirements and prohibitions for drivers and compressors.
c) It is important that driver and compressor mounting locations are stiff enough to accommodate reciprocating unbalanced forces and moments of the compressor and engine. Wide beam flanges alone are typically not adequate for this purpose.
d) A best practice is for the driver and compressor pedestals to be joined to minimize roll deflection so as to ensure that coupling alignment is maintained under all transient and steady-state load conditions.
e) It is important to provide additional transverse support below the mounting feet of large gas engines with oil pans.
f) At mounting bolt locations, provide stirrup plates welded to gussets and the beam web to accommodate bolt stretch length and transmit loads into the beam web.
g) Best practice is to avoid, or if necessary, to reinforce fastener holes in pedestal beam webs.
h) Preferred equipment mounting includes some combination of the following:
    1) Welded steel mounting blocks
    2) Post welding machining of mounting surfaces
    3) Grouted steel mounting blocks
    4) Rotary/spherical chocks (maximize diameter and minimize height), where permitted by the manufacturer
    5) Full pedestal height gussets on each side of each mounting bolt
    6) Anchor bolts with preload stretch length or other means of sustaining preload
    7) Heavy wall spacer sleeves to accommodate bolt stretch length
i) Recommended practice is to provide for a field vertical alignment adjustment of +/-3 mm (+/- 0.125 in).

L.10 Pulsation Bottles

In addition to the requirements specified in 13.5, some additional guidelines and best practices include the following.

a) Depending on the cylinder size, operating pressure and criticality of service, smaller compressor packages, e.g., under 298 kW (400 hp), upon approval by the pulsation analysis consultant, may not require pulsation volumes as the suction and discharge piping volume may suffice for pulsation control.
b) Use only dished (spherical or 2:1 elliptical) heads, not flat plate, for internal baffles, preferably with the concave side towards the cylinder connection. It is important that baffles are sufficiently thick to resist unbalanced pressure forces across the baffle without fatigue failure. For typical bottle sizes under 914 mm (36 in.) outside diameter, suggested practice is for baffles to be at least 13 mm (1/2 in.) thick. For larger sizes, the baffles are typically thick as the bottle wall thickness, up to 25 mm (1.0 in.). It is important to use full penetration welds for baffle attachment.
c) It is very important that chokes tubes, when used, are specified and constructed as specified by the pulsation study. Choke tubes are typically constructed of XS or heavier pipe for strength and rigidity. This reduces the potentially higher stresses resulting from a large mismatch between the material thickness of the choke tube and the baffle. It is imperative that internal choke tubes are adequately supported in the bottle to prevent vibration. Following are best practices for choke tubes and choke tube support straps (sometimes called tabs).
    1) Apply a radius to the choke tube inlet and gently taper the outlet.
    2) Use choke tube straps (support tabs) with a 13 mm (½ in.) minimum thickness, unless the choke tube material thickness is less than 10 mm (3/8 in.), in which case use a minimum thickness of 10 mm (3/8 in.).
    3) Perform the choke-to-strap weld before the baffle is welded to the shell. Use a full penetration groove weld with equal-leg fillet welds all around.
    4) Use a single-sided full penetration groove weld followed with a fillet weld for the final strap-to-shell weld.
    5) Unless otherwise specified by the acoustic or mechanical design analysis, support the ends of a choke tube if it extends 1 m (3 ft) or more from a fixed connection. Choke tube sections longer than 1 m (3 ft) typical use two support straps evenly spaced along the choke tube length.

6) Use two straps (support tabs) radially aligned on the choke tube at a 90° angle to provide sufficient support and stiffness in the vertical and horizontal planes. It is important to minimize the distance between the choke tube and vessel wall to ensure choke tube stability. The maximum recommended distance between the choke tube OD and vessel ID is 76 mm (3 in.).
7) Unless specified by the acoustic design, avoid locating pulsation bottle choke tubes on the compressor cylinder nozzle centerline.

d) On larger packages, wedge supports are typically utilized to support the discharge bottle. Although these can be beneficial, field experience shows that wedge supports often do not provide sufficient stiffness to control cylinder vertical vibrations. Several recommended practices are provided.
   1) A typical minimum clearance of 127 mm to 203 mm (5 in. to 8 in.) is recommended below the discharge bottles to accommodate wedge supports, although consideration must also be given to providing adequate clearance and access under cylinder discharge valve ports for valve removal and unloader mounting.
   2) A wedge support under a cylinder nozzle with a band clamp offset from the cylinder nozzles is an acceptable practice. If these are adjusted in the hot condition, the thermal loads/deflection on the cylinders are typically not significant with typical length discharge nozzles.
   3) Tighten the wedge supports to lift the cylinder 0.025 mm to 0.051 mm (0.001 in. to 0.002 in.) in when in the hot condition. If there is a cylinder head-end support, it is preferably loosened while the wedge supports are adjusted, and it may be necessary to re-shim the head-end support after the wedge supports are tightened.
   4) Traditional wedge supports have to be adjusted when operating temperature is reached and, then, regularly inspected to ensure that they remain in contact with the discharge bottle to provide support.
   5) It is important to conduct periodic checks to maintain wedge support effectiveness as this type of support is prone to loosening.

L.11 Skid Drip Edge and Drains

In addition to the skid drip edge and drain requirements of 19.8.3, a best practice is to provide drain troughs running longitudinally down both sides of the skid sloping toward the compressor end. Another best practice is to provide a screened drain box with an NPT 2 drain connection and with a perforated or expanded metal screen, with 6 mm (1/4 in.) maximum hole size, on the bottom side of the drain box grate.

L.12 Cold Temperature Considerations

Section 21 and Annex I provide requirements and recommendations, respectively, for cold temperature environments, including enclosed packages that are designed for operation in cold environments. Whenever normal ambient temperature can drop below 4˚C (40˚F) at a field gas compressor location, there are numerous additional best practices that may apply. These are outlined in Annex N.4, and it is important that these practices are considered in the design, fabrication, installation and operation of the compressor package.

Annex M
(Informative)

Compressor Package Noise Avoidance and Control

Annex M provides guidelines and tutorial information for compressor package noise avoidance and control. Section 10.9 of the GMRC *High-Speed Compressor Package Guideline For Field Gas Applications*[40] is acknowledged as the primary reference source for this Annex.

A field compressor package has several significant sources of noise during normal operation. These include, but are not limited to, the engine, compressor frame and cylinders, flowing process piping, air-cooled heat exchanger and auxiliary motors, valves and controls. Although typically of only a short duration, compressor purging/blowdown, pressure safety valve (PSV) and pneumatic starter exhaust vents can create very high noise levels during operation and when open to atmosphere. During abnormal operation, additional items can contribute to noise levels. These include excessive vibration due to resonance or items out of balance, fan blade pitch, faulty bearings, and recycle valves cycling, among other things.

The requirement for noise control and avoidance has become more of a factor for field compression due to the increased proximity of compressor stations to populated areas. Although most field gas compressor applications are not under regulatory jurisdiction, such requirements are relevant as a reference. Typical regulations require that the sound level attributable to an existing compressor station after any compressor unit additions not exceed an equivalent day-night average sound level (DNL) of 55 dBA at the nearby noise sensitive areas (NSAs), where the DNL level is currently below 55 dBA. Typical regulations also require that the noise attributable to the full load operation of the compressor station, including any compressor unit additions, not exceed the previously existing noise levels produced by the station at any nearby NSA that are above a DNL of 55dBA. It is always important to determine if there are any applicable local or state noise ordinance regulations that apply. A further consideration is that there may be federal health and safety regulations requiring the use of ear protection for personnel working around noise levels above a certain limit, e.g. 85 dBA.

The following discussion provides an overview of options to provide means of noise attenuation for gas compressor packages. Noise attenuation can be improved through various options offered by engine exhaust silencers, engine air intake silencers, package vent silencers and package cooler configurations.

M.1 Sound and Noise

Sound is produced by vibrations and requires a transmitting media to travel from one point to another. Unwanted sound is referred to as noise. Within an engine, combustion, friction and impact of mechanical parts, and fluid flow produce noise. Other parts of the compressor package, including friction and impact of mechanical parts and fluid flow in compressors, flow through piping and package systems, fans and air flow in cooling systems, vents and other sources, produce noise.

All noise sources, such as the engine exhaust outlet, emit sound energy that propagates in all directions. The total sound energy emitted by a source is called sound power. Sound power is independent of distance as it is the total energy. Sound pressure, on the other hand, is distance dependent. As the distance between the sound source and listener is increased, the sound pressure decreases.

M.1.1 Engine Noise

Engine noise consists of thousands of frequencies. These frequencies are grouped in manageable octave and 1/3rd octave bands. Engine manufacturers publish engine raw noise spectrum data in these bands. The engine raw noise spectrum is critical in selecting the proper silencer for the application. Without octave or 1/3rd octave band raw noise data, silencer performance cannot be accurately predicted or guaranteed.

Typically, engine noise can be classified into three categories, and requires three different techniques / devices to mitigate noise.

Engine Exhaust Noise. An exhaust silencer is used to reduce engine exhaust noise. This is normally the dominant noise source from an engine. Typically, a combination of reactive and absorptive silencers is used on the engine exhaust.

Engine Intake Noise. Intake silencers are used to mitigate intake noise. Typically, absorptive silencers are used. It is very important that the intake silencer manufacturer ensures that fibers from the sound absorbing material are stable and secure, so that they do not come out of the silencer and enter the engine intake.

Mechanical Noise. This is the noise that comes out of the body of the engine. Normally, if this noise is dominant enough, an acoustical enclosure with vented intake and discharge duct silencers is required to address this noise source.

It is important to address all dominant noise sources to achieve required overall noise limits. Depending upon the engine noise source(s) and the noise target, a compressor package may need an exhaust silencer, an intake silencer and a starter vent silencer. Besides the engine raw noise spectrum, flow and temperature of the exhaust and the intake air play a major role in sizing and selection of noise abating components such as exhaust and intake air silencers and accessories. It is important that the sizing of silencer and exhaust systems is based on actual volumetric flow rate (ACFM/CFM) and not standard volume flow rate (SCFM). Maximum allowable back pressure is another important parameter that affects the selection of a silencer. Intake lines normally have very low allowable back pressure and therefore normally only an end-in / end-out absorptive silencer is possible that has 25 mm to 50 mm (1 in. to 2 in.) of water column back pressure. All engines have maximum allowable back pressure limits for exhaust systems. It is necessary for all exhaust components and piping to be considered when sizing and selecting an exhaust system, to ensure that the exhaust system back pressure is within the engine manufacturer's recommended limit.

M.1.2 Flow Generated Noise

In some cases when the compressor package is close to a residence and the noise target is stringent, the silencer manufacturer will specify requirements for selecting the exhaust system size to avoid flow generated noise and to minimize its impact on the overall noise level of the package.

M.1.3 Cumulative Noise

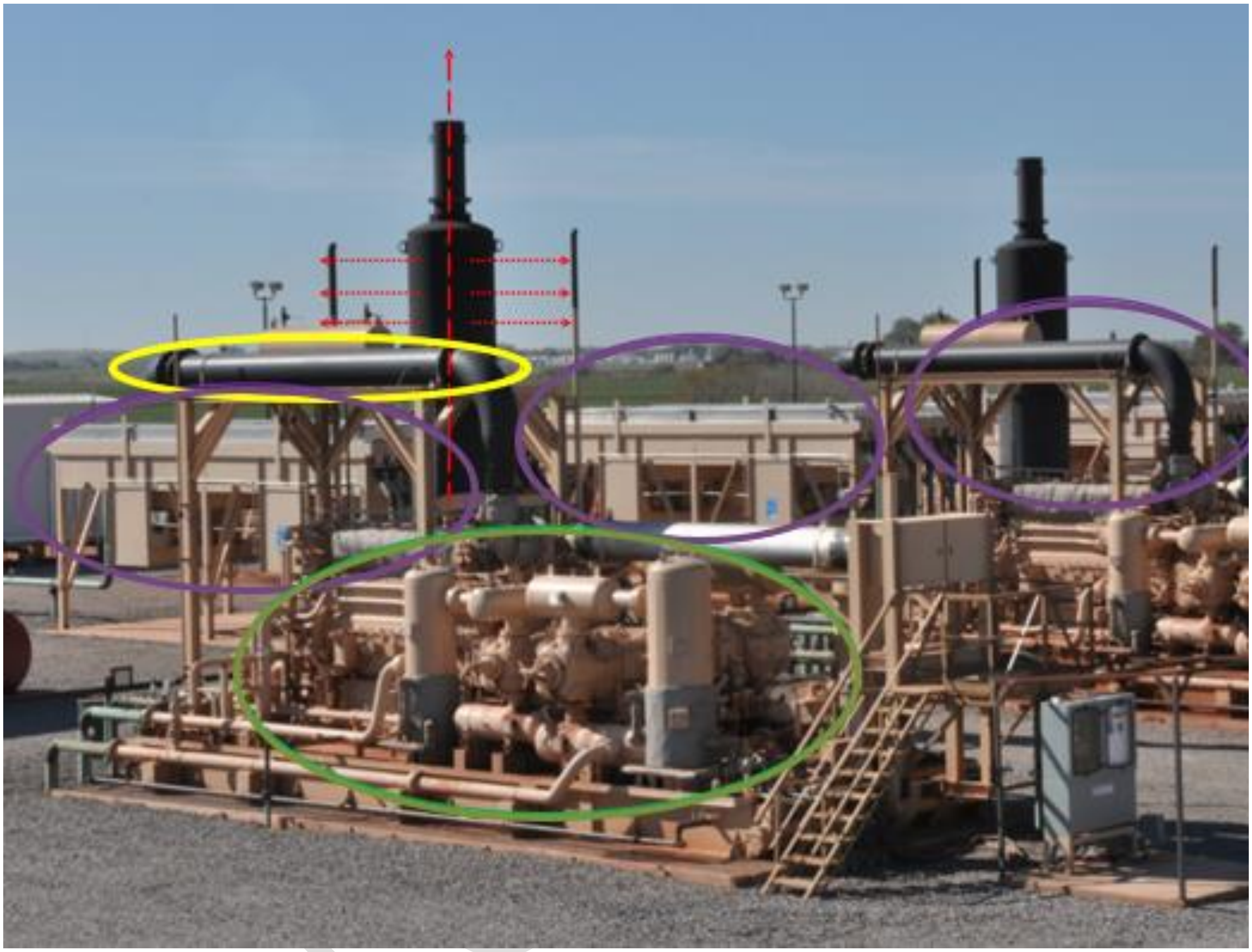


Figure M.1: Examples of the many noise sources in a compressor package - engine exhaust (partly shown in the yellow circle), engine air intake, compressor and cylinders (shown in the green circle), skid piping and pressure vessels (also shown in the green circle), coolers (shown in background within the violet circles), etc.

As shown in Figure M.1, there are many noise sources in a compressor package, including engine exhaust (partly shown in the yellow circle), engine air intake, compressor and cylinders (shown in the green circle), skid piping and pressure vessels (also shown in the green circle), coolers (shown in background within the violet circles), etc. Since noise is energy, when multiple compressor packages are located in one location, each source contributes to the overall noise level at each compressor package or at any location in the vicinity. All sound pressure levels are logarithmically added to get the overall noise level at a specified distance. When setting targets for individual sources, it is necessary for these cumulative effects to be considered as shown in the example represented in Figures M.2 and M.3. Figure M.2 shows that two 90 dBA noise sources add up to a cumulative level of 93.01. Figure M.3 shows that nine 90 dBA noise sources add up to a cumulative level of 99.5 dBA. In this range, each 90 dBA source increases the overall level by roughly one dBA.

Noise Sources / Engines	Sound Pressure Levels (SPL) dBA
1	90
2	90
3	0
4	0
5	0
6	0
7	0
8	0
9	0
Overall Noise Level dBA	93.01

Figure M.2: Cumulative overall noise from two 90 dBA sources.

Noise Sources / Engines	Sound Pressure Levels (SPL) dBA
1	90
2	90
3	90
4	90
5	90
6	90
7	90
8	90
9	90
Overall Noise Level dBA	99.5

Figure M.3 : Cumulative overall noise from nine 90 dBA sources

Figure M.2 shows that two 90 dBA noise sources add up to a cumulative level of 93.01. Figure M.3 shows that nine 90 dBA noise sources add up to a cumulative level of 99.5 dBA. In this range, each 90 dBA source increases the overall level by roughly one dBA.

M.1.4 Target Sound Pressure Levels

Since there are multiple noise sources on a compressor skid, it is important to add some margin when specifying noise targets for each component, keeping in mind the cumulative effect on package overall noise levels as explained in subsection M.1.3.

M.1.5 Silencer Grade and Noise Target

Silencers are classified by grades and range from Industrial (lowest grade) to Extreme (highest grade). Each silencer manufacturer has similar grades, but the range of noise attenuation with each grade is not regulated. Often in a remote area application, ordering silencers by grade may be sufficient, but a better approach is to specify silenced sound pressure level by each noise mitigating component, such as the silencer. An example would be a specification of a sound pressure level of 85 dBA at 3 m (10 ft) distance, remembering to account for cumulative noise effects from various noise sources.

M.1.6 Insertion Loss, Transmission Loss and Attenuation

Insertion loss (IL), transmission loss (TL) and attenuation are various terms used to describe characteristics of a silencer to reduce noise from a system.

M.1.7 Shell Radiated Noise

Like mechanical noise of an engine, noise breakout from the body of a silencer radiates to the surroundings. This is normally not an issue on most silencers, but special care is necessary in the design and application of higher performing silencers. In some cases, shell radiated noise, especially from the inlet chamber of the silencer, can be higher than the noise coming out from the tailpipe. Higher performing silencers are typically constructed with a double wall shell with absorptive material between two shells to reduce/minimize shell radiated noise. If radiated noise is an issue, external insulation can be applied to the silencer and exhaust piping to minimize shell radiated noise.

M.1.8 Noise Propagation

Noise propagates in all directions and is reduced as the distance from the source is increased. There are many factors that affect the atmospheric reduction of sound pressure level, such as direction, air density, distance, reflective surfaces, etc.

As shown in Figure M.4, which compares the noise level with the radial distance from the source, the area around the compressor package can be divided into various fields as they affect the noise propagation. In the vicinity of a noise source, the particle velocity is not necessarily in the direction of propagation of the sound wave. In this Near Field, the distance depends on the frequency along with some other factors. A distance equal to twice the subject wavelength is often referred to as the Near Field. In the Far Field, the particle velocity is in the direction of propagation of the sound wave. The area around the noise source is classified as the Free Field if there is no reflecting surface around, e.g., building, walls, trees, etc. In the presence of reflecting surfaces, Free Field turns into Reverberant Field, where reflection becomes equal to or stronger than atmospheric absorption.

In a Free Field, each time the distance is doubled, sound pressure level goes down by 6 dB. For example, in a Free Field, moving from 0.3 m to 0.6 m (1 ft to 2 ft) from the noise source will result in a 6 dB noise reduction, or moving from 30 m to 60 m (100 ft to 200 ft) from the source will also see a 6 dB noise reduction. This rule does not apply to Near Field and Reverberant Field, which are much more common than a Free Field. The field around a compressor package is a combination of all the aforementioned fields, and it varies from case to case, but the 6 dB noise reduction rule is commonly and loosely used. Some level of safety margin is recommended to avoid any surprises.

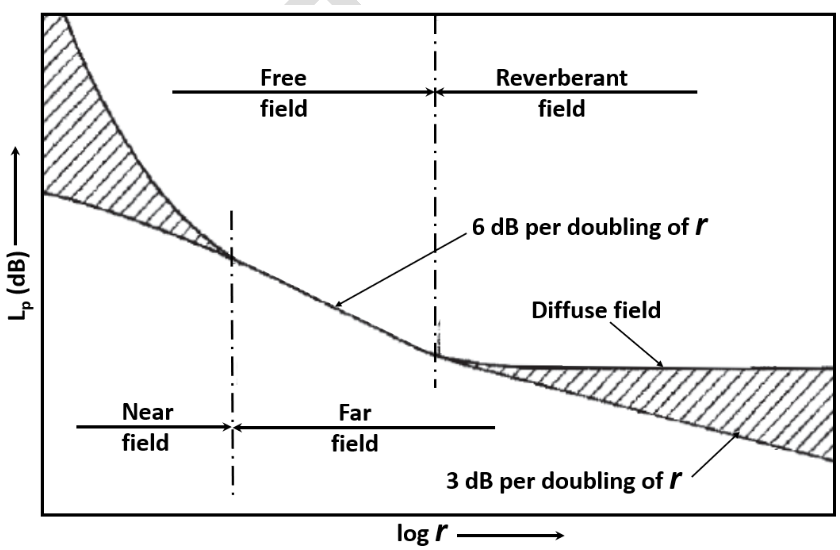


Figure M.4: Variation of noise level with radial distance from the source.

M.1.9 Noise Measurement

As explained previously, the total sound energy emitted by a source is called Sound Power. Sound Power is independent of distance, as it is the total energy. Sound Pressure, on the other hand, is distance-dependent, and as the distance between the sound source and listener is increased, the Sound Pressure level goes down. Also important is the DNL (Day-Night Average Sound Level), which represents the impact of a constant sound for an entire day. Most field gas compressors operate continuously, and changing day/night conditions affect the sound pressure travel.

It is important to account for cumulative noise effects from other various noise sources when conducting sound pressure surveys of compressor equipment. This can be the numerous noise sources on a single compressor package, or, when multiple compressor packages are located in one location, each noise source on each unit contributing to the overall noise level. Since noise is energy, all sound pressure levels are logarithmically added to get an Overall Noise level at a set distance. When setting a target for a new noise source at a property line, for example, the cumulative effect must be considered.

It is imperative that sound pressure level readings be consistently recorded at a set distance. In the absence of any state or local ordinances, company policies and other resources that must be adhered to, otherwise generally accepted practices include readings “at 3 m (10ft)” or “at property-line”.

M.2 Engine Exhaust Silencing

Following are a number of recommended practices and guidance for engine exhaust silencing.

Low Frequency and Long Distance. Low frequencies band travel much farther than high frequencies. This is why a silencer may meet the near distance target, but a house half a mile away may experience a noise issue. Low frequency at long distances may rattle windows, but not be audible. If low frequency breaks out from the body of the silencer before it is mitigated, then it could create issues when long distances of half a mile or more are involved. For this reason, on high performing silencers taking care of breakout/shell radiated noise from the inlet chamber becomes important. This is often achieved by internal or external insulation of the silencer.

Engine Vibrations. Exhaust systems are not designed to withstand vibrations. Exhaust silencer manufacturers recommend long flexible connectors between the engine and the exhaust system in order to prevent engine vibration from being transmitted to the silencer and the rest of the exhaust system. A flex connector is placed immediately after the engine, designed and selected to prevent piping weight and thermal expansion from exceeding the engine’s exhaust connection loading limits. An expansion joint of shorter length than the flex connector can also be used instead of the flex connector to isolate engine vibration. Consult the exhaust system supplier and the engine manufacturer for application specific recommendations.

Silencer Size and Shape. There are many shapes and designs of silencers, ranging from common cylindrical to low profile. A solution can usually be found that meets any site constraints on size and shape.

Noise and Emissions Control. Best practice is to use one supplier to address noise and emission control equipment on the exhaust. This will ensure that there are no compatibility issues between the emissions and noise control components.

Engine Exhaust Specifications. The information that is typically necessary and provided when designing for proper engine exhaust noise attenuation includes:

a) Site requirements, best defined by specifying the Target dBA by octave band at a given distance and height. Less adequate, but often acceptable, is specifying the Target dBA (without octave band) at a given distance and height. Least adequate is a specification only by classification (e.g., Residential, Hospital or Critical).
b) Engine make and model along with narrow band sound level data from the engine manufacturer.
c) Engine manufacturer’s estimated source impedance data.
d) An understanding of the site permit expectations as to what attenuation is implied when referred to as critical, hospital or extreme grade. Since there are no dBA attenuation standards that translate across suppliers, one supplier’s critical grade solutions could have a different attenuation band than another.

e) The required attenuation as dB or dBA outlet sound levels.
f) Shell noise requirements/impact on overall noise attenuation for the far field results. This influences the use, or not, of external insulation on silencer, exhaust piping and catalyst housings. This has further implication on the materials used, depending on the exhaust temperatures. To reduce the risk of oxidation degradation damage, it is necessary to avoid installing external insulation over carbon steel where the exhaust temperatures are greater than 482°C (900°F). It is important to provide unit arrangement drawings, so that exhaust pipe and tail pipe designs may be considered in the estimate of total insertion loss.
g) Request the octave band data from the silencer manufacturer for use in site sound surveys and design.

Exhaust silencers (mufflers) are used to reduce the noise of most engines. Smaller units have the silencer mounted directly onto the engine. Medium to larger packages are often designed to have the silencer mounted on top of the cooler. Some applications may require the exhaust silencer to be mounted off-skid, as shown in the example in Figure M.5, to reduce sound pressure travel. This particular installation placed the silencer at ground level to reduce sound travel over walls at an urban golf course. Since silencers produce high levels of heat, care must be taken to protect personnel from exposure during maintenance when mounted lower to a work surface.

Figure M.5: Silencer placed at ground level to reduce sound travelling over walls at an urban golf course.

Figure M.6: Example of a starter exhaust silencer.

As noted in M.1.5, exhaust silencers are classified by grades, and they range from Industrial (lowest grade) to Extreme (highest grade). Although "hospital grade" has become a common term in the industry, it is important to recognize that silencer manufacturers may have similar grades, but the range of attenuation for each grade is not regulated. Often in a remote application, ordering silencers by grade is not sufficient. A better approach is to know and specify the desired decibel reduction level, for example, a Sound Pressure Level of 85 dBA at 3 m (10 ft) It is important to discuss the site conditions with the silencer manufacturer, as the site conditions can impact the sizing of silencing equipment.

M.3 Gas Vent Noise Control

Commercial silencers are available for compressor purge/blowdown, PSV, and pneumatic starter exhaust vents. Due to the high noise level produced by these sources, vent silencer devices are recommended for compressors located near populated areas. An example of a commercial silencer for a gas exhaust vent is shown in Figure M.6.

M.4 Cooler Noise Control

Field compression applications typically utilize engine-driven, vertical style or horizontal style air-cooled heat exchangers. These coolers are usually skid-mounted and generally have single fans for units under 1461 kW (2000 HP). The primary noise source for the cooler is the fan. Fan noise is a function of tip speed and fan type, and there are several options that can be considered to reduce noise levels.

As an example, noise levels from one of the most commonly used fans operating at 3658 m/min (12,000 ft/min) tip speed are generally in the SPL range of 92 to 94 dBA at 0.9 m (3 ft). Slowing the tip speed to 3048 m/min (10,000 ft/min), which will increase the number of blades required on the fan to maintain the same airflow, and adding vortex tips (VTs) will reduce noise by as much as to 2 to 4 dBA. Slowing the tip speed to 2743 to 3048 m/min (9000 to 10,000 ft/min) and going to an extended chord (EC) fan will reduce noise another 4 to 6 dBA (6 to 10 dBA total). Slowing the tip speed to 2438 m/min (8000 ft/min) and going to a minimum acoustic velocity fan will reduce the noise another 6 to 8 dBA (12 to 18 dBA total). These values are estimates, not exact, and they vary with each application, but they provide a general indication of the relative effectiveness of available alternatives. There are costs associated with each alternative, generally increasing as the noise level is decreased. In some situations, if coolers are over-sized for an application, airflow and fan tip speed can be reduced with a sheave change or a variable frequency drive to reduce the fan speed to reduce noise levels without having to add blades and increase the cost. In most applications, the need for the cooler's peak cooling capacity is only required a few days or even a few hours each year. With a variable speed drive, during the rest of the time, the fan speed can be slowed down to the speed required for temperature control, reducing noise and parasitic power and avoiding over-cooling.

Not all cooler noise is associated with the fan. Belts, guards, frame structure, and pipe affect the noise levels as well. Some margin is suggested to account for this added noise. In general, about 3 dBA margin is recommended.

When cooler intake silencers and sound walls are utilized, cooler performance can be negatively affected. Air-coolers depend upon free intake air flow and free discharge air flow. When either is inhibited or restricted, the cooler will not perform as designed. It is necessary that air flow and static conditions related to intake silencers and sound walls are accounted for in the initial cooler design to avoid detrimental effects on the performance of cooler.

The information that is typically necessary and provided when designing for proper cooler noise attenuation includes:

a) Site noise requirements, best defined by specifying the Target dBA at a specified distance
b) Site ambient conditions (ambient temperature range and elevation)
c) Engine performance data
d) Compressor performance data

Additional requirements for the cooler specification are provided in Section 10.

M.5 Engine Air Intake Noise Control

Intake silencers are used to mitigate the noise of engine air intakes. Normally, absorptive silencers are used. It is important to use only intake silencers manufactured such that fibers cannot come out of the silencer and be ingested into the engine where they could damage turbochargers, block intercoolers or interfere with the sealing of engine valves.

M.6 Sound Control Walls

After a compressor package has been placed in service, sound walls can be strategically placed for optimum effect to further reduce the noise levels of an overall system. For reasons such as wind loading, support structure and obtaining proper noise reduction levels, best practice is for sound walls to be designed, built and installed by qualified, experienced personnel. Sound walls and sound mitigation enclosures can greatly reduce accessibility to equipment and create numerous safety issues for service personnel. They can also disrupt airflow for coolers and negatively affect heat exchanger performance. It is recommended that the cooler manufacturer and/or compressor packager be consulted and their recommendations followed in the design and placement of sound walls.

Annex N
(Informative)

Site Selection and Preparation Considerations

Annex N provides guidelines and tutorial information for compressor package site selection and preparation. Section 8 of the GMRC *High-Speed Compressor Package Guideline For Field Gas Applications*[40] is acknowledged as the primary foundation reference source for this Annex.

In field gas compression applications, the site operator and the compressor operator are often different parties. When this is the case, good communication is very important in preparing the site for a compressor installation. Some of the issues that are important to consider for site layout and preparation are discussed in this Annex.

N.1 Physical Location Considerations

N.1.1 Access Roads

When designing a field compression site, it is important to consider the proximity of compressor packages to access roads. It is convenient for operating and maintenance personnel to have the packages close to roads. In addition, heavy equipment is periodically required for compressor servicing. Access roads and the location around the unit require appropriate preparation and sufficient maintenance to support truck traffic. The field gas compressor access road and construction site may have to be specially compacted to sufficiently support the incoming loads.

Access roads are typically dirt or gravel, and they can introduce excessive dust that can foul engine inlet air filters. Road dust can also contribute to fouling of fins on air-coolers, requiring more frequent cleaning to maintain acceptable cooler performance.

N.1.2 Package Directional Orientation

Directional orientation is an important consideration when setting compressor packages. Best practice is for the cooler to face the prevailing winds during summer months. The direction and intensity of the prevailing winds varies at different locations and geographic regions. As an example, Figure N.1 shows how mean prevailing wind direction varies with the location within the lower United States. It is recommended practice to investigate and confirm prevailing winds with local meteorological experts prior to design of the compressor site and the installation of the air-cooled heat exchangers, whether part of a compressor package or remote/free-standing. Directional orientation and the position of the cooler relative to other coolers, equipment and structures are also important considerations when setting compressor packages.

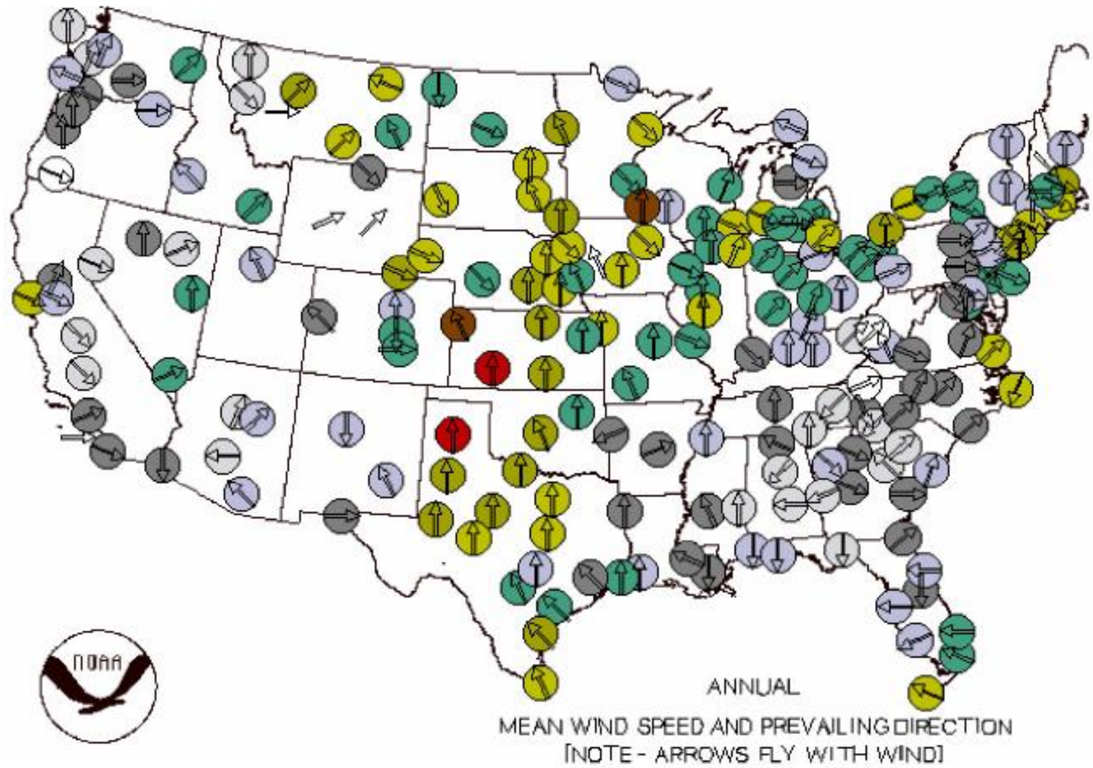


Figure N.1: Mean prevailing wind direction in the United States.

N.1.3 Air-Cooled Heat Exchanger Orientation Considerations

Unintentional warm air recirculation can also be a concern with placement of air-cooled heat exchangers as shown in the graphic in Figure N.2. Warm air can be drawn from the cooler discharge back to the inlet. This mixes with the cool air approaching the cooler and increases the inlet air temperature, reducing the cooling capacity of the air cooler.

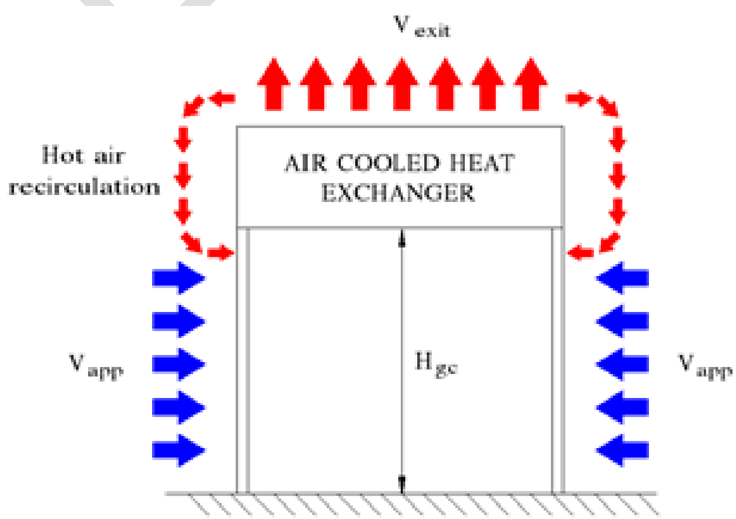


Figure N.2: Unintentional warm air recirculation can be a concern with cooler placement.

Figure N.3 shows how wind direction can affect hot air recirculation, not only into the cooler from which the hot air originates, but also into adjacent coolers. Sufficient free space is required on the sides of each cooler to allow unrestricted flow of fresh air across the cooler sections.

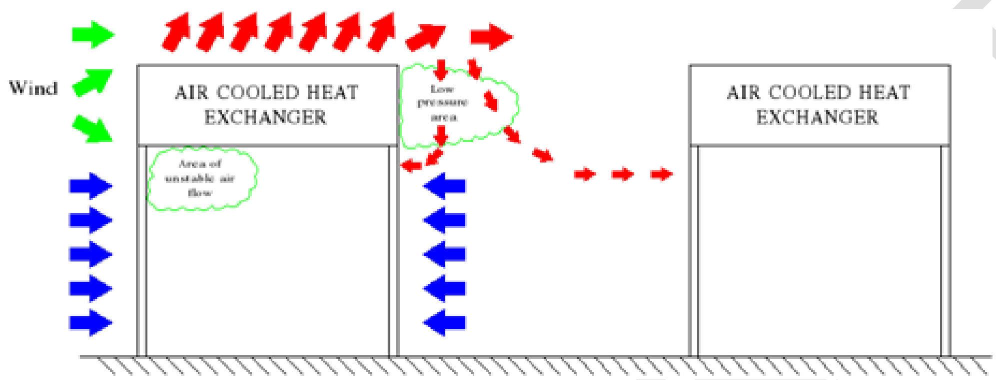


Figure N.3: Wind direction can affect warm air recirculation into coolers.

Hot engine exhaust can also flow into the cooler sections. This is exacerbated by obstructions near the cooler or by poorly located exhaust stacks relative to the wind direction. To avoid unintentional warm air recirculation or unnecessary air restriction, it is important to maintain appropriate clearance around air-cooled heat exchangers. Sound walls, containment walls, firewalls, buildings and exhaust air from other air-cooled heat exchangers are examples of items that can negatively affect a cooler's performance.

When hot air or exhaust recirculation is a concern, induced-draft fans may be a better choice. On a forced-draft cooler, there is a minor tendency to not fully distribute the airflow to the outside corners of the cooler. This effect is less of a concern on an induced-draft unit, as it is pulling the air from only the surface area of the bundle. Best practice is to consult with the cooler manufacturer and/or compressor packager, and follow their recommendations.

N.1.4 Equipment Access Considerations in Environmental Protection Strategy

Although environmental protection is an important consideration at production sites, a balance must be maintained with personnel safety. For example, as shown in the example in Figure N.4, containment walls or berms placed around a field gas compressor will block access by service trucks, and inhibit access by personnel. In this case, a crossover stairway was provided to enable personnel access, however, the wall still interferes with truck and crane access and it requires that personnel carry heavy parts up the stairs and over the wall. Recommended practice is to maintain proper clearance for equipment servicing and personnel safety needs. A minimum clearance of 3 m (10 ft) all around the unit is normally required for truck access. If the location is to be fenced, a gap or gate large enough for a service truck to get through can be provided.

Figure N.4: Although the stairs help personnel scale the environmental wall, service trucks cannot reach the package for maintenance.

Figure N.5: A layer of sand was placed on this environmental liner to reduce the risk of personnel slipping.

Liners placed under the package, as shown in Figure N.5, can create a slippery surface when water or oil contacts them. In this case, placing a layer of sand on top of the liner greatly improved the safety for personnel needing to walk around the compressor package.

N.1.5 Considerations in Placement Near Flare Stacks and Ancillary Production Equipment

It is very important to take safety precautions when locating the compressor on a field location with ancillary production equipment. For example, dehydrators and flare stacks are potential ignition and/or fire sources. Although general rules may not be adequate due to the uniqueness of each site, one recommended practice is to locate the compressor package a minimum of 7.6 m to 15.2 m (25 ft to 50 ft) away from such ancillary equipment, taking into account the site layout and other considerations. Prevailing wind direction, as well as heights and gas density, are important considerations for the safe location of compressor vents when ignition sources are present at the location.

N.1.6 Flammable and Combustible Liquid Storage Considerations

Containers of flammable and combustible liquids, such as methanol, glycol and lube oil, can contribute to a compressor engine fire and spread it quickly. It is important that these are located a safe distance away from the unit or separated by a fire-resistant barrier.

N.2 Pad and Foundation Design and Installation

The goal of the foundation and skid design is to ensure that the compressor, driver and other equipment have a stable base for safe, long-term operation. The skid is the fabricated steel structure that supports the compressor and driver as well as the vessels, piping, cooler and other equipment included in a complete compressor package. Figure N.6 shows a typical arrangement of a skid-mounted compressor package. The skid is sometimes composed of two main structures, one being a pedestal and the other being the main skid. The pedestal, sometimes called a pony skid, is the structure that supports the driver (usually a natural gas reciprocating engine or an electric motor) and the compressor. The main skid is a structure that supports the pedestal as well as the other components of the compressor package, often including the package cooler (not shown). The pedestal may be part of, or integral to, the main skid in some cases. The foundation is the structure that supports the skid. The foundation and skid support the rotating machinery, ensuring frame and coupling alignment and providing energy paths for dissipation of unbalance forces and all time variant vibratory forces. Properly designed and installed foundations maintain reasonable soil loading and/or low foundation stresses to prevent excessive foundation settlement and stresses that lead to failure.

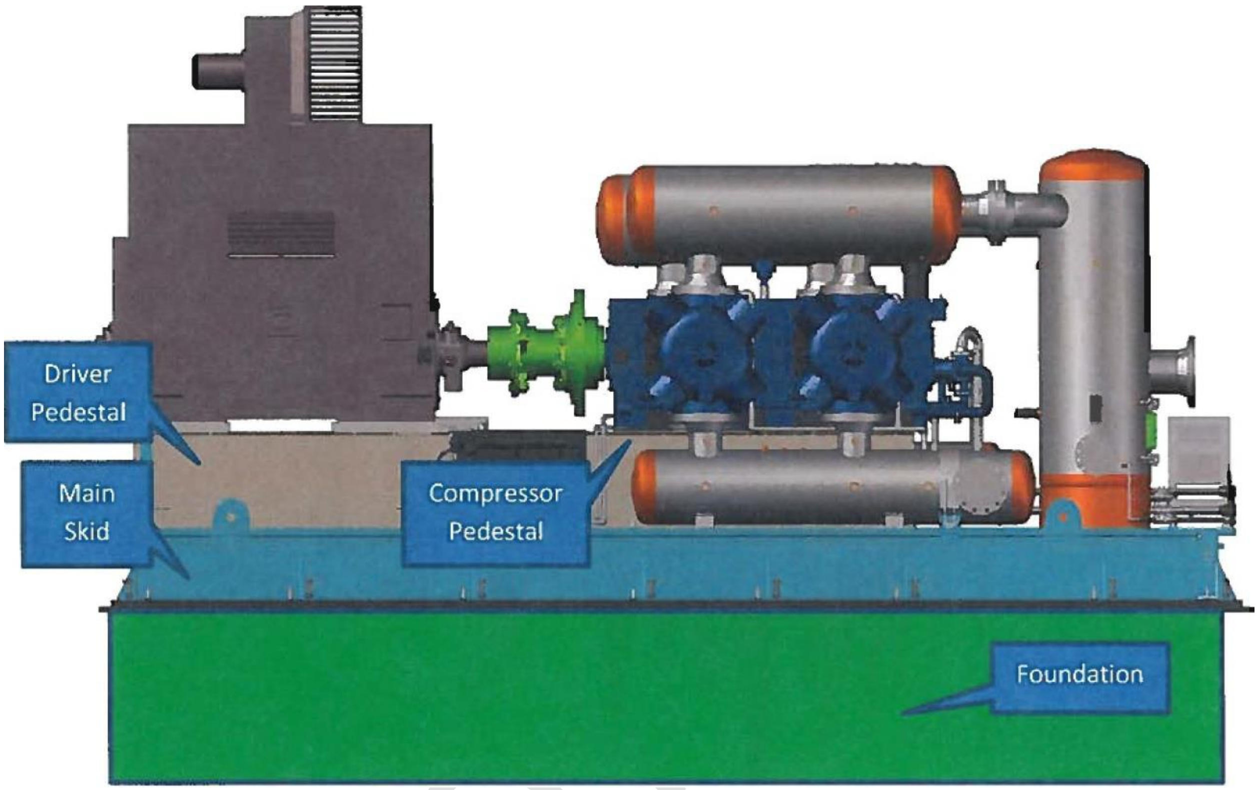


Figure N.6: Typical arrangement of a skid-mounted compressor package.

N.2.1 Types of Foundations

There are several types of foundations that are commonly used for reciprocating compressors. The appropriate type depends on many factors including the physical size of the package, the power rating of the package, the criticality of the compression application, the expected life of the installation, the type of soil, and the soil condition and drainage in all seasons. The foundation may range from a heavy reinforced concrete block for a large horsepower package to a caliche or gravel pad for small and medium size packages. The types of foundations used successfully for field gas compressor packages include the following examples. There are variations of these types and hybrid designs, but they generally fall into one of these five categories.

Skid on block foundation, Figure N.7, where the driver and compressor are mounted on a fabricated steel skid that is then mounted on a reinforced concrete block foundation;

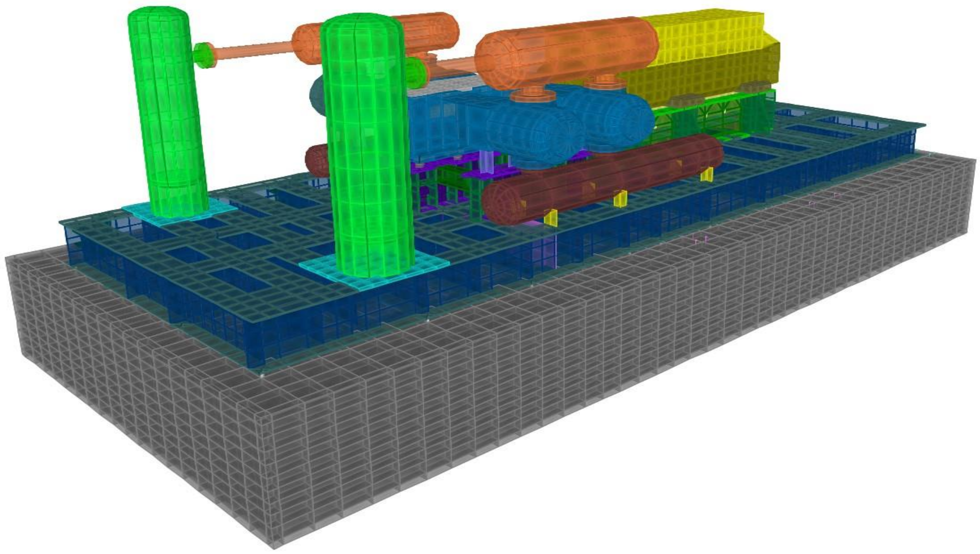
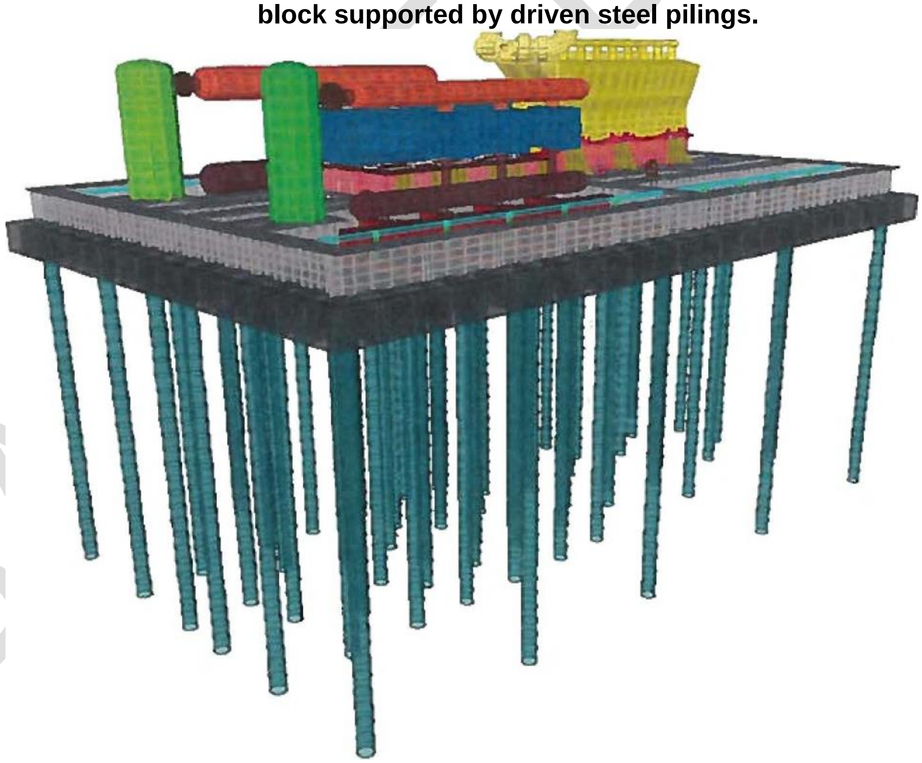


Figure N.7: Driver and compressor mounted on a fabricated steel skid that is mounted on a reinforced concrete block foundation.

Skid and block on driven steel pilings, Figure N.8, where the equipment is mounted on a fabricated steel skid that is mounted on a reinforced concrete block supported by driven steel pilings;

Figure N.8: Equipment mounted on a fabricated steel skid that is mounted on a reinforced concrete block supported by driven steel pilings.



Skid on driven steel pilings, Figure N.9, where the equipment is mounted on a fabricated steel skid supported by driven steel pilings;

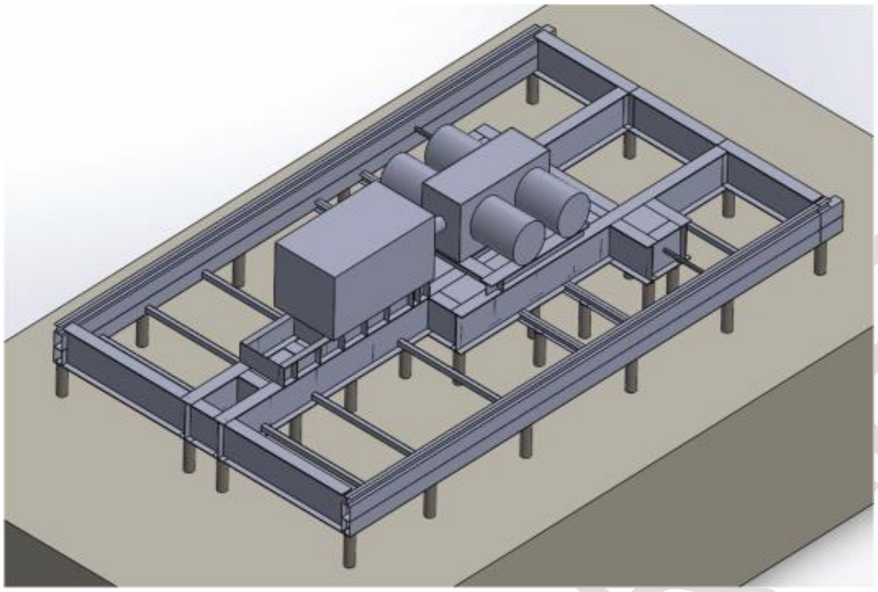


Figure N.9: Equipment mounted on a fabricated steel skid supported by driven steel pilings.

Skid on screw pilings, Figure N.10, where the equipment is mounted on a fabricated steel skid mounted directly onto driven screw pilings; and

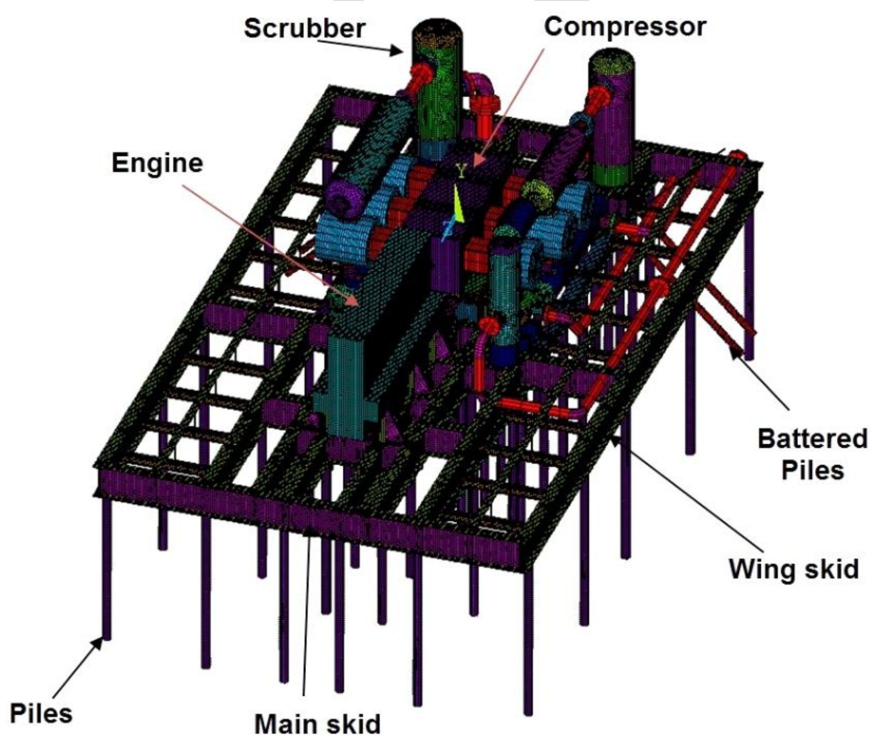


Figure N.10: Equipment mounted on a fabricated steel skid mounted directly on driven screw pilings.

Skid on caliche pad, Figure N.11, where the equipment is mounted on a fabricated steel skid mounted directly onto a carefully prepared caliche or gravel pad.

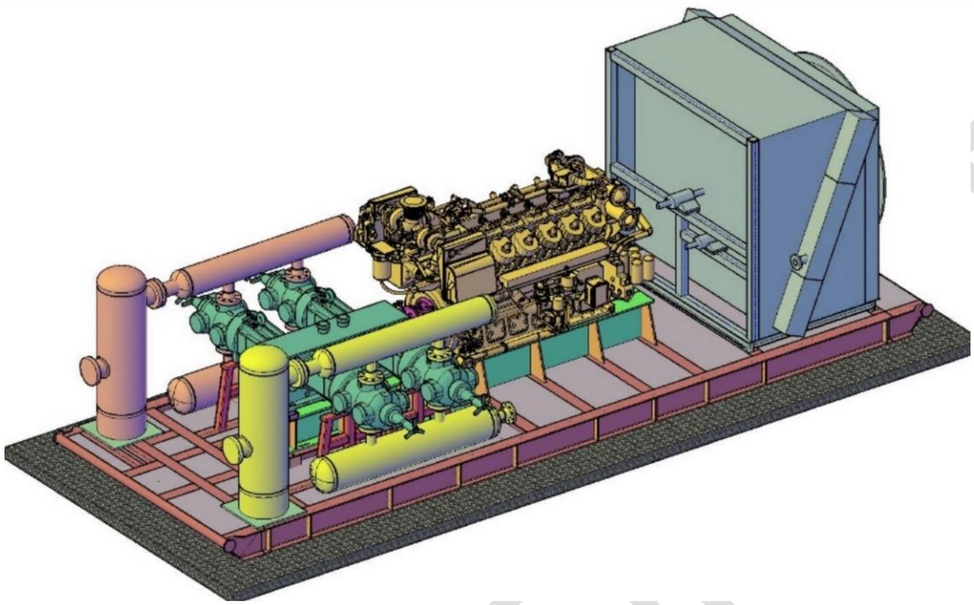


Figure N.11: Equipment mounted on a fabricated steel skid mounted directly onto a carefully prepared caliche or gravel pad.

It is important that each skid is designed for compatibility with its foundation. For example, a skid on a pile foundation will require a different design than a skid on a reinforced concrete block foundation. In general, the more flexible the foundation, the stiffer the compressor skid has to be.

Recommended practice is to analyze and evaluate the skid design for lifting, transportation and other environmental loads, as well as dynamic loads that occur during operation. Best practice is to also evaluate the foundation to ensure that it is suitable for carrying both the static and dynamic loads from the compressor package.

The following subsections provide recommendations and suggested guidelines for owners, engineering firms, packagers and other stakeholders for use in the specification and design of foundations and skids for high-speed reciprocating compressor packages in field gas applications.

N.2.2 Owner Considerations and Responsibilities

There are many challenges involved in the design and construction of a foundation/skid system. A successful project requires effective planning, coordination between the technical specialists, and attention to construction details.

The normal responsible parties in a project are:

a) **End User**, usually the owner, who contracts and manages the coordination of schedules and information exchange between all parties.
b) **Engineering Consultant (EC)**, is responsible for the overall facility/station design.
c) **Compressor Packager**, is generally focused on the skid design as part of its scope of work. They are typically responsible for coordinating the package mechanical and pulsation analyses and design via specialized analysts. They generally also provide field assistance in setting, assembling and commissioning the compressor package at site.

d) **Construction, installation and mounting specialists**, including grouting. A variety of services are involved in these activities.

Specialists providing consulting studies and services take direction from one or more of the responsible parties, and they may include the following:

e) **Geotechnical Specialist** provides soil testing and a detailed report of the soil conditions and properties at the site. They also consult with the foundation or pile contractor on difficult sites and observe and inspect foundation or pile characteristics and load testing.
f) **Structural Specialist** is involved in static skid design, including consideration of the effects of equipment weights, lifting, loading, etc. and providing detailed construction requirements.
g) **Mechanical Analyst** provides a dynamic analysis of the combined skid, foundation and compressor. This analysis is often closely linked to the compressor package mechanical dynamic analysis.

The specialists/consultants can generally be expected to make recommendations and provide technical advice for the foundation and skid design. The end user is usually the final decision maker, although in some cases, some of this responsibility for decisions is delegated to the EC and/or packager.

Effective project management and coordination between these various specialists and/or groups is a key function. It is recommended that a project manager be assigned by the end user, either an experienced employee or a qualified consultant. It is important that the pulsation and vibration consultant is selected and involved early in the design process, ideally even before the specification is issued to packagers for quoting. Although the pulsation and vibration consultant is commonly contracted by the packager, a preferable practice is for the pulsation and vibration consultant to work directly for the end user or its representative to ensure that reliability and vibration goals are met and that decisions requiring efficiency and reliability trade-offs are made prudently and quickly. As a minimum, project responsibilities need to be assigned in a kick-off meeting, held within the first week of project initiation.

N.2.3 Milestones and Timing in Skid and Foundation Design

The first decisions relate to the selection of the type and size of compressor. Next, the type and size of driver is chosen. A rough sizing of the skid footprint can be made after the driver and compressor have been chosen.

Since the final design of the skid is strongly influenced by the foundation design, the next decision is usually the type of foundation. The foundation is often dictated by the soil conditions, drainage and other factors, such as the type of compressor, type of driver and distance to neighbors. Therefore, a site inspection to measure the soil properties and understand environmental factors is required very early in the project. A geotechnical report can be expected to recommend the type of foundation that is appropriate for the site, as well as providing basic soil properties for the foundation design and vibration analysis.

N.2.4 Skid and Foundation Performance Criteria

It is important that skids and foundations are designed to resist the driver dynamic (roll) torque, frame unbalance forces and moments, vertical crosshead forces, time variant gas and inertia forces at each compressor throw and the effects of frame flexibility. Ideally, the skid and foundation are designed as a system by the same engineering entity.

Compressor and driver unbalanced forces are dissipated by trying to move a large foundation mass. To avoid vibration problems, the vibratory energy created by the operating equipment has to have a continuous path into an appropriate foundation as shown in Figure N.12.

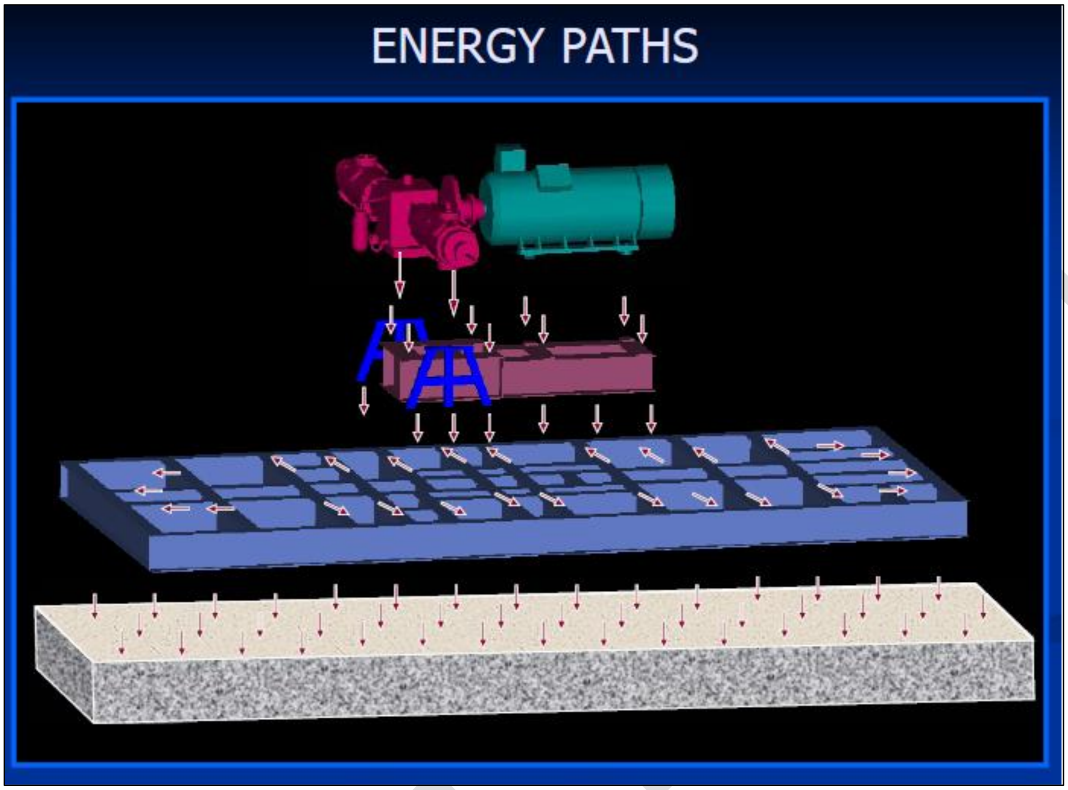


Figure N.12: Vibration energy has to have a continuous path into an appropriate foundation.

If a skid is isolated or not properly anchored to or not in full and intimate contact with the foundation, there is no energy path, and the unbalanced forces cannot get into the foundation to be dissipated. If the foundation is not large enough, it will not dissipate enough energy. High unbalanced forces that are not dissipated by the foundation can excite the natural frequencies of other components and cause instrumentation failures, small bore piping failures, pressure vessel nozzle failures, fastener loosening, and other problems. These can result in unscheduled shutdowns and safety hazards.

Structural vibration is the result of vibratory forces and flexibility of all components. If the frequency of the vibratory forces is the same as the foundation or skid natural frequency, the structure is in resonance and high vibration is likely to occur. It is important to keep foundation natural frequencies at least 20% away from the equipment operating speed range. For units on concrete foundations, horizontal transverse (sometimes referred to as horizontal translational), horizontal torsional (sometimes referred to as twisting) and horizontal longitudinal (sometimes referred to as axial translational) natural frequencies are typically detuned to below the operating speed range of most high-speed reciprocating compressors. However, packages mounted on piles typically have these modes tuned above the operating speed.

Vertical, rocking and pedestal natural frequencies are typically placed above the operating speed range. Soil stiffness will change foundation natural frequencies and therefore has to be considered in the analyses. Using dynamic analyses, the vibratory forces are applied to the modeled equipment as forcing functions at their generated frequencies. The primary purpose of the skid dynamic analysis is to find and eliminate resonances, evaluate predicted vibration levels, and determine mode shapes for the range of operation.

Each driver and compressor combination has a fundamental frequency associated with the rated operating speed. In addition, there are harmonic frequencies (i.e., multiples of operating speed) that result from mechanical and gas pulsation forces. If the driver operates at a constant speed, such as a synchronous electric motor, this results in a discrete set of forcing frequencies. However, variable speed drivers, such as gas engines and variable frequency electric motor drives, create ranges or bands of driving frequencies that must be dealt with. Placement and control of natural frequencies is much more challenging when variable speed equipment is required. Wide speed ranges make the task of mechanical natural frequency placement very difficult, and if the speed ranges are too wide, the harmonic bands overlap such that there is no zone for placement of the higher frequency modes. Therefore, from a vibration stand-point, constant speed equipment is always preferable. The wider the speed ranges, the higher the risk of serious vibration related problems. To minimize vibration, flexible unloading schemes (e.g., combinations of automatic clearance volume pockets) are almost always preferable to wide operating speed ranges. Also, if complete end deactivation or infinite step unloaders will be used, it is very important that these unloading schemes are considered in the analysis, since they may result in elevated vibration response amplitudes.

Best practice is for performance criteria, guidelines and design strategy to be agreed upon prior to the start of skid and foundation design.

N.2.5 Foundation Design Guidelines

The skid and the foundation support the weights and resist the torque reactions and unbalanced forces of the compressor and the driver. Foundations are generally categorized as either shallow or deep. Shallow foundations typically refer to caliche/gravel pads or reinforced concrete block designs. Deep foundations are pile foundations that include a concrete block with piles or, alternately, a skid that is mounted directly to the piles. Both foundation types can be either surface mounted or embedded.

A preliminary foundation selection flow chart is shown in Figure N.13. This provides initial guidance only. Past experience with similar sized compressor packages in comparable soils, coupled with a thorough geotechnical analysis, may dictate the use of a different type of foundation.

Economics associated with the availability of concrete, pile driving or screwing equipment, etc. will generally influence the choice of foundation. Size and type of compressor in terms of power, unbalanced moments and forces, and number of throws will influence the choice of design. For a given power level, fewer cylinders require a more carefully specified foundation. Poor soil conditions usually force the decision toward deep foundations.

Steel pile foundations are sometimes used for compressor packages. Steel pile foundations are of two types: driven piles (pipe, tubing, or structural members) and screw piles. Driven piles are a proven technology for compressor foundations. Screw piles are a newer technology for reciprocating compressor applications that may reduce installation time and cost. However, they are more sensitive to soil conditions and can be more structurally flexible than driven piles.

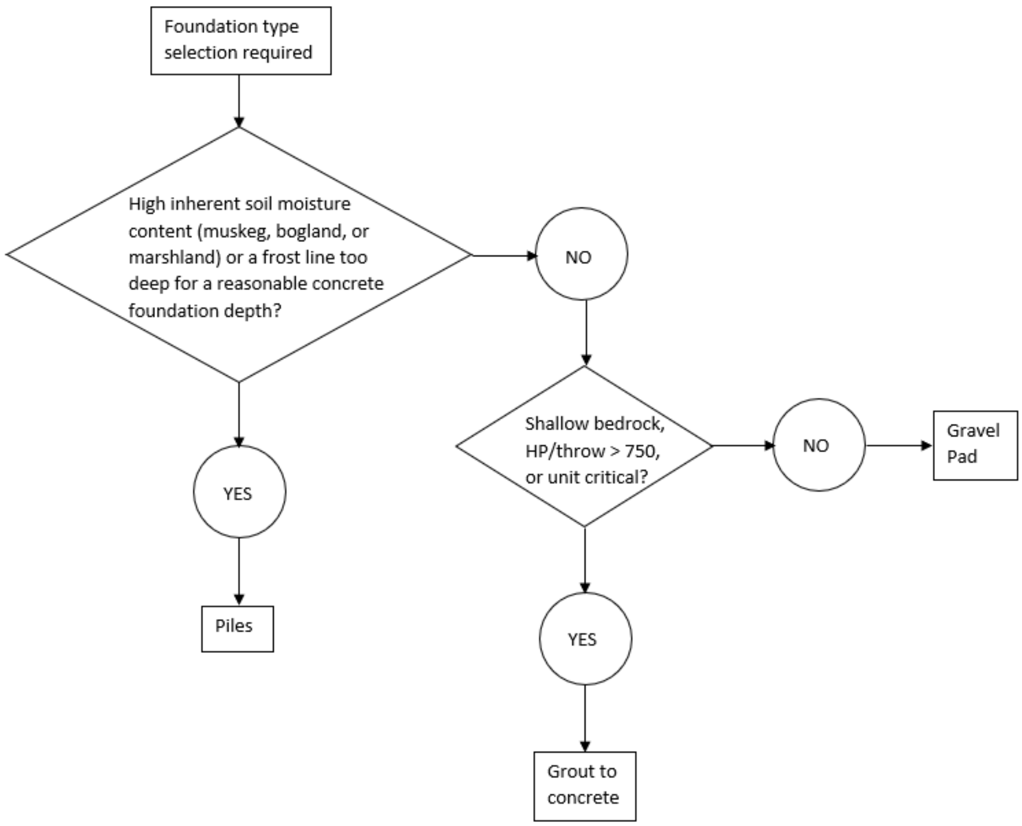


Figure N.13: Preliminary foundation selection flow chart.

In field gas applications, it is common to utilize a caliche or gravel pad instead of a reinforced concrete foundation or some type of piles. The load bearing capability of caliche is greatly affected by moisture content, ranging from rock hard to gooey. It is important to consider annual rainfall and drainage in the selection of caliche versus gravel pads. The design of skids for packages mounted on caliche or gravel pads requires special design considerations including heavier beams to reduce flexibility. It also requires the use of concrete fill in all or part of the skid for added mass to reduce mechanical natural frequencies and provide more damping to reduce vibratory response.

Best practice is for the dynamic design of the foundation to include a model of the skid and an equivalent model of the soil under the skid. For best results, measured soil properties are utilized in the dynamic analysis model. Dynamic loads to consider in the analysis include driver dynamic (roll) torque, crankshaft inertia unbalance forces and moments, vertical crosshead forces, and time domain gas and inertia forces at each compressor throw.

N.2.5.1 Reinforced Concrete Block Foundation Design Considerations

An appropriate poured reinforced concrete block foundation has an engineering design with high strength, low and even settlement, sufficient rebar (size and location), energy paths and energy dissipation, adequate sole plates and grout, suitable anchor bolts and center of gravity matched with the mounted equipment.

Significant foundation material properties include the resistance to bending, shear and deflection, maximum concrete compressive strength, reinforcing steel tensile strength, and modulus of elasticity ratio. Major concerns include the engineering design, wet mix water content, handling of the wet mix and cured concrete strength.

Recommended practices for mission critical concrete foundations and for permanently installed units larger than 1491 kW (2000 HP) are provided in the *GMRC Guideline for High-Speed Reciprocating Compressor Packages for Natural Gas Transmission & Storage* Applications[3], which provides an extensive review of recommended practices. ACI 318 *Recommendations for Construction of Concrete Pavements and Concrete Bases* provides additional specific guidance.

For field gas units typically under 1491 kW (2000 HP), following are a number of recommended practices for appropriate concrete foundations.

a) **Size.** The length and width of reinforced concrete block foundations is 0.3 m to 0.6 m (1 ft to 2 ft) longer and wider, respectively, than the equipment (if block mounted) or the skid (if skid mounted). The depth of the concrete block has to extend below the frost line. A rule of thumb is to make it a minimum of 1.2 m to 1.5 m (4 ft to 5 ft) for drivers less than 1864 kW (2500 HP).
b) **Soil Conditions.** It is very important that soil conditions are understood and accounted for in the design. Settlement considerations may require drilled concrete piers under the foundation. See Annex N.2.6 for recommendations for soil testing and analysis.
c) **Concrete Strength.** For high strength, concrete for foundations meet 2758 N/cm^2 (4000 psi) after 28 days in accordance with American Concrete Institute (ACI) 318. It is important that the final concrete specifications, material selection, installation, workmanship and quality are specified, and preferably monitored, by an experienced civil engineering consultant.
d) **Reinforcing Bar (rebar).** Preferably, use ASTM A-615 Grade 60 [41,370 N/cm^2 (60,000 psi) minimum yield strength] and 19 mm (¾ in.) #6 minimum diameter rebar. A spacing of 305 mm (12 in.) is typical except around anchor bolts, where closer spacing is typically required as shown in Figure N.14. Anchor bolts are typically enclosed in a 3-dimensional rebar cage. The use of rebar support cages, aka chairs, is very important in the development of the full strength of the bottom layer of rebar. Care is necessary to ensure that the cages are not disturbed during the placing, vibrating and finishing of the wet concrete. For equipment pedestals, where applicable, rebar is typically on 152 mm (6 in.) or 305 mm (12 in.) horizontal centers. Vertical centers are typically 152 mm (6 in.) near the top, 229 mm (9 in.) near the middle and 305 mm (12 in.) near the bottom.

Figure N.14: Typical concrete rebar arrangement with anchor bolt cages.

Figure N.15: Rebar tied together with wire.

e) **Rebar Interconnection.** Intersecting rebars are typically tied together with wire as shown in Figure N.15. Welding is not preferred as it requires special verification of materials and special procedures for good results. The rebar in the concrete block foundation is typically covered with at least 76 mm (3 in.) of concrete where it is permanently exposed to earth, and at least 21 mm (2 in.) where exposed to weather.

f) **Anchor Bolts for Skids.** Anchor bolts for compressor foundations are generally high strength ASTM A193 Grade B7 ([86,188 N/cm^2 (125,000 psi) tensile] with rolled threads. Correct anchor bolt sizing considers the material and clamping force necessary to hold the skid tightly to the foundation to ensure vertical support, horizontal friction and dynamic stiffness. The anchor bolt diameters are normally determined by the compressor package skid designer with clearance holes in the skid being3 mm (1/8 in.) larger than the bolt diameter. The minimum bolt diameter is typically 29 mm (1-1/8 in.), although smaller sizes may be used for the smallest compressor packages. In order to develop sufficient stretch and locate the bottom disc or the skid anchor bolt in a lower stress section of the concrete foundation, the bolts are typically at least 610 mm (24 in.) in total length. The practice of staggered lengths of anchor bolts (in the mistaken belief that this practice will minimize connecting cracking) is to be avoided. Proper rebar detailing is the only way to contain the cracking that can start at the lower anchor rod plate or disk. Further guidance can be sought from various ACI references, if needed.

g) **Anchor bolts for Auxiliary Equipment.** Anchor bolts for auxiliary equipment, such as bottle supports, scrubbers and coolers can be a straight anchor rod with a thick bottom plate/disk with a full-length sleeve to allow for full length stretch.

h) **Exterior Skid Beam Bolting.** A canister design that provides a variable anchor rod projection and horizontal alignment (to allow centering in the skid anchor bolt hole only 3 mm (1/8 in) larger than the anchor rod) is preferred to enable exterior skid beam grouting. This style allows full retraction of anchor bolts below the top of the concrete, which allows horizontal skid placement on rollers when unloading off a truck trailer.

i) **Interior Skid Beam Bolting.** For internal anchorage of the interior longitudinal wide flange skid beams supporting the compressor and the driver, a coupled canister style anchor bolt design allows the top anchor rod/stud, which typically terminates at the top flange of the longitudinal wide flange, to be removed during the skid package placement.

j) **Spherical Washers.** Spherical washers are recommended under the top anchor bolt nut. Even a perfectly installed straight anchor bolt can become misaligned during operation from thermal expansion. A double spherical washer helps reduce the bending stress that can develop with a flat washer.

k) **Bolting Template.** For alignment, a precision steel anchor bolt template, with holes optically set to 1.6 mm (1/16 in.), is a requirement that is often overlooked. Anchor bolt sleeves are not intended to allow bending of the anchor bolt, only to allow anchor bolt stretch. It is very important that anchor bolts are not bent. Figure N.16 shows a steel template strong enough to support the entire weights of each anchor bolt assembly without deflection and drilled template holes exactly in the proper location.

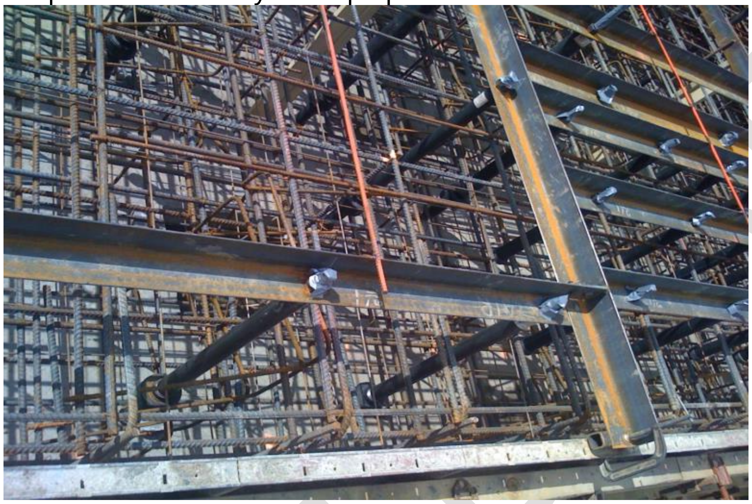


Figure N.16: Anchor bolt template with drilled holes exactly in the proper locations and strong enough to support the weight of each anchor bolt assembly without deflection.

l) **Installation Protection.** All properly designed skid anchor bolts for both the main skid anchoring and the smaller auxiliary equipment anchor bolts require a long sleeve around the anchor rod up to the top of concrete. A foam donut is typically at the top to temporarily keep concrete out of the sleeve during concrete placement, but further protection in the field can be provided by an application of silicone caulk and tape over the foam donut and also tape around the exposed upper anchor bolt projection, as shown in Figure N.17.

Figure N.17: Long sleeve around the anchor rod up to the top of concrete, with protection to keep concrete out of the sleeve and away from threads during concrete placement.

N.2.5.2 Temporary Rental Unit Foundations

For rental compression units, which are typically temporarily or only semi-permanently installed at a particular site, gravel or caliche pads are preferred. However, when such pads are not deemed adequate, and where the soil condition does not require piles, concrete pads or foundations are often used for rental compression units. Following are several "rules of thumb" for minimal requirements for concrete pads and foundations for rental compression units.

a) Assuming the soil has a load bearing capacity of at least 2068 N/cm2 (3000 psi) the minimum amount of concrete required is 2 kg per kg (2 lb. per lb.) of compressor package weight.

c) Reinforce the concrete with #4 rebar on 305 mm (12 in.) grid centers and 305 mm (12 in.) lifts.

d) To insure that the compressor is properly set on the concrete pad, and to allow for "waves" in the concrete, the best practice is to grout the skid to the foundation. Depending on the duration of the project, grout can be a 12 sack-sand-cement mix, or epoxy. It is important to closely follow grout suppliers' installation procedures to ensure proper support and bonding with the skid. Notably, upon removal of the compressor package, it will be necessary to chip out the grout prior to return of the unit.

N.2.5.3 Driven Pile Foundation Design Considerations

Piles are usually required when soil moisture is too high or where the frost line is too deep to make a concrete slab feasible. Skids may be mounted directly onto the piles, as shown in Figure N.18, or on reinforced concrete blocks which are supported by the piles.

Figure N.18: Skid mounted on driven piles.

There are several "rules of thumb" that have been found to be helpful for successful block and pile foundation designs, and most also apply to skid on pile foundation designs.

a) Reduce foundation static design parameters (ultimate base resistance, factored base resistance and shear strength) by 50% for reciprocating equipment.
b) Limit the maximum dynamic load amplitude to no more than 1.5 times the maximum static load, so that dynamic loads do not induce fatigue.
c) Limit the ratio of the height of the machine crankshaft above the base to the width of the foundation (or the pile group in the plan, if applicable) to no more than 0.65 to increase damping in the rocking mode.
d) Limit the ratio of the weight of the block pile cap to the weight of the machine to a minimum of 5.0 for reciprocating equipment.
e) To minimize torsional effects, it is recommended that a vertical line drawn through the centroid of the machine or resultant of several machines passes within a distance of 5% of the plan dimensions of the base from the centroid of the contact area (or pile group).
f) Increasing the size of foundation soil contact area increases damping, everything else being equal. This is aided by making the plan area of the pile group as large as practical.
g) It is recommended that the distance between centers of driven steel piles be no closer than 2.5 to 3.0 times the pile diameter. Where piles are driven in groups, they are driven from the center outwards. All piles in a group are driven to approximately the same tip elevation.
h) Pile group effects have to be considered when four or more piles are required.
i) It is important to install piles under the compressor crosshead guide supports as well as below the compressor crankcase. If there are multiple throws on one side of a compressor frame, the typical number of piles required on each side of the frame is equal to the number of throws plus one.
j) A suggested practice for attaching skids to steel piles is shown in Figure N.19. Gaps often exist between the top of the pile and the underside of the skid, making welding impractical. A split ring collar can be used to connect the pile to the skid beams rather than a plate pile cap. The collar provides a simple way of filling gaps between the pile and the skid beam, and ensuring a solid connection between the pile and the centerline of the beam.

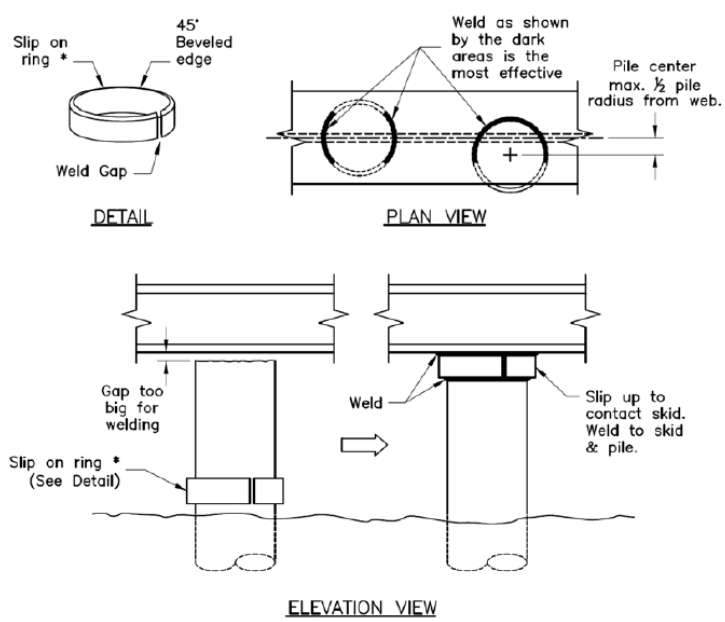


Figure N.19: Suggested practice for attaching skids to steel piles.

N.2.5.4 Screw Pile Foundation Design Considerations

Screw piles have long been used as a foundation system for equipment, buildings, towers and other stationary objects. Screw piles consist of a 76 mm to 254 mm (3 in. to 10 in.) diameter steel pipe with a helix at the end that can be screwed into the ground using a rotary hydraulic powered driver until a specified depth and minimum torque are reached. They have emerged as a foundation system under a variety of reciprocating compressor packages instead of more traditional concrete foundations. Screw piles have the advantage of a faster installation process and are typically lower cost. However, they must be able to adequately support the compressor package and all of its inherent dynamic loads to control or prevent excessive vibration.

Screw piles are typically installed in a vertical orientation to support primarily vertical loads. They can be installed at depths ranging from 3 m to 15 m (10 ft to 50 ft) or more depending on soil conditions and required load bearing capacity. A single screw pile can typically support a compressive or tensile load of between 45,351 kg to 90,703 kg (100 kips to 200 kips). Static load testing is very important on all projects to verify site-specific load capacities. Although vertical screw piles have very high load bearing capacities in the vertical direction, they are relatively flexible in the horizontal directions. Therefore, to support horizontal loads, it is often necessary to install battered piles at an angle (often 45 degrees). An example of a screw pile mounted reciprocating compressor package is shown in Figure N.20.

Figure N.20: Screw pile mounted compressor package.

The primary concern with using screw piles to mount a reciprocating compressor skid package has been the risk of excessive vibration due to the absence of the concrete foundation that provides significant mass, damping and stiffness. Therefore, to achieve a good design with acceptable operating characteristics, it is important to provide an engineered design for the screw pile system. This can be accomplished by using the following design approach. These steps are typically accomplished in parallel with other design and construction activities to avoid delays.

a) An initial pile stiffness test is performed by installing several test piles at the construction site. An on-site field test is performed to measure the site-specific dynamic stiffness properties of the piles interacting with the soil.

b) The measured stiffness values from step 1 are used as part of a finite element model. This model is used to calculate the dynamic responses of the system and to determine the necessary pile characteristics (quantity and locations).
c) Once the screw piles are installed on site and the compressor skid is mounted on the piles (typically by welding), a post-installation shaker test can be performed. This test is usually done as soon as the skid and the major mechanical elements are installed, but before the off-skid piping is attached and the compressor is operational. For this test, a hydraulic or pneumatically driven omni-directional mechanical shaker is mounted on the skid and swept through a range of frequencies. It is the goal to run this shaker in frequencies through the first two to three orders of running speed. Vibration measurements are recorded on the skid during the test to identify key mechanical responses. The pile configuration can be adjusted and tested during this step as needed for improved operation.
d) As an optional final step, once the compressor package is fully operational, a detailed on-site pulsation and vibration survey can be conducted to verify acceptable operation of the system, per the manufacturer's specifications.

Due to the dynamic loads in a reciprocating engine and compressor package, it is important to provide support at many key locations, such as under the compressor, the driver, vessels, etc. A typical compressor skid could have anywhere from 16 to 60 piles, depending on skid size, skid weight, compressor operating speed, pile size, soil conditions, etc.

Since skids used with piles have several point supports, instead of continuous support, a comprehensive review of the skid design and dynamics is important to assure that it has adequate beam sizes and support locations. These are the same type of design considerations that would be necessary for an offshore compressor skid. In many cases, the approach to skid design used by most compressor packagers results in skids that are adequately stiff without special modifications necessary for use with screw piles.

Another potential issue is that localized sections of the skid could be more susceptible to low amplitude, high frequency vibration or "buzzing" driven by high frequency pulsation or gas compression loads. This is compounded by the reduced damping provided by the piles and a less effective path of transferring energy into the ground. This is unlikely to lead to any structural concerns for the skid itself, but it can be noticeable to operators and could lead to vibration and potential fatigue issues on small bore auxiliary piping and deck plates mounted on the skid. The effects of this, if encountered, can be minimized by using sufficiently rigid skid designs and by minimizing high frequency pulsation energy.

It is also important to provide alternate supports for other auxiliary items such as pipe supports mounted on outrigger beams from the side of the skid. Prior knowledge of these auxiliary items can be incorporated into the original foundation design, but field modified items will still need to have sufficient supports applied. This can be accomplished with pile systems by using additional screw piles or, if necessary, small concrete pads.

Similar to a successful concrete foundation design, a well detailed and managed design and construction process is critical to the success of a screw pile installation. Appendix C-8.1 of the GMRC *High-Speed Compressor Package Guideline For Field Gas Applications*[40] provides more detailed guidance based on extensive end user experience.

It is also important to address cathodic protection issues with screw piles. Corrosion allowances are overdesigned concurrent with the heavy wall steel piles required for mechanical and structural strength of the screw pile foundation systems. This coupled with simple electrical connections to underground pipe cathodic protection systems can provide a virtual lifetime of corrosion protection for the underground steel screw piles. A corrosion allowance is designed into the pile shaft and is shown in the pile calculations, then submitted with the shop drawings. A heavier wall section needed to withstand the high installation torques also doubles as an over designed corrosion allowance. Corrosion allowance has been recommended by corrosion engineers as the most appropriate and cost-effective method of increasing the pile life. Electrical based rectified cathodic protection systems can also be used successfully to offset corrosion at a fairly inexpensive cost, since some compressor station projects also include cathodic protection systems for the underground pipe being installed at the station.

N.2.5.5 Caliche or Gravel Pad Design Considerations

Caliche, gravel or even packed sand pads have been used successfully for small and medium size packages, especially rental compression packages that will not be permanently required at a site as shown in Figure N.21. The image on the left shows a packed sand pad. The middle image shows a pad of screened caliche and the image on the right is a pad of crushed rock. These types of package pads are not suitable for all locations or soil conditions, and there are many variations. Normally, caliche or gravel pads are not appropriate with shallow bedrock, where a concrete pad is recommended instead. They are also usually not suitable for skids that have relatively small skid beam cross-sections.

Figure N.21: Examples of packed sand, screened caliche and crushed rock pads.

In general terms, caliche is a calcium carbonate mineral used in construction. It has been used as a principal raw material in Portland cement production. In many areas, caliche is also used for road construction, either as a surfacing material or, more commonly, as base material. Caliche is widely used as a compressor package base material when it is locally available and inexpensive. However, it does not hold up to moisture (rain), and is never used if a hard rock base material, such as limestone is available.

Gravel for use as a base for compressor package pads is crushed gravel or “crusher run” gravel, which is a mixture of smaller crushed gravel sizes and sand. Gravel that contains mostly round elements is not suitable for compressor pads, as it acts like a stack of marbles, which cannot be compacted into a stable base.

Although there are widely diverging specifications and practices among compression rental fleets and end users for different areas and soil conditions, a number of best practices are provided below for the selection, design and installation of a caliche or gravel pad. Appendices C-8.2 through C-8.5 of the GMRC *High-Speed Compressor Package Guideline For Field Gas Applications*[40] provides more detailed gravel pad specifications based on extensive end user and rental fleet operator experience. As previously emphasized, the results of geotechnical testing and analysis are the best basis for determining a suitable specification for caliche or gravel pads.

Following are some important considerations and recommendations.

a) Caliche or gravel pad levelness and compaction are key issues required for the stiff, uniform support of package skid beams. Complete continuous contact between the bottom surface of the skid and the foundation is key. A recommended installation technique is to place the compressor package on the pad, remove the package, evaluate the imprint, fill in low spots and compact them, and then reinstall the package, repeating this process until a 100% contact pattern is achieved.
b) A shallow layer on bedrock will not result in a successful gravel pad design.
c) The caliche or gravel pad normally extends at least 1 m (3 ft) beyond the edges of the skid in all directions.

d) A metal frame around the outside of the gravel pad can help to contain the gravel and prevent outward movement of the gravel and therefore loss of solid contact around the edges of the skid. Free, uncontained gravel is not effective as there is no cohesion at the perimeter.
e) Full depth beam gussets are used at all compressor feet, driver feet and below scrubbers.
f) Engine and compressor pedestal beam webs are aligned with skid beam webs for direct load paths to the foundation.
g) Cantilevered outrigger supports and overhung discharge bottles (outside the skid perimeter) are not recommended for gravel pads. Full-perimeter rails are a best practice.
h) A uniform range of grain sizes is important for good ability for compaction. Best size is smaller than 19 mm (¾ in.), ideally about 6 mm (¼ in.).
i) The pad is constructed and compacted in layers no more than 305 mm (12 in.) thick, adding water before compacting (to help lubricate the grains so they can move relative to each other during compaction) and let it soak in. A minimum compaction of 95% is recommended.
j) Depth may vary, but deeper is better. A depth of at least 0.9 m to 1.5 m (3 ft to 5 ft) is typical.
k) For best results, avoid using only crushed rock or sand under the skid. Many users of compacted gravel put a thin layer - maximum of 51 mm (2 in.) of sand on top of the gravel pad before setting the skid down to deal with the bottom of the skid being uneven due to beam depth tolerances and distortion from welding.
l) Use of straight compacted gravel topped with152 mm to 305 mm (6 in. to 12 in.) of gravel fines for “self-leveling” is a commonly used successful practice for smaller compressor packages in the 37 kW to 746 kW (50 hp to 1000 hp) range.
m) Use of compacted gravel topped with a 51 mm to 102 mm (2 in. to 4 in.) thick layer of cementatious grout for leveling and void make-up between the bottom of the package skid and the compacted gravel has been used successfully for compressor packages of 373 kW to 1119 kW (500 hp to 1500 hp) at sites with problematic soils. Appendix C-8.6 of the GMRC *High-Speed Compressor Package Guideline For Field Gas Applications*[40] provides detailed guidance on the use of cementatious grout for leveling based on extensive end user experience.
n) The top surface of the pad extends above the surrounding grade, and the material along the perimeter of the pad is sloped away from the pad as shown in the examples in Figure N.21.
o) Another recommended practice is to ballast the skid and gravel with hand-placed crushed rock after the skid is set in place. This improves the appearance and helps to confine the gravel.
p) Larger coolers can be installed on piers. Helical piers are a very good and cost-effective solution if deep enough to be supported by the type of soil.

N.2.6 Soil Testing and Analysis

If sufficient knowledge of the soil properties is not obtained, a proper design and analysis of the foundation system cannot be completed. The following problems may occur:

a) If the foundation system has natural frequencies near the compressor operating speed range, unbalanced forces from the compression equipment may excite these natural frequencies and cause harmful vibration.
b) If the foundation system does not have proper energy transmission paths and/or dissipation properties, unbalanced forces from the compression equipment may not be dissipated and can excite natural frequencies of skids, equipment, vessels and piping.

This subsection is intended to define the necessary geotechnical information and requirements for adequately designing the foundation system and accurately completing both stress and dynamic analyses.

N.2.6.1 Bore Holes

As a general guide, geotechnical bore holes are located under the middle of the intended compressor foundation length and width. When a number of adjacent compressor package foundations are required to be located in close proximity, the bore hole locations and numbers shown in Figure N.22 are recommended. Observed variations in terrain and soil quality may dictate additional bore holes to ensure that the soil properties are effectively characterized.

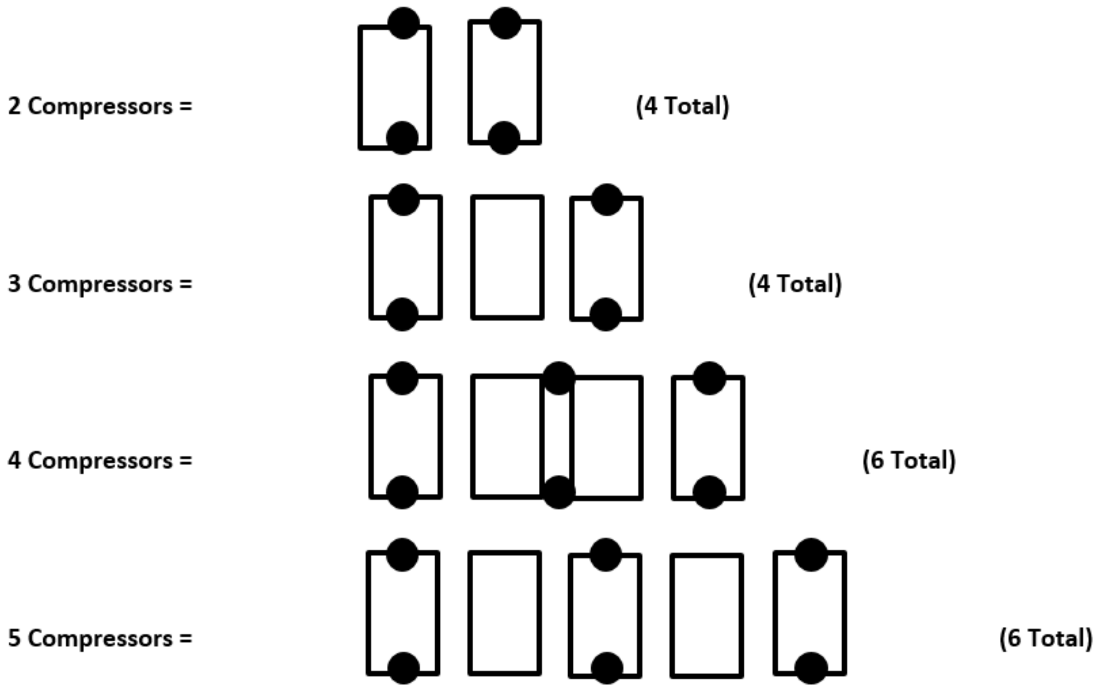


Figure N.22: Recommended bore hole pattern for multiple skids at a site.

N.2.6.2 Geotechnical Testing Scope

This subsection details the recommended geotechnical testing and report scope.

It is very important that the geotechnical report includes a site description including the definition of conditions and elevations. Site exploration procedures are to be explained. A boring location map that locates the intended compressor foundations, the bore holes, pipelines and other equipment is included and present elevations and any known site modifications are described.

The drill crew provides a field log of each boring. These logs include visual classifications of the materials encountered and the driller's interpretation of the soil conditions between samples. The reported boring logs include any modifications from laboratory observations of the samples. The boring logs indicate the following information at a maximum interval of every 1.5 m (5 ft) in depth and at approximate boundary lines between soil and rock types: surface elevation, soil stratification descriptions, depth, sample number, Unified Soil Classification System (USCS) soil description symbol, standard penetration test (SPT) hammer blows per ft., water content percent, dry unit weight per cubic ft., and unconfined strength (lb. per square ft.) measured with a calibrated hand penetrometer.

The written report specifically addresses surface soil, sub-surface soils and ground water. Recommendations are provided for site preparation, earthwork, evacuations, backfilling, slabs, foundations, drilled shafts, and construction considerations.

Laboratory testing of soil samples includes the following: moisture content, unit weight (specific gravity), Atterberg Limits (plasticity index), No. 200 sieve measurements, unconfined compression strength tests, and unconsolidated undrained tri-axial strength tests.

N.2.6.3 Geotechnical Soil Report

The purpose of the geotechnical study is to explore the subsurface soil conditions at the compressor station site, which will enable an evaluation of an acceptable support system and foundation design. It is very important that field soil samples are taken at locations directly under the intended compressor foundations as represented in Figure N.22. The samples include the following:

a) Field exploration with soil boring holes down to 15 m (50 ft) and providing description of major soils strata directly under the foundation(s).
b) Description of moisture content and any ground water tables.
c) Recommendations as to foundation type, site preparations, soil shrink-swell potential and typical settlement.

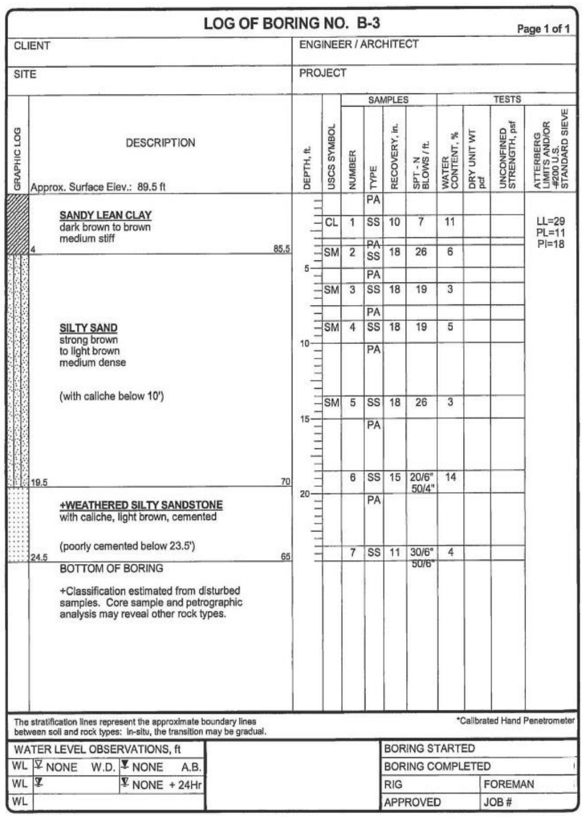


Figure N.23: Typical Boring Log

Soil properties are typically shown on the boring log at each location. A typical boring log is shown in Figure N.23. Many soil characteristics influence the dynamic response of a foundation-skid system. For each particular site, the most appropriate foundation support system has to be determined. The characteristics that will have the most influence on the selection of the supporting conditions are: soil type, water content, depth of water table (if any), depth to reach bedrock (if applicable), and estimated initial and consolidated settlement.

N.2.6.4 Crosshole Seismic Testing Scope

The crosshole seismic report includes a site description with the definition of conditions and elevations. Site exploration procedures are explained. A boring location map that locates the intended compressor foundations, the bore holes, pipelines and other equipment is included. Present elevations and any known site modifications are described.

An electromagnetic source is typically utilized to produce radially polarized compression wave energy and vertically polarized shear wave energy. The data is recorded on a PC or other data gathering device. Two 3-component tri-axial geophones are utilized as receivers. As shown in Figure N.24, the electromagnetic source and receivers are lowered to the same depth in the adjacent boreholes for each test and coupled to the casing with an air bladder. The tests are typically taken at 1.5 m (5 ft) intervals, with a starting depth of.13.7 m (45 ft) and an ending depth of 1.5 m (5 ft) below ground.

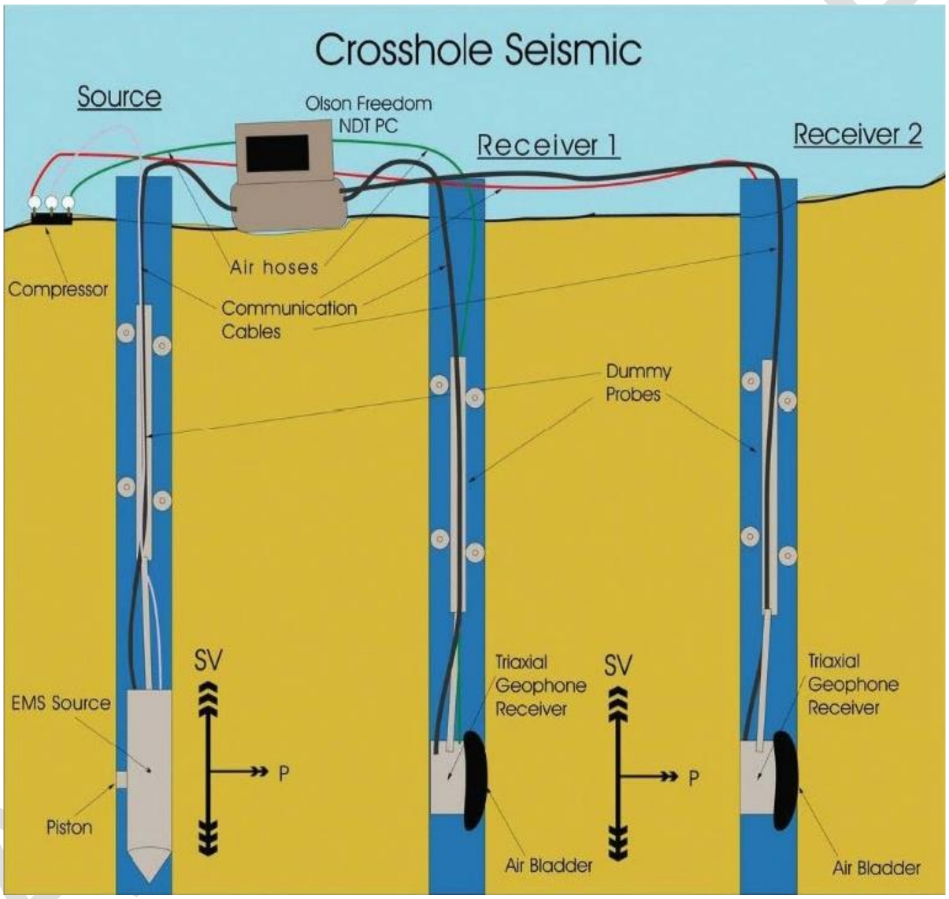


Figure N.24: Electromagnetic source and receivers in adjacent boreholes used to measure soil shear waves (SV) and compression waves (P).

The vertical component of each measurement is used to record shear waves (SV) and compression waves (P). The horizontal components are utilized to record the radially polarized compression wave energy. Testing is performed per ASTM Standard Nos. D4428 and D4428M.

It is very important that the seismic crew complete a field log of each boring. The boring logs indicate the following information at every 1.5 m (5 ft) interval of depth: compression wave velocity (ft/sec), shear wave velocity (ft/sec), constrain modulus (lb/ft^2 x 10^6), shear modulus (lb/ft^2 x 10^6), Young's modulus (lb/ft^2 x 10^6) and Poisson's ratio.

N.2.6.5 Crosshole Seismic Soils Report

A crosshole seismic study determines the actual dynamic properties of the soils that support the foundation. The two major items that are determined and reported are the shear modulus and the compression modulus. This information allows the calculation of soil stiffness, which enables accurate natural frequency and vibration analyses of the foundation-soil system.

The soil properties that support the foundation and pilings (if required) will be simulated as springs with damping in the vibration study. The spring stiffness is based on shear and compression modulus values, which vary with soil composition at different depths.

N.2.6.6 Soil Loading and Settlement

Soil has different layers with different compositions. Clay and sand are major types of soils that exist. Wet clay can expand and contract, causing settlement and uplift. Dry sand has no cohesion and low-to-moderate bearing capacity. Slightly moist mixtures of clay and sand have moderate-to-high load bearing capacity, good stiffness, and are desirable. Rock, shale and limestone are extremely dense (hard) and form good bed rock.

Each soil layer has different stiffness and damping properties. Moisture content has a large effect on soil properties and will vary with the seasons of the year. Proper soil analysis is required for each foundation. Soil stiffness is necessary for an accurate FEA dynamic analysis. A geotechnical report only offers a soil stiffness range from textbook information. This data typically is given as a large range and is not sufficiently accurate. As described previously, specialized geotechnical testing is required to measure the soil dynamic properties. A crosshole seismic analysis is required to obtain accurate soil stiffness values at each soil stratification. Suggested practice is to select a local geotechnical consultant, since they can be expected to have specialized knowledge regarding the local soil and climatic conditions.

It is important to map out the entire area that must support the foundation. Understanding the effects of layering is critical to foundation design. It is important that soil properties are obtained for each layer. The required depth of the soil analysis is influenced by the type of foundation. Generally, a depth equal to four times the foundation equivalent radius is adequate for shallow foundations, but best practice is to assess more depth to ensure the absence of an undesirable layer. Experienced, local geotechnical companies will usually be able to provide guidance in this regard.

The suggested practice is to assume that the actual design bearing capacity of the foundation soil is less than 1034 N/cm2 (1500 lb/ft^2). In no case is it advisable to assume more than 1379 N/cm^2 (2000 lb/ft^2). It is very important that foundation, pier or piling areas are designed so that the settlement of the foundation soils does not exceed 13 mm (0.50 in.), preferably no more than 10 mm (0.40 in.).

In order to generate long term settlement that is even across the entire foundation with the equipment installed, it is recommended that the center of gravity (COG) of the mounted equipment is near the COG of the reinforced concrete foundation block within the following tolerances: (1) longitudinal tolerance = 5% or 305 mm (12 in.) maximum and (2) transverse tolerance = 2.5% or 152 mm (6 in.) maximum.

N.2.7 Package Installation on Pad

As discussed previously, field gas compressor pads and foundations vary greatly. Reciprocating compressor packages can be designed and built for a variety of site installation types. Smaller horsepower packages can contain sufficient ballast that they do not require additional foundation mass and require little off skid support. Larger packages require site constructed foundations and may require support beyond the skid perimeter.

Factors affecting installation design include:

a) Size and type of the package
b) Transportation weight limits
c) Extent of shop disassembly and site re-assembly
d) Unbalanced forces and couples generated by the package
e) Length of time the package is expected to be at the site
f) Whether the package is expected to be used later at another location
g) Geographical location and site surface and subsurface conditions including seasonal variations due to rain and temperature

Mounting on a pad without a foundation requires that the package has sufficient self-contained mass to absorb the various forces and couples generated by the package to keep the vibration within acceptable limits. It is important that the site is flat, level, stable and drains well. It is vital that the underside of the package makes good contact with a stable base, be it soil, sand or gravel. If there are high spots, the package will vibrate more and will settle. As it settles, connecting pipe is stressed. Settling may not be even, which can lead to issues with liquid level controls.

Installation of the package on the foundation is typically accomplished several ways. If the project is short term, it may be possible to avoid grouting the package to the foundation mass. It is still imperative that there be good contact between the bottom of the skid and the foundation surface. There will be irregularities in both surfaces. If the contact is limited to high spots there will not be good energy transfer and the package will have higher vibration levels. A layer of deformable material of at least 13 mm (½ in.) thickness is needed between the skid and the foundation. The engineering of anchor bolts will have to consider the effects of this layer, as normally desirable pre-stress may not be achievable. Several rounds of re-tightening of anchor bolts may be necessary. It is important that jacking bolts are backed off, as leaving them loaded is akin to intentional high spots. Package skids often have a slight canoe shape. Grout compensates for this but a consistent thickness of deformable material will not. It may be necessary to add partial layers of the deformable material.

When using a concrete foundation, to ensure the compressor is properly set on the pad, and to allow for “waves” in the concrete, it is preferrable to grout the skid to the foundation. Cementitious grout may be used, but epoxy grout is stronger and will typically perform better and last longer. Best practice is to chip the top surface of the foundation to produce a bonding profile into the aggregate matrix. The as-poured surface is only a sand and cement matrix that is a weak link.

Anchor bolts with rolled threads are recommended and best practice is to make them as long as practicable. A welded or threaded bottom plate is preferred to a “J” or “L” bend which can pull out. The upper portion of the bolt has to be isolated from the concrete with a sleeve and then from the grout with a foam donut, so that a sustainable pre-stress stretch can be achieved. If the grout and/or concrete is attached to the full length of the bolt, the proper stretch cannot be achieved. If the bond is at the high stress area at the top of the bolt, it may gradually fail, allowing the bolt to stretch, become loose and require periodic re-tightening. Alternatively, the concrete may fail in a cone shape compromising the embedded length. A free stretch length of 10 to 12 diameters is typical.

Concrete, steel and grout have different thermal expansion rates. The concrete foundation, the steel skid and the grout are exposed differently to equipment temperature and changes in ambient temperature. As a result, the grout needs expansion gaps to prevent bond failure due to shear stress resulting from differential thermal growth.

Grouting a compressor package is a time critical operation. It requires planning, preparation and coordination. Remediation of a bad grout job is time consuming and very expensive. One method, “wet setting”, involves adjusting the leveling screws, lifting the package clear, filling the grout forms and then placing the package back on the anchor bolts before the grout sets. This is a method for experienced installers, not for novices.

The more common method is to place the package over the anchor bolts, adjusting the leveling screws, and then flow the grout under package. Head boxes and folding push poles facilitate getting the grout under all of the beams.

Access holes in deck plate or pour tubes in the pedestals can also ensure good coverage. Getting good grout contact under all the interior beams is imperative. The primary energy sources are the compressor and driver in the center of the package. Large voids in the grout under these areas will result in vibration. After the grout has set, the forms are removed and rough or sharp edges and corners are rounded to reduce the risk of being broken off. The leveling screws are then backed off or removed.

It is recommended that grouting is only done by experienced personnel. Depending on the duration of the project, grout can be a 12 sack-sand-cement mix, or epoxy. It is important to remember that upon removal of the compressor, the grout will have to be chipped out prior to shipment.

Regardless of the pad design, it is important that the entire field compressor package skid is adequately supported at all points. Figures N-25 shows an example where the end of the skid is not supported. Figure N.26 emphasizes the need to ensure that ends of the skid, as well as all other points, are well supported.

Figure N.25: End of skid not supported.

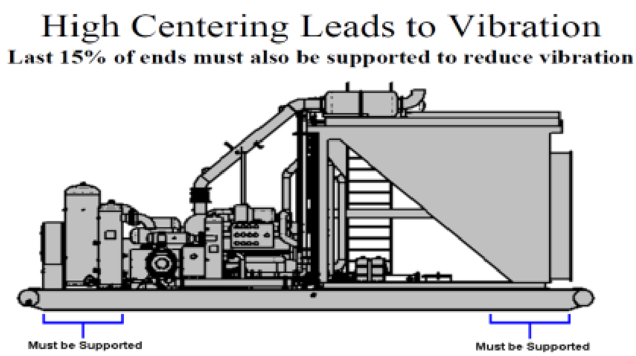


Figure N.26: Ends of skid must be supported.

As indicated in Annex N.2.5.4, screw piles are a cost-effective solution for many compressor applications. However, they do present a risk of vibration due to lack of mass. Like all foundations, screw piles require an engineered design for the specific compressor and location. Figure N.20 shows a gas compressor package mounted on screw piles. Another type of foundation, often called a swamp base, is shown in Figure N.27. This approach has been used for rental fleet packages in swampy soils without incurring the cost of installing a deep foundation or piles.

Figure N.27: Swamp base for rental fleet package set on swampy soil.

N.3 Building and Shelter Considerations

In addition to the requirements specified in Section 21, there several additional considerations when compressor packages are located within buildings or shelters.

When field compressors are enclosed, tight clearances and obstructions can pose safety issues. Safe access and egress require a clear path around the unit, both for routine service and in the event of an emergency. Providing an adequate number of emergency exits is important, especially meeting the requirements of all applicable regulations.

Compressor service and maintenance needs often necessitate a service truck and/or a crane. This requires that sufficient means of access is provided. Installing overhead doors with a concrete apron is a best practice.

Where portable cranes cannot access equipment inside buildings, it is very important that the buildings have monorail or bridge cranes with suitable capacity and clearance to handle the heaviest piece of removable equipment in the building.

Adequate ventilation is required for any compressor package installed in a building or enclosure. It is important that fresh air is consistently provided through an acceptable means and that toxic engine exhaust gases are completely delivered to the outside air at all times.

Avoid the storage of unnecessary combustible materials inside a compressor package enclosure. If necessary to locate them inside, it is important that compressor and engine lube oils and coolants are stored in proper containers, meeting applicable regulations, and located a safe distance from any ignition source.

For fully enclosed compressor packages, it is imperative that all vents are piped outside the enclosure. Since vent stacks are typically higher with long pipe lengths, they need to be securely braced so that they are not loosened or damaged by vibration or forces generated by vented gas. When delivering to atmosphere, vent stacks are to be of sufficient height to completely clear the roof of the building, without allowing natural air currents to blow gas back inside.

It is very important to ensure that the correct hazard classification for all electrical systems is applied, following NEC/NFPA 70E or similar applicable code for the jurisdiction. Fixed monitoring and alarm systems may be required for flammable gas and/or sour gas.

N.4 Cold Temperature Considerations

When normal ambient temperatures are below 4˚C (40˚F) at a field gas compressor location, there are numerous best practices that apply. It is important that these practices are considered in the design, fabrication, installation and operation of the compressor package.

a) Make oil feed lines NPS 2 or larger, heat traced and insulated to ensure continuous flow. In some cases, it is also necessary to heat trace and insulate oil tanks.
b) It is important that the lowest ambient temperature allowed, as well as the maximum ambient, are determined and clearly communicated. The compressor package and installation must be compatible with safe operation over the entire range of ambient temperatures, or provisions made for preventing start-up, limiting operation, or ceasing operation, as appropriate, when ambient conditions are outside the reasonable and safe operating range.

c) Without compromising safety, lay out the site design to minimize distances between the air system, lubrication and coolant supply systems, coolers, scrubbers, and other auxiliaries to the engine and compressor package.
d) Heat race off-skid drains to the waste fluids tank.
e) Make drain lines larger to ensure drainage, at least 1-½ times larger diameter than lines seeing normal ambient temperatures.
f) Make engine fuel gas pressure cuts away from the engine. Where this is impractical, the fuel gas line may be heat traced and insulated, both before and after the pressure regulator, to prevent the formation and collection of liquid in the fuel lines.
g) Make engine and compressor lube oil fill lines at least NPS 2 nominal pipe size for quick filling of crankcases.
h) Provide preheating systems, sized appropriately for system oil volume(s). In cold climates, make preheating systems automatically activated upon shut down and not turned off until package startup is achieved. In other applications, the preheating system can be controlled by the crankcase oil temperature, so that startup is not initiated until oil temperature has reached at least 16˚C (60˚F).
i) In some cases, jacket coolant heaters may be recommended, rather than oil heaters, for the unit to achieve a proper start.
j) Heat tape and insulate compressor lubricator box supply lines and oil supply tanks to ensure a continuous supply of oil to the lubricator pumps. If the lubricators are fed from the compressor crankcase, this requirement may not be necessary.
k) Program OEM specified engine and compressor coolant and lube oil temperature minimums into the control system to prevent premature loading of a cold unit. If OEM specifications are not provided, typical start-up permissives are: compressor oil temperature of at least 10˚C (50˚F) and engine oil temperature of at least 10˚C (50˚F). Typical load permissives are: compressor oil temperature of at least 35˚C (95˚F), engine oil temperature of at least 52˚C (125˚F), engine jacket water temperature of at least 74˚C (165˚F), and engine auxiliary water temperature of at least 49˚C (120˚F).
l) Size and design air inlet filters for colder ambient temperatures to prevent filter icing and snow ingestion.
m) If a package is installed in a building with air filters mounted outside, slope the intake air ducting downward from the engine to the filters to prevent any ice formation in the piping of an idle unit.
n) In cold climates, units requiring catalytic converters may require that the exhaust piping be insulated to keep the exhaust temperature high enough for the converter to achieve efficient conversion.
o) Avoid the use of PVC as a material in cold climates for crankcase ventilation systems due to brittleness.
p) Size engine air start systems based on the higher torque loads required for starting a cold engine with colder oil than normal applications. Likewise, the starting air system will likely require upgrading to a larger receiver capacity and larger diameter pipe to supply sufficient flow to the starter(s).
q) Adhere to engine inlet air temperatures that are consistent with permissible startup and operation per OEM guidelines. Cooler louver controls and coolant temperature regulation may have to be employed to regulate the post turbocharger air temperature supplied to the engine for combustion.
r) Provide cooler louvers with automatic temperature control to control coolant and gas temperatures. In extreme cold ambient temperatures, a cooler exhaust air recirculation system, or variable speed fan drive may also be required.
s) A thermodynamic review of the gas at the various operating conditions through the compression and cooling stages throughout the system is advisable when operating in cold ambient conditions. Where there is a risk of hydrate formation, coolers are generally supplied with a methanol injection port in the gas piping upstream of the cooler coils.
t) Design the coolers for use with an appropriate mixture of water and glycol specified for the minimum ambient temperature. A 50% glycol/water mixture is typical.
u) Provide hail guards on vertical discharge coolers.
v) Design temperatures below -29˚C (-20˚F) will require special materials and welding procedures.
w) Heat trace and insulate scrubber bridles and drains.
x) Use “No Freeze” type scrubber dump valves.

y) Design and install scrubber piping so that there are no low spots between the package scrubber and the compressor or between the station scrubber and the package.

z) Control panels may require heaters. Consideration for this is based on the control system's minimum operation temperature. Many PLC-based systems cannot handle subfreezing temperatures.

aa) Unless exempted by ASME code or other jurisdictional pressure vessel code, Charpy impact tests are recommended on all pressurized equipment operating at -29˚C to -46˚C (-20˚F to -50˚F). Grade B carbon steel may typically be used to a temperature of -104˚C (-155˚F) without Charpy testing, provided the maximum operating pressure does not exceed 0.3 times the rated system design pressure. Otherwise, use stainless steel when pressurized components are operating at, or exposed to, temperatures lower than -46˚C (-50˚F).

bb) Consider Arctic packages for colder climates, i.e., less than about 4˚C (40˚F) ambient. As shown in the examples in N.28 and N.29, these packages are based on a wider skid, which includes an enclosure around the complete package, in lieu of placing the unit in a dedicated building. These packages are self-contained, but care must be taken in the design to insure that routine maintenance can be performed and that the outer walls and roof can be removed when more extensive work is required. Additional guidelines and best practices for enclosed packages are provided in Annex I.

Figure N.28: Exterior view of integrated building on package skid.

Figure N.29: Interior view of integrated building on package skid.

Annex O
(Informative)

Package Loading, Shipping and Unloading Considerations

Annex O provides guidelines and tutorial information for compressor package loading, shipping and unloading. Section 14.3.4 of the GMRC *High-Speed Compressor Package Guideline For Field Gas Applications*[40] is acknowledged as the primary reference for this Annex.

When obtaining a bid for packaging a gas compressor, it is advisable to request itemization from the vendor for any costs that may be incurred after completion of the packages. Such charges may include disassembly, shipping covers or tarps, and cranes for loading/unloading. These charges are often not included in the vendor's bid unless requested.

The purchaser is normally responsible for providing shipping and site preparation suitable for delivery, off-loading and installation of the package. Annex N provides guidance for site selection and preparation.

Personnel safety is vital during compressor unit loading or unloading, and it is very important that all safe lifting, rigging and construction practices are reviewed and followed at all times. Normally, the purchaser has the responsibility arranging for and ensuring that safe lifting, rigging and construction practices are employed and adhered to. Many field gas compressor packages are smaller size units that are loaded and unloaded with a tail-board winch truck. Figure O.1 shows areas in front of the truck cab and all around the compressor that are danger zones during tail-board loading or unloading. A snapped winch line or unexpected movement of the load could result in a serious injury or fatality. It is very important that personnel stay clear of these areas during loading or unloading.

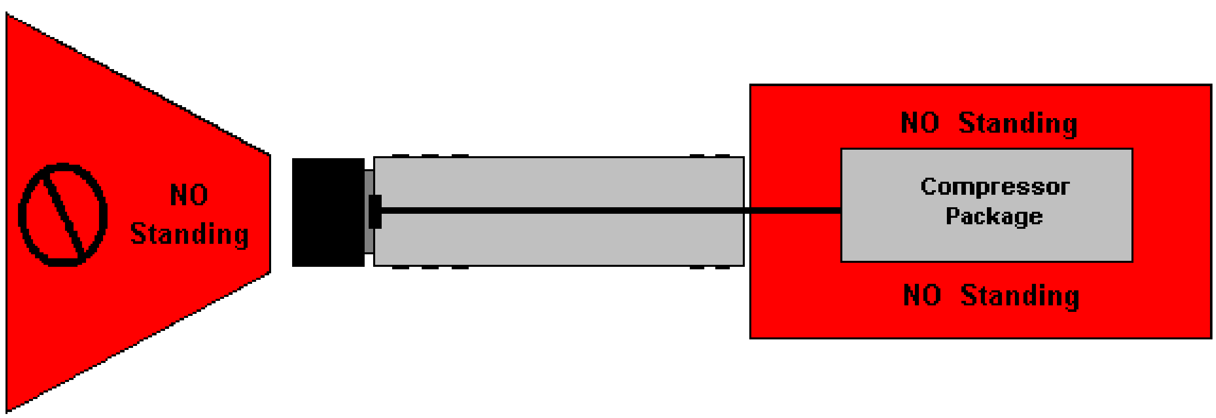


Figure O.1: Danger zones (shown in red) to be avoided by personnel during tail-board loading or unloading.

Prior to delivery to remote locations and/or new construction sites, it is recommended that the trucking company be requested to perform a route survey in order to confirm that the proposed trucks and trailers can navigate any challenges along the route. Examples include roads that are unpaved, rough, narrow, muddy, or snow-covered, or that have steep grades, sharp turns, narrow bridges, etc.

It is important to prepare the package equipment for shipment in a manner that prevents corrosion damage. This includes disassembly as needed for shipping and installation of watertight covers on all openings. It is normally the responsibility of the end user to specify any requirements for protecting the unit for long term or outdoor storage if it is not immediately destined for installation. This is a good subject for review and discussion by the purchaser and the packager as the package nears completion and before it is prepared for shipment. Construction delays can result in equipment sitting idle at the customer's site or stored elsewhere for longer than expected. Unless carefully protected, outdoor storage of equipment for more than several days can lead to equipment corrosion, both external and internal. Depending on the environment and the season, the corrosion risk may be high or lower.

In order to avoid improper identification, handling, storage, or installation of shipped-loose materials at the construction site, the following documentation is recommended with sufficient description: storage and installation procedures, material packing lists, drawings, bills of material, and labeling/tagging of the shipped-loose materials. It is also a good practice to make a photographic record of all shipped materials, including small shipped-loose items, prior to shipment.

It is important that all equipment and/or skids are outfitted with necessary lifting lugs to allow ease of unloading and installation in the field. It is further important for package and equipment vendor drawings to identify the equipment weights and location of lifting points so that the proper rigging (slings, spreader bars, etc.) and equipment for unloading can be arranged and applied at the construction site. For larger units, it is recommended practice to identify the correct lifting lugs on the compressor package and their load rating, as well as the center of gravity.

Coordination at the site for unloading is very important. This includes the project coordinator or their designee providing sufficient advance notice to construction crews so that necessary equipment and personnel will be ready when the compressor package arrives. Other considerations include providing only experienced and qualified personnel for inspecting the package upon receipt and unloading the package and associated equipment. It is important to verify the load ratings of the proposed rigging and lifting equipment and to inspect it for suitability and condition prior to unloading.

The field gas compressor access road and construction site may have to be specially compacted to sufficiently to support the incoming loads. Insufficient compaction of the soils could cause loads to shift and become unstable. For packages requiring multiple shipments and deliveries, it is recommended to communicate with the construction site the total number of trucks that will be arriving, clarify what equipment is on each truck, and coordinate the delivery sequence of each truck.

Once received and unloaded at the construction site, it is important that the shipped-loose parts are properly stored and protected from water damage until they are ready to be installed on the package. Smaller items are often shrink wrapped, boxed, or otherwise combined together and secured against being lost in transit. Recommended practice is to visually check all items received against packing lists or other documents.

If the package and other equipment have been unloaded and stored for a longer period of time than originally anticipated or intended, disassembly for inspection will be necessary before installing and operating begin. It is important to carefully inspect all equipment to confirm that it has not been contaminated or damaged by water, corrosion, inadequate protection or improper handling during the transportation, handling and storage processes.

To reduce contamination of open equipment, cleanliness has to be paramount throughout the process. This is always a challenge at a construction site, and it requires special effort.

Depending on the size of the unit, a field compressor package may be shipped as one complete unit, or it may be partially disassembled for shipment. Generally, larger packages have the cooler and ancillary items removed and shipped separately, while smaller packages are commonly shipped as one complete package. Smaller compressor packages can normally be loaded or unloaded in a single lift as shown in Figure O.2 or tail-boarded with a winch truck as shown in Figure O.3.

Figure O.2: Complete small compressor package being lifted by a single crane with spreaders.

Figure O.3: Complete small compressor package being loaded by tail-boarding.

As shown in Figures O.4 and O.5, larger compressor packages generally require partial disassembly, due to size and weight considerations. The level of field reassembly varies from package to package. Refer to Annex P for package installation and connection considerations.

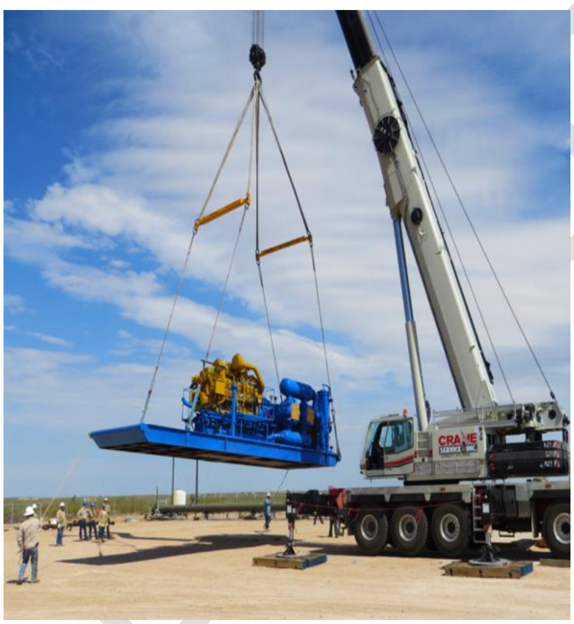


Figure O.4: Package being lifted at site with cooler removed.

Figure O.5: Separated engine being lifted onto its package already positioned onsite.

Annex P
(Informative)

Package Installation and Connection Considerations

Annex P provides guidelines and tutorial information for compressor package installation and site connection considerations. Section 14.3.5 of the GMRC *High-Speed Compressor Package Guideline For Field Gas Applications*[40] is acknowledged as the primary reference for this Annex.

In field gas applications, compressor packages may be owned or leased by end users. Although leasing or renting transfers much of the responsibility to the contract compression company, it is not unusual for an end user to eventually purchase the rental unit after a period of time. The recommendations and suggested practices discussed herein are intended to help packagers, operators and service providers to install and operate compressor packages, to the fullest extent that is practical and cost efficient, in the safest possible manner. However, it is important to note that some practices discussed in this Annex may not be suitable for all applications.

It is important that end users, rental fleet operators and compressor packagers understand and take responsibility for their roles in the safe installation and operation of the field gas compressor package, including those items affected by the site conditions. Unless specifically delegated by the end user/purchaser, most of the items in this subsection are essentially the responsibility of the end user/operator.

Many of the guidelines and best practices in this Annex can complement the content of Annex L for compressor package design and fabrication.

P.1 Safety Considerations

Guidelines and some typical best package design and installation practices related to compressor package safety, accessibility and maintainability are provided in Annex K. Guidelines and tutorial information on compressor package loading, shipping and unloading considerations, including safety, are provided in Annex O. Some additional package installation and connection safety considerations are emphasized herein.

Proper planning includes consideration of safe access and egress for a field gas compressor package. This includes ensuring a clear path of escape from any location around the unit in the event of an emergency. If the immediate area around the compressor is fenced or blocked by sounds walls, for example, suitable emergency exits are required.

It is also important to recognize that engines, compressors and other package components require service and repairs. As a result package installations need clearance for a service truck with a crane close to access the unit, for efficient and safe lifting of components.

P.1.1 Fire Protection

All field compressor installations, whether located inside buildings or enclosures or outdoors, are typically considered and clearly identified as “No Smoking” areas. Typically, unless suitable “Hot Work” practices are taken, no ignition sources are allowed anywhere around the unit. It is important to provide an adequate number of fire extinguishers on or near the unit, for any small, incipient stage fires that may occur. These are generally located at accessible locations, a safe distance away from likely sources of fire.

P.1.2 Trip Hazard Avoidance

One of the most common safety hazards for field gas compressor maintenance personnel is trip hazards. Figure P.1, obtained from an accident report for a Lost-Time injury, shows an example of unsafe surface piping, with several trip hazards. As much as possible, a clear, level path of travel is required in the immediate area all the way around the skid, free of holes or other hazards. Most trip hazards can be eliminated during the initial site set-up.

Figure P.1: Example of a trip hazard from piping on the surface around a skid.

Figure P.2: Example of clear access with minimal trip hazards around a compressor package.

Figure P.3: Example of gravel applied to reduce trip hazard of piping around the package.

Figure P.4: Example of brightly colored oil supply piping that is buried to avoid being trip hazards.

Figure P.2 is a much better example. Piping is painted a bright color, partially buried and routed to allow a clear path of travel and emergency escape around the entire compressor package. Figure P.3 shows the application of gravel under way, being installed to cover piping around a new compressor installation and provide a safe trip-free travel path. Figure P.4 shows oil supply tanks that are equipped with brightly painted pipe, with the horizontal runs installed subsurface to the package, eliminating the need for hoses and their associated trip hazards. A best practice is to install piping, tubing and hoses sub-surface, with elbows or bends installed close to the skid for the lines to connect. As-built P&IDs are recommended for all connection piping, especially buried lines. It is also important to locate ground rods out of the footpath, and for them to be capped or covered. A bright color paint, such as Safety Yellow, can be used to highlight any object that could present a trip hazard.

Best practice is for suction and discharge gas piping to be buried, supported, or otherwise adequately secured to prevent vibration. Note the use of a stanchion to support suction piping in Figure P.2. When bracing lines, the use of shims can ensure continuous contact and avoid vibration problems. One common practice is the use of concrete blocks, such as parking lot curbs, to support piping headers, although these can be trip hazards if left uncovered. An excellent solution is the use of pipe racks, where feasible. It is important to avoid locating piping or pipe racks in such a way that it presents a hazard and/or blocks access to the package where needed. Regardless of the chosen method, service truck or crane access and other safety requirements are key factors in planning compressor connection piping support.

P.1.3 Pressure Ratings and Pressure Relief Protection

It is always imperative to verify maximum working pressure (MAOP) ratings before installation of any piping, tubing and hoses. Threaded suction and discharge piping connections are discouraged as there can be an increased risk of stress and/or breakage due to vibration as the skid or foundation settles.

It is also imperative to ensure that an adequately sized pressure relief valve, or pressure safety valve (PSV), is present between the suction block valve and the compressor's first stage suction scrubber. Best practice is to size the PSV to protect the package from a failed suction control valve with maximum differential pressure or the maximum flow of the upstream gas source. The PSV is then set to relieve at a pressure equal to the lowest of the MAOPs of the suction scrubber, the first stage cylinder and any suction piping on or off the skid.

Many field compressor packages have a place on the scrubber to install this PSV, as shown on top of the scrubber in Figure P.5. For larger PSV sizes or when longer vent stacks are required, vibration may be a problem. Rather than mounting on the scrubber, best practice is to mount the PSV on a supported area of the skid with pipe from the process gas line to this point. In that case, it may have to be installed on the suction piping off skid, such as the pilot-operated PSV shown in Figure P.6. It is important that all PSVs are mounted and braced securely enough that the weight of the valve and associated piping, as well as the normal vibration and forces applied during operation, do not overstress the relief valve's threaded connection. Additional guidance for PSV application and mounting is provided in Annex L.4.

Figure P.5: PSV mounted on top of suction scrubber with short vent line to atmosphere.

Figure P.6: Pilot-operated PSV located off-skid on suction piping.

P.1.4 Energy Isolation Precautions

It is important to provide for energy isolation, commonly referred to as Lock Out/Tag Out, requirements when setting up the site. Lockable type valves are recommended for all valves used in piping connected to the compressor. For isolation of the gas in discharge piping, a full opening, lockable block valve is necessary downstream of the discharge check valve. For suction piping, a full opening, lockable block valve is necessary in the line downstream of the station separator or suction header, located as close to the compressor package as possible. These are necessary for safe isolation of the compressor when compressor or other pressure containing component maintenance is required.

It is important to consider and provide appropriate energy isolation provisions for other pressurized lines connected to the compressor package, including starting air or gas, engine fuel gas, scrubber drains, etc.

P.1.5 Safe Location of Vents

Most compressor packages have PSV vents, blow down vents, packing vents, and air or gas starter vent lines. To reduce the risk of fire and explosion hazards, it is necessary for these vent lines to be piped a safe distance or height away from the compressor unit, any potential ignition source, or any point that personnel may need to access when the equipment is in service. It is important to avoid locating vent discharges next to work platforms or other places where personnel routinely, or even occasionally, have to work. Air or gas starter gas vents are normally piped separately from other vent lines, with adequately sized lines, to ensure proper operation of the engine starter. Other vent lines and drain lines can normally be connected together into a common header sized to limit back-pressure.

P.1.6 Hydrogen Sulfide (H_2S) Exposure Avoidance

Hydrogen Sulfide (H_2S) is an extremely toxic, highly flammable, colorless, heavier-than-air gas, that is formed by the decomposition of organic animal and/or plant materials by bacteria, that can cause death at low concentrations (400 to 600 ppm). It is commonly found in many producing oil and gas formations. H_2S is often referred to as sour gas, poison gas, rotten egg gas, acid gas, sewer gas, and sulfur gas. Typically, if the concentration of H_2S is over 10 ppm, then special precautions are necessary in both the design and operation of the package. Compressor package design requirements for sour gas applications are specified in Section 18 and some additional guidance is provided in Annex H.

Compressor package operational considerations vary depending on the exact concentration, the installation's setting (i.e., enclosed vs. non-enclosed) and applicable government jurisdictional rules and regulations. Periodic gas sample analysis, leak testing and site surveys, radius-of-exposure calculations, warning signs, windsocks, fixed monitoring stations, portable monitors, emergency breathing-air equipment, and the use of the buddy system to ensure that no worker is on site alone are all basic H_2S safety practices that may be required to protect personnel at a field compressor site having H_2S levels above 10 ppm. ANSI/ASSP Standard Z390.1 provides detailed recommended training practices for protection of personnel from H_2S gas. Site and compressor operators are strongly encouraged to be familiar with and to follow site safety practices and, for additional guidance, to refer to ANSI Z390.1 and/or consult with hydrogen sulfide safety professionals when potential H_2S exposures could exceed 10 ppm.

P.2 Setting the Package

Annex N.2 explains the typical types of reciprocating compressor foundations and provides detailed guidance for selection and design of foundations. Proper setting of the compressor package on the foundation or supporting pad is a critical success factor for reliable operation with acceptable vibration. Annex N.2.7 provides additional guidance for setting compressor packages.

P.3 Inlet Separation

It is important that a separator or slug catcher is installed immediately upstream of the compressor package if any free liquids are contained in the inlet gas stream. The first stage scrubbers on compressor packages are designed as safety devices to protect the cylinder(s) from ingesting a small amount of condensation. They are not intended to be used as the primary method of liquid removal from the inlet gas stream, and they generally are not sized to handle large amounts of liquids.

P.4 Suction and Discharge Piping

A best practice to minimize the volume of gas released during blow-down is to install a full opening block valve upstream of the compressor as close to the compressor as possible. The suction block valve is also required to isolate the package for maintenance as discussed in Annex P.1.4.

It is also important to have a suction pressure control valve upstream of the compressor package if the pressure can exceed the rated suction pressure of the compressor package.

Downstream of the aftercooler discharge, a piston type check valve is recommended, located as close as possible to the cooler. Flapper type check valves are not recommended in reciprocating compressor gas streams as they can be prone to pulsation-induced vibration failure. As discussed in Annex P.1.4, a full opening block valve is required in the line downstream of the check valve to isolate the compressor package for maintenance.

It is important to properly size the process gas piping to ensure adequate suction pressure and volume into the compressor and to provide minimum pressure drop through the discharge line into the pipeline. Best practice is to bury, support or adequately secure gas piping to prevent vibration. If metering equipment is present, it is important that it is located far enough from the compressor to minimize any effects of pulsation and vibration. This can often be analyzed as part of the pulsation study for the compressor station.

P.5 Starting Bypass Line

The starting of the compressor typically requires the use of a starting bypass line which connects the discharge piping back to the first stage suction. The starting bypass is sized to allow the compressor to be started with minimal load on the machine. Without a starting bypass, or alternately, the use of suction valve unloaders on the compressor cylinders, the starting load typically has to be reduced by blowing down the entire package to atmospheric pressure, which results in released and lost gas from the system. Many packages have a starting bypass designed into the package, as pointed out by the arrow in the example in Figure P.7. If a starting bypass is not included on the compressor package, and there is no other means of reducing the starting load, it is likely that a starting bypass will be required in the off-skid piping. Figure P.8 shows a starting bypass line on a package as pointed out by the arrow, with added blind flanges that could be used for a larger recycle line added later, if needed. In both cases, the starting bypass has to be located inside of the suction and discharge block valves. Since the starting bypass lines are typically small, as shown in Figure P.7, and they often are tapped into the discharge ahead of the cooler, they are only suitable for operation during startup prior to significant load being applied to the compressor.

Figure P.7: Small on-skid startup bypass line between compressor discharge and suction.

Figure P.8: On-skid startup bypass with blind flanges for later addition of a larger recycle line.

P.6 Suction Make-Up (Recycle Line)

Every compressor package has minimum and maximum suction pressure limits. If the suction pressure drops below the minimum, a low suction pressure switch will typically shut down the compressor to avoid damage to the unit. A properly installed suction make-up/recycle valve can alleviate this problem by recirculating a portion of the discharge gas volume, "recycling" the gas back to suction to maintain the suction pressure above the minimum limit. A suction make-up system, shown in Figure P.9 with an on-skid recycle valve noted by the arrow, is recommended for larger horsepower units, compressors installed in a booster station, or any unit that is in a critical application. A recycle system can also be used to recirculate discharge gas to limit the discharge pressure. Such systems are also sometimes used to reduce the overall package pressure differential to prevent exceeding the rated compressor rod load. Continuous recycle systems have to be connected downstream of the gas cooler to prevent overheating that would result if hot discharge gas were continually introduced into the compressor suction.

Some compressor stations may have recycle systems installed for the entire station or between the station suction and discharge headers as shown in Figure P.10, which is a recycle system for two screw compressor packages at a booster station. The recycle valve is highlighted by the circle. These types of systems can serve multiple compressors at a station rather than having individual valves for each compressor package. It should be emphasized that although recycle systems are important for helping compressors handle upsets or to avoid having to shut down due to low suction pressure, recycling of gas is a very inefficient mode of operation.

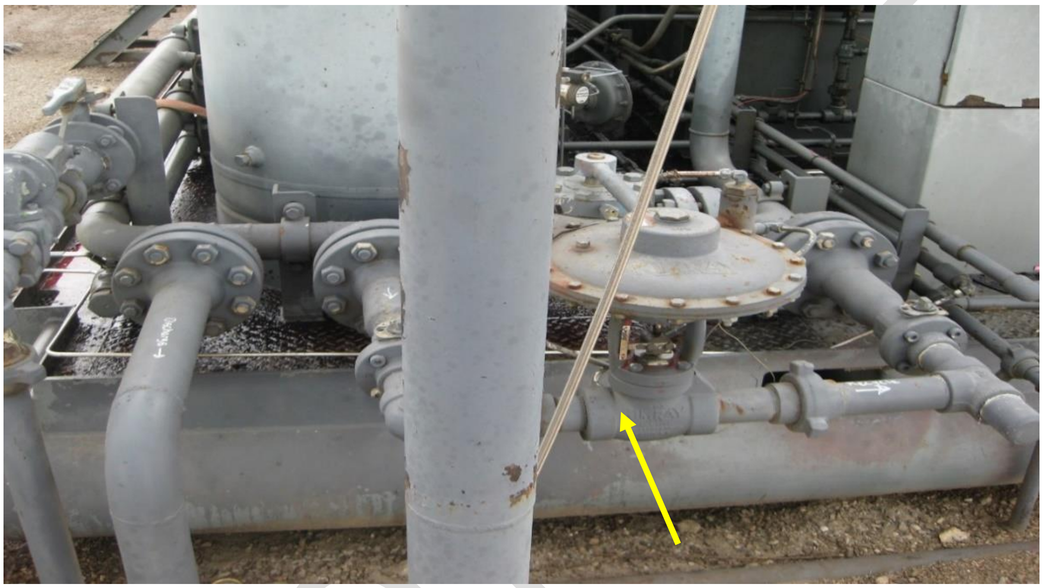


Figure P.9: Control valve for an on-skid compressor recycle system.

Figure P.10: Recycle system connecting suction and discharge headers at a field gas compressor station.

P.7 Starting and Fuel Gas Supplies

If the compressor is driven by a natural gas engine, the engine will require a fuel supply with regulated pressure. A fuel supply pressure of 345 kPa (50 psig) is common for many reciprocating gas engines, however the compressor packager normally provides precise specifications for fuel flow and pressure. In addition to fuel supply, many packages use a gas starter. The supply pressure for gas starters may be as high as 1034 kPa (150 psig). Clean starting gas and fuel gas are critical for reliable operation. Some packages have a single point supply for both starting gas and fuel gas. On these packages, the fuel is regulated down to a lower pressure as part of the skid piping, as shown by the circle in the example in Figure P.11.

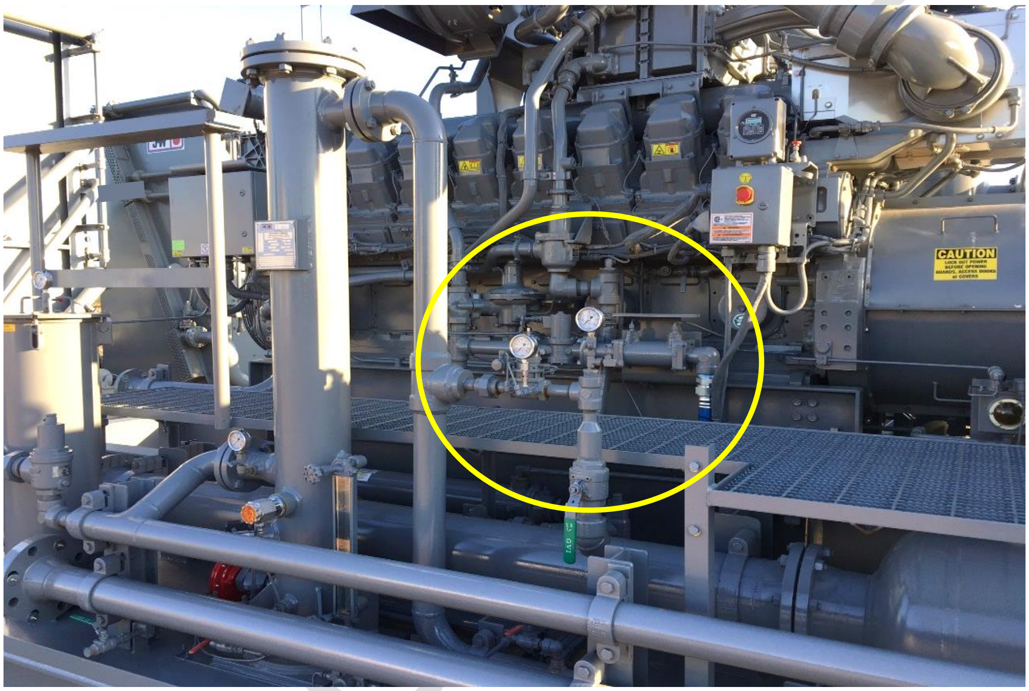


Figure P.11: Example showing on-skid regulation of engine fuel and starting gas.

P.8 Ancillary Equipment and Fluids

As explained in Annexes N.1.5 and N.1.6, it is very important to take safety precautions when locating the compressor on a field location with ancillary production equipment. For example, dehydrators and flare stacks are potential ignition and/or fire sources. Although general rules may not be adequate due to the uniqueness of each site, one recommended practice is to locate the compressor package at least 7.6 m to 15.2 m (25 ft to 50 ft) away from such ancillary equipment, taking into account the site layout and other considerations. Prevailing wind direction, as well as heights and gas density, are important considerations for compressor vents when ignition sources are present at the location.

Containers of flammable and combustible liquids, such as methanol, glycol and lube oil, can contribute to a compressor package fire and spread it quickly. It is important that these are located a safe distance away from the unit or separated by a fire-resistant barrier.

An overhead lube oil supply tank is required with most compressor units. Best practice is to connect the supply tank with NPS ¾ or larger rigid pipe and set it far enough away from the package so that it will not interfere with servicing the unit. For colder ambient applications, Annex N.4 provides additional guidance.

If the compressor package arrives without coolant in the system, the initial fill is typically made with water which allows any leaks to be repaired without wasting expensive coolants. As soon as possible after initial start-up, the water is drained and replaced with a commonly available premixed antifreeze/glycol solution of the specified concentration for the application.

P.9 Piping Cleanliness

Prior to final installation, it is very important that all on- and off-skid piping is checked to verify that it is free of internal foreign matter such as sand, rust, mill scale, metal chips, weld spatter, rags, grease and paint. Proper cleaning procedures used with appropriate cleaners, acids, and/or mechanical cleaning are important for meeting the cleanliness requirements of the packager's and major component manufacturers' specifications.

Even with the best efforts at cleaning, construction debris may still be present in the piping upstream of the package. Therefore, before start-up, it is important to install inlet cone or basket type debris strainers with 150 micron (100 mesh per in.)(screen and perforated metallic backing (aka witch's hats) in a pipe spool upstream of the first stage scrubber, as shown in Figure P.12. Installing debris screens in suction bottle outlet nozzles is also a very good practice for catching any welding debris or sand inside the suction bottle.

Figure P.12: Witches hat debris screen installed in upstream side of scrubber.

Figure P.13: Assembly of these misaligned flanges will lead to piping strain.

It is very important to monitor the differential pressure across inlet debris strainers and to clean them before the differential pressure approaches a level that would collapse the screen. High differential pressure alarm or shutdown switches can be used to protect against screen collapse. It is important that start-up screens only be used temporarily during commissioning, and it is recommended that the screens be removed as soon as they are no longer collecting debris, to prevent future risks of screen disintegration.

P.10 Piping Alignment and Support

To avoid excessive strain on flanges and connected piping, it is important that they be well aligned before assembly. Excessive gaps, angular misalignment or linear misalignment, as shown in Figure P.13, will lead to excessive piping strain when the flanges are forced into alignment for assembly. Using a pry bar to align flange bolt holes, or "drawing down" to pull piping into position, is unacceptable. Before torquing, it is important to be able to thread all the flange bolts into holes by hand with no flange contact. A maximum flange gap of nominally 0.5 mm (0.020 in.) before applying any bolt torque is a best practice for avoiding excessive piping strain.

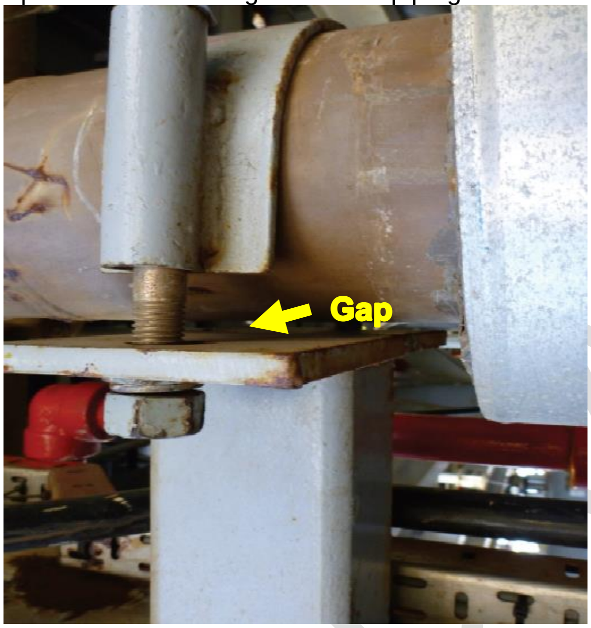


Figure P.14: Shims are needed to avoid gaps like this between the piping and the support.

It is important that piping is supported and secured in accordance with good engineering practice. Best practice is for all piping NPS 2 and larger to be mounted using band clamps or pipe straps on I-beam supports. The use of U-bolt style clamps for process piping, except under NPS 2, is not advisable, as they can cause damage and wear to the piping coating and the piping wall if there is piping movement from expansion or vibration. Best practice is to install vibration absorbing material between clamps and pipe to prevent paint damage, fretting and corrosion of the pipe. Another best practice is to attach clamps directly to a structural member of the skid or to directly support them by a structural member that is securely attached to the skid, the foundation or special piers as shown in the example in Figure P.15. Supporting piping from the skid deck plate or with uni-strut clamps is not sufficient. It is important that the piping rests securely on shims on the support. Figure P.14 is an example of a poor installation that has an unshimmed gap between the piping and the support, as well as a clamp with marginal thread engagement of the nuts on the bolts. Proper installation requires that shims are installed between the support and the bottom of the pipe as shown in the example in Figure P.15. It is important that clamps are not used to pull down the pipe to close large gaps. Figure P.16 provides best practice examples for pipe clamps.

Figure P.15: Example of a shim under a pipe at a clamping location.

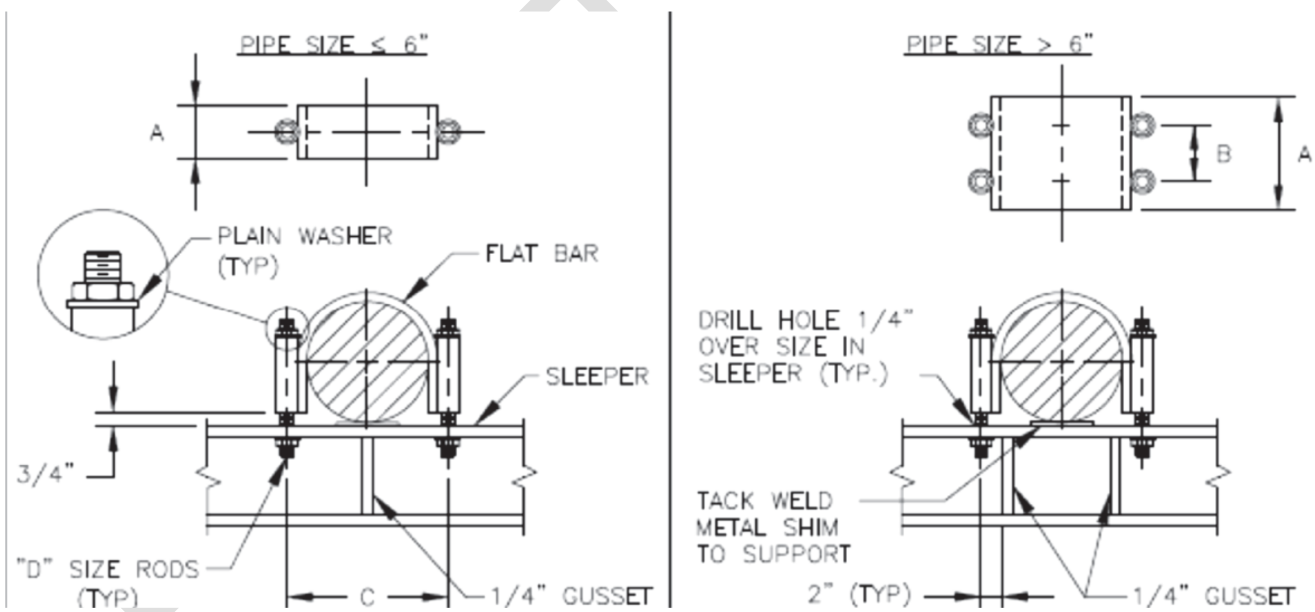


Figure P.16: Best practice pipe clamp examples.

P.11 Vent Lines

Proper routing and support of vent lines during installation is critical to proper and safe operation of the compressor package. Well intended vent line routings can become problematic when the execution inhibits proper function. It is important to always follow the equipment manufacturer's recommendations for venting. Several best practices follow.

a) Provide a blow-down vent that can safely and completely relieve the pressure from the entire system for maintenance purposes. Many blow-down systems are actuated automatically in the event of an emergency. Increasingly, vented gas is captured and recompressed into another system in order to avoid losing the gas to atmosphere.
b) Avoid tying different vent systems together. Different pressure states can lead to unintended back flows that can have damaging consequences.
c) An alternative to the preceding item above is to provide separate low-pressure and high-pressure vent headers. If combining multiple vent lines from different pressure sources, a back-flow prevention check valve is recommended for any vent or blow-down line connected to a common vent or flare header to prevent damage to the lower pressure component.
d) Be cautious of the potential for releasing flammable gases locally around the package. It is important to pipe all vents to a safe atmosphere, flare or capture system.
e) Properly size vents and install them to carry a continuous upward slope with no inversions that might collect liquids, pulling from all high points in the system. Avoid any low point liquid traps in vent lines, as these will restrict flow and create back-pressure in the vent line.
f) Crankcase vents, when installed, may have a slight downward slope to a liquid dropout leg. For routings without the dropout leg, hoses are run with a continuous upward slope from the crankcase. If crankcase breathers are relocated off the equipment, it is important not to reduce the total number of OEM supplied breathers. Consult the manufacturer for guidance.
g) If oil mist eliminators are used on engine crankcase or other vents, closely follow the manufacturer's specifications for installation of piping upstream and downstream of the mist eliminator.
h) Install a horizontal tee, flapper-type rain cap or other means of protection at the top of each vent to mitigate rain or snow from entering, collecting (and potentially freezing) and blocking the vent line.
i) Venting the cooling system is critical to avoid issues with trapped air/vapors that can lead to engine overheating or pump or system internal cavitation.
j) It is important to adequately support vent lines to avoid vibration, using flex connections where appropriate.
k) Starting and pre-lube systems also require venting in most cases. Review and follow all manufacturer's recommendations/guidelines for best function.
l) Direct gas starter vents to a safe area, and direct both gas and air starter vents away from personnel areas.
m) Conduct a final review of the installation of all vent systems. Check again that there is no potential for venting gas into the immediate area around the package and that high-pressure vents and exhausts are not tied into low-pressure vent systems.

P.12 Environmental Rails and Blow Cases

Most compressor packages are equipped with "environmental" or "ecology" rails that are designed to contain any fluids on the skid, so that they don't leak onto the ground. Collected fluids are drained off through openings in the skid. Since environmental regulations require all waste fluids be properly disposed of, it is necessary to connect these skid drains to a system for capturing and removing the fluids. This is especially critical in environmentally sensitive areas, such as near a stream, wetland or body of water. A common solution includes the use of a small "blow case" tank. Figure P.17 shows a commercially available blow tank or case, and Figure P.18 shows one mounted near a compressor package in the field. These blow cases can either be manual-type, which requires the operator to physically open and close valves to pressurize the fluid with a small amount of gas taken from the location, and empty the fluids out, or automatic-type, which uses a float and valve system to accomplish the same thing. Waste fluids are typically sent to a larger, above-ground storage tank for temporary storage until collected by a waste disposal truck. Because liquids drain from the compressor skid to the blow case via gravity, in order to work correctly, the tank has to be lower than the top of the skid. Trash and debris can collect on the skid and clog up the drains into the blow tank or interfere with the operation of the blow tank. Therefore, routine maintenance is important to clean screens or drain openings to prevent clogging.

Figure P.17: Example of a commercially available blow case.

Figure P.18: Off-skid blow case used for collecting liquids from the compressor package.

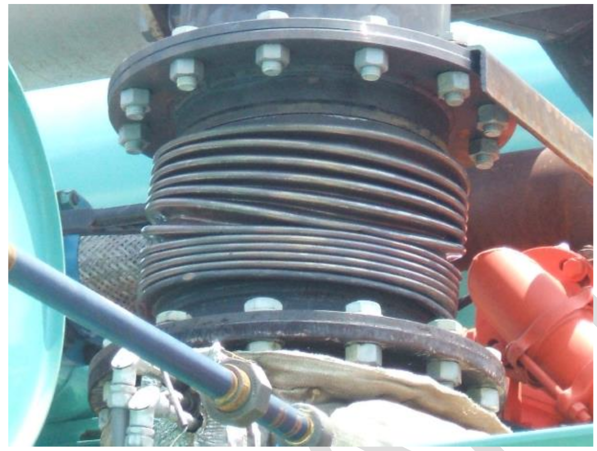
Safety concerns for blow cases can include being a trip hazard if not well-located and a source of gas that must be safely vented, especially for enclosed units. If a package does not contain ecology rails, other options include concrete pads with grating-covered trenches along the side, earthen trenches, or containment walls along the sides of the compressor sealed with an impermeable coating or liner. However, the presence of open earthen trenches or walls can present significant trip hazards as well as interfering with access to the machine with a service truck or crane.

P.13 Inlet and Exhaust Connections

Many small compressor packages are factory built with the intake and exhaust systems preassembled on the package. Medium and large compressor packages require assembly at site, and many require integration with enclosures and buildings. It is important that the design of the intake and exhaust systems are integrated with any enclosure or building and that all installations follow the engine manufacturer's specifications for proper design of the supports to relieve loading and alignment stresses from engine mounted intake and exhaust connections. When the exhaust system is to be mounted off of the engine, it is important to seek and apply the engine manufacturer's guidance to ensure that the installation adheres to their basic requirements for providing adequate support, clearance and vibration resistance. Figures P.19 and P.20 show examples of damage that can occur to horizontal and vertical flexible elements, respectively, in exhaust lines when the lines are not adequate supported and aligned.

On air intakes for larger engines, a best practice is to use dual clamps on each end of air inlet rubber boots to reduce the risk of boot slippage and air leaks that increase the need for maintenance. On larger packages, a best practice is to locate heavy duty air cleaners where they can be accessed from grade level for maintenance.

P.19: Horizontal flexible exhaust line element with excessive misalignment and loading.



P.20: Vertical flexible exhaust line element with damage from excessive loading.

Annex Q
(Informative)

Package Start-Up and Commissioning Considerations

This Annex Q provides guidelines and tutorial information for start-up and commissioning of a high-speed field gas compressor package. Section 14.3.8 of the GMRC *High-Speed Compressor Package Guideline For Field Gas Applications*[40] is acknowledged as the primary reference for this Annex.

The process of commissioning has to be performed in a safe and efficient manner, as well as within a defined timeframe and budget. Commissioning is composed of pre-commissioning preparation, planning, and procedures, followed by the actual implementation of commissioning which includes inspection, testing, start-up and handover. This is followed by a close out period where documents, mark-ups, instruction, and a final hand off to the operators are accomplished.

Package commissioning can generally be looked at as a procedure that involves flushing and cleaning, assessing readiness and completeness of systems along with their calibration and adjustment, establishing protocols for starting, shutdown, and emergency shutdown, and instrument/control system checks to confirm alarms and trips, and confirming that the package operates safely and properly.

Q.1 Pre-commissioning

Pre-commissioning is a time to plan the commissioning of the package and to accumulate all the drawings, P&IDs, vendor commissioning documents, industry procedures, and other reference material that will be necessary to do the commissioning in a comprehensive, safe and efficient manner. It is the proper time to schedule personnel, third party contractors, and engine and compressor vendors that will be involved in performing the commissioning and start-up. It is also the time to check that start-up spare parts have been ordered and staged, and to address any deficiencies in readiness.

Q.2 Commissioning Pre-start Checks

Inspection is very important and is the first phase of commissioning a package. Even if a package was inspected and tested in the packager's plant, damage and changes may occur as the package is loaded, transported, unloaded, installed and connected at the site of use. Using the drawings and P&IDs, check the package layout for accuracy and completeness. Check that the foundation, bolting and grouting (where applicable) are installed per specifications. Check all pipe runs and vents. Check all conduit runs. Check working pressures on vessels. Check control panel connections and operation. Carefully verify that everything is wired and piped per design drawings and the P&IDs, that the design is logical and consistent with the compression specification, and that everything has been completed and connected. Carefully verify that the station systems for oil makeup, coolant makeup, starting and instrument air, drainage, engine inlet air, engine exhaust, fuel gas, venting, and power are connected and operational.

The use of written checklists during commissioning procedures cannot be over-emphasized. These are critically important tools. Most manufacturers will not honor warranty claims if proper commissioning checklists were not followed and documented prior to start-up. Further guidance is provided in following Annexes Q.2.1 through Q.2.11.

After all the inspections and checks have been completed and readiness has been verified, then the operational phase of the compressor package commissioning may proceed.

Q.2.1 Mounting and Alignment Pre-Start Checks

The following minimum mounting and alignment checks are recommended best practices.

a) Foundation has been installed per specifications.
b) All foundation bolts are pulled down and properly torqued for the skid and any off-skid components.
c) Inspection for soft foot has been completed, and if found, has been corrected with appropriate realignment and/or shimming.
d) All equipment mounting and piping bolted connections have been aligned and torqued per specifications.
e) Engine and compressor have been leveled per manufacturers' specifications.
f) Engine and compressor crankshaft web deflections have been measured and meet manufacturers' requirements.
g) Cold alignment of engine or motor and compressor has been completed per manufacturers' specifications.
h) Completion of any other checks required by the engine, motor or compressor manufacturer.

Q.2.2 Cooler and Cooling System Pre-Start Checks

The following minimum cooling system checks are recommended best practices.

a) Expansion tank is located at the required height above the water pump.
b) Expansion tank includes a pressure cap per the engine manufacturer's specifications.
c) Vent lines slope continuously upward and enter expansion tank below the coolant level.
d) Fire-safe valves are installed at locations specified on the drawings.
e) Piping is properly supported so as not to exert additional forces on engine connections.
f) Cooler louvers, actuators, and linkages are installed and operation tested.
g) Cooler fan belts are installed, aligned, and adjusted for proper tension.
h) Cooler fan belt guards are installed.
i) Cooler bearings are lubricated and grease lines are full of grease.
j) Cooler fan blade pitch is properly set and blade attachments are tight.
k) Cooler hold down bolts are properly torqued.
l) Commissioning filters are installed in the jacket water and auxiliary water circuits for initial start-up.
m) Cooling system piping is cleaned and is ready for operation.
n) Cooling system is filled with specified coolant and purged of air.
o) Completion of any other checks required by the engine, motor or compressor manufacturer.

Q.2.3 Lubrication System Pre-Start Checks

The following minimum lubrication system checks are recommended best practices.

a) Oil make-up tank(s) and oil piping have been cleaned.
b) Fire-safe valves are installed at locations specified on the drawings.
c) Piping is properly supported so as not to exert additional forces on engine connections.
d) Engine and compressor sumps and make-up tank(s) have been filled to specified levels with oil(s) that meet packager and manufacturers' specifications.
e) New (clean) oil filters have been installed.
f) Compressor distance piece and packing drain pots have been filled to operating levels.
g) Completion of any other checks required by the engine, motor or compressor manufacturer.

Q.2.4 Engine Air Intake System Pre-Start Checks

The following minimum engine air intake system checks are recommended best practices.

a) Intake air ducting is properly supported so as not to exert additional forces on engine connections.
b) Air intake ducting has been properly cleaned.
c) Temporary shipping covers have been removed.
d) Air cleaner covers are securely in place.

e) Completion of any other checks required by the engine manufacturer.

Q.2.5 Engine Exhaust System Pre-Start Checks

The following minimum engine exhaust system checks are recommended best practices.

a) Exhaust system is supported so that no external forces are applied to the engine exhaust connection.
b) System is mounted so that thermal growth is directed away from the engine.
c) System is mounted without lateral deformation of bellows.
d) Catalysts are installed and correctly mounted per specifications.
e) Drains are installed at lowest points.
f) Completion of any other checks required by the engine or motor manufacturer.

Q.2.6 Engine Fuel System Pre-Start Checks

The following minimum engine fuel system checks are recommended best practices.

a) Upstream fuel supply piping has been safely purged of debris and water prior to start-up.
b) On-skid fuel piping has been cleaned.
c) Where applicable, new (clean) fuel filters have been installed.
d) Piping and system components are properly supported so as not to exert additional forces on engine connections.
e) Completion of any other checks required by the engine manufacturer.

Q.2.7 Engine Starting System Pre-Start Checks

The following minimum engine starting system checks are recommended best practices.

a) Upstream starting air or gas piping has been safely purged of debris and water prior to start-up.
b) Starting piping has been cleaned.
c) Piping and system components are properly supported so as not to exert forces on engine connections.
d) Starting vents and pneumatic solenoid vents are piped to a safe location.
e) Completion of any other checks required by the engine manufacturer.

Q.2.8 Electrical Systems Pre-Start Checks

The following minimum electrical system checks are recommended best practices.

a) Wiring conforms with local codes and safety requirements.
b) Grounds are connected as specified in the drawings.
c) Continuity has been verified on all circuits.
d) All connections are tight and secure.
e) DC power supply polarity has been confirmed.
f) Pre-lube timers have been set per specifications.
g) Completion of any other checks required by the engine, motor or compressor manufacturer.

Q.2.9 Engine Pre-Start Checks and Commissioning

It is always important to utilize the engine manufacturer's commissioning checklist and procedure as a minimum. This typically includes, but may not be limited to, the following steps and types of information.

a) Date, site name, unit number, engine make, model and serial number.
b) Work order number, service technician's name and company.
c) Engine rating.

d) Engine cold alignment, deflection, and end play.
e) Crankshaft web deflection.
f) Flywheel and coupling bolts torqued.
g) Engine end clearance measurements.
h) Engine anchor bolts set, shimmed, and torqued.
i) Check for tightness of all jack shaft and idler shaft pillow block bearings.
j) Belt alignment.
k) Check ignition timing based on gas analysis information.
l) Oil filters and air filters installed.
m) Lube oil level is correct. Check engine crankcase oil level controller for proper control and operation.
n) All engine end devices are connected per panel tags and operational.
o) Thermostats are all installed and oriented in the correct direction.
p) OEM approved coolant installed, and air purged from system.
q) Engine set points and shutdowns have been set and checked.
r) Fuel gas pressure has been set and start air pressure has been set.
s) Engine configuration and monitoring settings validated.
t) Check pre-lube system and circulate oil for a minimum of 10 minutes.
u) Record engine data during start up run (pressures, temperatures, speed).
v) Adjust and record engine valve settings.
w) Perform a hot alignment.
x) Check engine coolant strainers and remove after system is clean.
y) Have OEM's warranty forms completed and submitted.
z) Perform an emission test and review results.
aa) Engine Records. An engine records checklist normally includes:
    1) Separable engine and compressor alignment (hot and cold).
    2) Start-up checklist (pre start and post start).
    3) Running data readings for first 48 hours.
    4) Valve adjustment records.
    5) Documentation check list.

Most packagers and engine manufacturers provide checklists for use during commissioning. If checklists are not available from those sources, Appendix A-14 of the GMRC *High-Speed Compressor Package Guideline For Field Gas Applications*[40] provides comprehensive checklists that can be used.

Q.2.10 Compressor Pre-Start Checks and Commissioning

It is always important to utilize the compressor manufacturer's commissioning checklist and procedure as a minimum. This typically includes, but may not be limited to, the following steps and types of information.
a) Date, site name, unit number, compressor make, model and serial number.
b) Work order number, service technician's name and company.
c) Compressor rating and cylinder sizes.
d) Compressor cold alignment, deflection, endplay.
e) Compressor anchor bolts set, shimmed, and torqued.
f) Check compressor for soft foot. If over .002 in. (0.05 mm) pulldown, correct with appropriate realignment and/or shimming.
g) Crankshaft web deflection.
h) Flywheel and coupling bolts torqued.
i) Record compressor piston end clearance measurements and set to OEM requirements.
j) Record piston rod run out and correct to OEM specifications if necessary.
k) Check data book lube sheet for proper lube rates and correct as necessary.
l) Verify cylinder and packing lube lines are clean and flow.
m) Purge air from all lubricator lines and verify oil flow at the points of connection to the compressor.

n) Check compressor crankcase oil level controller for proper control, operation, and oil level.
o) Oil filters installed.
p) All compressor end devices are connected per panel tags and operational.
q) Coolant system for packings and cylinders, if included, is connected and operable.
r) Compressor frame and cylinder set points and shutdowns have been set and checked.
s) Check pre-lube system and circulate oil for a minimum of 10 minutes.
t) Record compressor data during start up run (pressures, temperatures, speed).
u) Perform a hot alignment.
v) Have OEM's warranty forms completed and submitted.
w) A compressor records and checklist normally includes:
    1) Separable compressor alignment (hot and cold).
    2) Start-up checklist (pre-start and post-start).
    3) Running data readings for 48 hours.
    4) Documentation checklist (compressor).

Most packagers and compressor manufacturers provide checklists for use during commissioning. If checklists are not available from those sources, Appendix A-14 of the GMRC *High-Speed Compressor Package Guideline For Field Gas Applications*[40] provides comprehensive checklists that can be used.

Q.2.11 Other Package Component Pre-Start Checks and Commissioning

As a minimum, it is always important to utilize the individual component manufacturers' commissioning checklists and procedures for other on-package items such as coolers, control panels, motors, pumps, valves, etc. This typically includes, but may not be limited to, the following steps and types of information.

a) Any long-term preservation has been removed.
b) All temporary plugs and covers have been removed.
c) Pressure safety valves are installed and set as specified.
d) Pressure safety valve vent lines are supported and directed to safe locations away from potential ignition sources and areas where operating and maintenance personnel might be present.
e) Temporary start-up screens or debris strainers are installed in process gas piping upstream of scrubbers and/or suction bottles on all stages. Monitor differential pressure across screens during commissioning to avoid excessive blockage or collapse. When the strainers remain clean after a running period, they may be removed.
f) Scrubbers have been filled with liquid to normal operating levels.
g) Scrubber and distance piece drain pots have been filled with liquid.
h) Starting air is charged to specified pressure.
i) Instrument and control air systems are blown out and charged to specified pressure.
j) If an electric drive, bump check the motor to verify rotation (before coupling installed).
k) If an electric drive, find magnetic center of the motor (before coupling installed).
l) If an electric drive, make sure motor heaters are working.
m) Coupling and flywheel guards are installed.
n) Vent lines are all connected and vented appropriately.
o) Drain valves (that aren't piped to collection or disposal lines) are all closed.
p) All manual valves are in correct positions for starting and operation.
q) All temperature, pressure and vibration transmitters, switches and controllers are properly calibrated and set-points are per requirements of the packager's specifications.
r) Control panel checks are completed including stepping through automation and confirming functionality of all alarms and shutdowns.
s) Fuel valve operation checked including confirmation that valve shuts upon engine shutdown.
t) All automatic unloaders (deactivators and clearance pockets) are operational.
u) Process gas valve(s) operation checked, including confirmation that valve(s) shuts upon engine shutdown.
v) After start-up and stabilized operation, perform vibration and pulsation measurements as a baseline for the package.

w) After start-up and stabilized operation, check exhaust system for expansion problems, misalignment and cracks.
x) After start-up and stabilized operation, perform a hot alignment per compressor and driver manufacturer's requirements.

Q.3 Package Operating Considerations

Actual operating procedures will vary depending on the application, the type of compressor package and the combination of features and systems included on the package and present at the installation site. It is very important that comprehensive operating procedures and safety protocols are carefully developed and documented. Although packager, engineering contractor and equipment manufacturer information is used for this purpose, it is the responsibility of the end user to ensure that procedures and protocols are established, integrated and documented prior to placing the compressor package into operation. It is also important that the end user and operator provide adequate training and familiarization with package documentation for all compressor package operators and maintenance personnel.

Annex R
(Informative)

Compressor Capacity Control and Automation Design

Annex R provides guidelines and tutorial information for compressor capacity control and automation. Section 5 of the *GMRC High-Speed Compressor Package Guideline For Field Gas Applications*[40] and Chapter 29 of *Gas Compression: A Primer on Compression Equipment and Technology*[44] are acknowledged as the primary references for this Annex.

Field gas, or upstream oil and natural gas related applications, constitute a large and diverse market for reciprocating compressors. Most applications cover a wide range of operating conditions and typically involve high compression ratios. Among the many upstream compression applications are well drilling, gas lift, wellhead gas compression, gas gathering and boosting, coal bed methane compression, landfill gas compression, acid gas injection and advanced recovery processes such us carbon dioxide (CO_2) injection, nitrogen (N_2) injection and fire flood. With more stringent environmental regulations on venting of hydrocarbon gases to the atmosphere, vapor recovery has also become a very common upstream application.

It is important that all application operating conditions can be accommodated efficiently and safely within rated compressor and driver power, rated compressor rod load, compressor pin reversal margin, etc. The compressors in most applications typically require some means of load or capacity control. The planning of the compression installation and the required capacity and operating requirements of each specific compressor package are very important parts of a successful packaged compressor installation.

It is important to note that some practices discussed herein are unlikely to be suitable for all applications. For example, compressor rental companies maintain large fleets of units that, by necessity, are compact, portable and versatile. As such, they are typically not optimized for automatic capacity control, but are configured to be able to operate safely within a reasonable range of operating conditions. Some of the capacity control suggestions in this Annex could result in undue limitations for rental fleet equipment deployment. The recommendations and suggested practices discussed in this Annex are intended to help in the development of designs that satisfy all requirements to the fullest extent that is practical and cost efficient. However, recommendations and best practices must always be viewed through the lens of the particular need the compressor package is intended to fulfill. It is important that compressor packagers, rental fleet operators and end users understand and take responsibility for their role in the design, installation and operation of the field gas compressor package and accessories, including all features designed to enhance the safety, accessibility and maintainability of their machine.

R.1 Appropriate Level of Capacity Control and Automation

Basic packages, such as rental fleet units, typically have no remote start or control capability, however they do usually have some level of remote monitoring. Automatic capacity control, if any, is typically limited to gas recycle and suction throttling.

Advanced packages may have remote start and control capability with significant remote monitoring. In addition to automatic recycle and suction throttling, they may utilize variable speed, volumetric clearance pockets and cylinder end deactivators for automatic capacity control.

Mission critical packages often have remote start and control along with advanced remote monitoring. Automatic capacity control is often used for optimizing performance to safely maximize flexibility, throughput and efficiency.

R.2 Methods of Reciprocating Compressor Capacity Control

Best practice is to select the driver, compressor and cylinder sizes to safely accommodate the highest power, flow, discharge pressure and rod load combinations that are required for the application.

The compressor capacity can be controlled on the basis of suction pressure, discharge pressure, flow rate, power consumption, or combinations of these parameters. The control approach can be manual or automatic. If automatic, the system can be controlled by mechanical, pneumatic, hydraulic or electrical means, or a combination of these means.

Speed variation, volumetric clearance adjustment, gas recycling, suction pressure throttling, cylinder end deactivation, and combinations of these approaches may be used for capacity control. Some methods may require shutdown and depressurization to change the capacity.

Preferably, unloading devices, methods and control philosophies are selected to provide safe operation and efficient loading at all planned and specified operating conditions. It is important to consider the timing of operational changes (e.g., fluctuating, gradual, seasonal or random) in the selection of the appropriate load and capacity control method and hardware as well as the decision to rely on manual adjustments, physical configuration changes or automatic capacity control.

Table R.1 lists the various types of capacity control that are used on reciprocating field gas compressor packages and compares their relative merits. Each type is explained in more detail in the following subsections.

Table R.1: Comparison of capacity control methods

Comparative Benefit: [1] Best → [5] Worst			
Type of Control	**Relative Change/Precision**	**Efficiency**	**Ease of Use**
Speed Variation	[2] Adjustable in small steps with flow reduction typically up to 25%.	[1] Highest.	[1] If automatic. [2] If manual.
Suction Pressure Control	[2] Adjustable in small steps, typically over a significant range.	[4] Wastes energy from gas stream that must be made up by more compression. May increase or decrease the required power.	[1] If automatic. [2] If manual.
Recycle	[1] Adjustable in small steps, typically over a large range.	[5] Wastes power.	[1] If automatic. [2] If manual.
Fixed Volume Clearance Pocket	[3] Small to medium fixed step change.	[1] Small parasitic loss.	[1] If automatic. [2] If manual.
Variable Volume Clearance Pocket	[2] Adjustable in small steps, typically over a large range.	[1] Little or no parasitic loss.	[1] If automatic [2] If manual.
Valve or Head Spacers	[3] Small to medium permanent change.	[1]	[5] Requires depressurizing and disassembly.
Clearance Bottles or Plugs	[3] Small to medium permanent change.	[1]	[5] Requires depressurizing and disassembly.
Cylinder End Deactivation	[1] Large fixed step change.	[3] Parasitic loss.	[1] If automatic. [2] If manual.
Suction Valve Removal	[1] Large fixed step change.	[1] Little or no parasitic loss.	[5] Requires depressurizing and disassembly.

R.2.1 Speed Variation

Speed variation or control is the simplest and most efficient means of capacity control. The capacity of a reciprocating positive displacement compressor is proportional to its operating speed. Normally, compressors are operated at the maximum rated speed of the driver, where capacity is maximized and the (natural gas engine) driver operates most efficiently and with the best exhaust emissions rate.

When it is necessary to reduce compressor capacity, the operating speed can often be reduced, either manually or automatically. Electric motor drivers with a variable speed drive (VFD) often have a speed turn-down capability of as much as 50%. Most gas engine drivers have a speed turn-down ability of at least 25%. It must be recognized that the available driver power decreases proportionately with speed, so speed control is generally not an effective way to reduce load (as a percentage of driver rating). In addition, the gas engine's exhaust emissions rate may change with speed. In most applications, maintenance of environmental compliance is always a first consideration when selecting the range of operating speeds at which the driver can be operated in a given application.

Especially with high-speed reciprocating compressors, when varying the speed, it is important to predetermine that operation at a slower speed will not cause problems with insufficient crosshead pin reversal or excessive compressor rod load. In most cases, both of these can be accurately pre-calculated with the compressor manufacturer's performance software, which will also indicate whether operation of the compressor will be within permissible limits at the intended speed and operating conditions.

The compressor frame-driven lube oil pump capacity declines as speed is reduced. Therefore, prior to operating at lower than 75% of rated speed, it is important to check the compressor oil pump capacity with the manufacturer to ensure that there will be adequate pressure and flow to sustain proper lubrication.

Additional considerations are an awareness of the package's torsional and mechanical natural frequencies that could be excited by changes in operating speeds. This is normally examined by detailed vibration analyses in the package design phase and confirmed by testing of the complete package during the initial commissioning phase in the field. It is also important to understand that the acoustic pulsation dampening system design is more challenging for variable speed applications, as bands of frequencies, rather than individual discrete frequencies, must be addressed. These challenges sometimes result in having to isolate bands of speeds where operation is not permitted.

R.2.2 Suction Pressure Control

Suction pressure control involves the use of a pressure reducing valve in the inlet line to the compressor package. Reducing the suction pressure always reduces the capacity of the compressor. But since the power vs. suction pressure characteristic of a reciprocating compressor is parabolic, depending on where the unit is operating, reducing the suction pressure may decrease or increase the required compression power. If operating at a high compression ratio, reducing the suction pressure reduces the power. If operating at a low compression ratio, reducing the suction pressure increases the power.

In some cases, suction pressure control is also used to intentionally increase the pressure ratio across the compressor to avoid a rod load or non-reversal issue in order to extend the operating range of the compressor package.

This widely used method of capacity control is simple and easy to automate, however it is fundamentally inefficient in that the potential energy stored in the pressurized inlet gas stream is lost in the throttling process. This pressure most be restored by additional compression power somewhere in the system.

R.2.3 Recycle

Recycle systems can be used to limit discharge pressure and increase suction pressure by recirculating gas from the compressor discharge back to its suction. Recycle systems involve adding a process gas line, containing a flow control valve, from the compressor discharge line to the compressor suction line upstream of the inlet scrubber on the package. Connecting the line upstream of the scrubber prevents accumulation and ingestion of cylinder lubricant or other liquids that may drop out of the gas stream and be recycled in the gas stream. Recycle systems can utilize either hot discharge gas, taken upstream of the gas aftercooler, or cold discharge gas, taken downstream of the aftercooler. Either hot or cold gas recycle systems can generally be used for start-up to reduce the load required for starting the unit. However, for capacity control under continuous loaded operation, a recycle with cold gas (i.e., taken downstream of the aftercooler) is required. Continued use of a hot recycle system will lead to high cylinder operating temperatures after only a short period of operation.

In some cases, recycle control is also used to intentionally decrease the compression ratio across the compressor to avoid a rod load or non-reversal issue in order to extend the operating range of the compressor package.

This widely used method of capacity control is simple and easy to automate, however it is very inefficient. Energy and equipment wear and tear are expended to compress the recycled gas to full pressure, only to have it wasted by the throttling process across the recycle valve. When efficiency is a consideration, capacity control by recycle is not a good choice.

R.2.4 Volumetric Clearance Adjustment

Increasing the cylinder fixed volumetric clearance will decrease its capacity. Unlike suction throttling, the reduction in capacity obtained with clearance volume addition always results in an attendant reduction in required power.

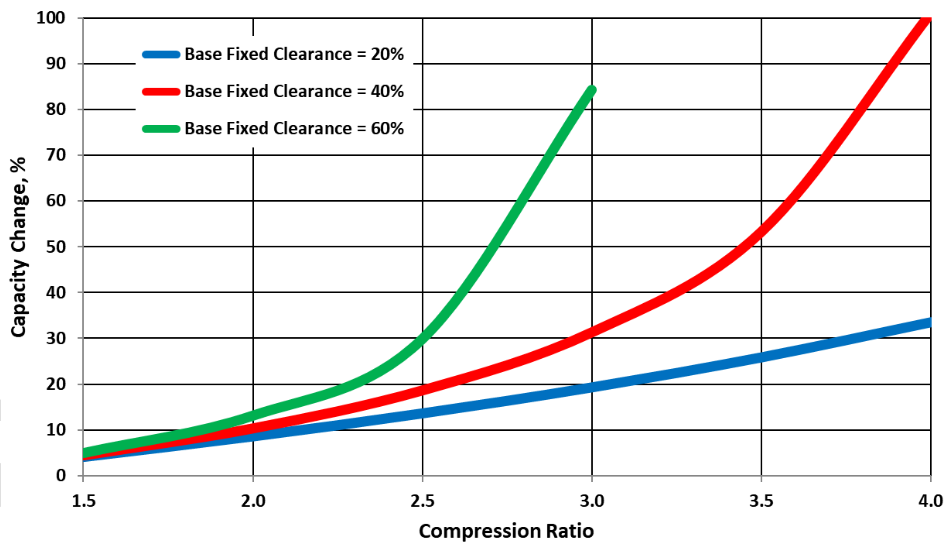


Figure R.1: Capacity change of a reciprocating compressor cylinder end as function of compression ratio for incremental 10% fixed volumetric clearance additions.

The effectiveness of added volumetric clearance varies with the compression ratio as shown in Figure R.1, being much more effective in changing capacity at high compression ratios than at low compression ratios. Figure R.1 shows the percentage change (reduction) in capacity on one end of a reciprocating compressor cylinder when 10% fixed clearance is added to three different base fixed clearances, 20%, 40% and 60%.

There are a number of methods for adjusting the fixed clearance of a compressor cylinder. They may be used alone or in combination. On double-acting cylinders, clearance changes are most commonly applied to the head end, which is more accessible for adding volume pockets and actuation devices. Application of clearance changes on the crank end requires utilization of a special compressor valve assembly or a special port or pocket designed into the compressor cylinder. Where the clearance volume pocket includes a pneumatic, electric or hydraulic actuator, automatic capacity control can be implemented. Otherwise, manual control, and in some of the cases, compressor depressurization and physical modification are required to implement the clearance volume change.

R.2.4.1 Manual Head End Variable Volume Clearance Pocket

Historically, most field gas compressor cylinders are equipped with manually actuated variable volume clearance pockets located on the head end of the cylinder, and they are typically standard options on most cylinders. These are generally most effective on the first stage cylinders, although they may be used on all stages to maintain required capacity and pressure balance between the stages. These pockets provide a wide range of capacity control with little or no reduction in efficiency. Because of the manual effort required to move the pockets under operation, and since there is a risk of sticking the threads on the adjustment screw, it is often common practice to stop the compressor while adjustments are made. Depressurization is usually not required. Nevertheless, the manual effort required for adjustment, along with the inconvenience of stopping and restarting the unit for adjustment, tend to limit the frequency of the adjustments and, therefore, the optimization benefit. Most operators leave the pockets at a setting that keeps the unit out of trouble during upsets, which then leaves it under-loaded most of the time.

If a variable volume clearance pocket is adjusted during operation, it is important to treat it the same as any other valve under pressure. Several precautions are recommended:

a) avoid standing directly in front of the device;
b) use a non-sparking hammer to loosen the lock nut(s);
c) turn the screw only with enough force to move the piston in and out as allowed by the act of compression within the cylinder;
d) be careful not to “bottom out” the clearance piston in the pocket, i.e., give the pocket a ¼ turn on either end to avoid operating the pocket with the piston completely against the stops, either closed or open.

R.2.4.2 Automatic Head End Fixed Volume Clearance Pocket

Pneumatically actuated fixed volume clearance pockets are used to provide a fixed, discrete step of added fixed clearance volume. On field gas compressors, these are typically located on the head end, in place of the manual variable volume clearance pocket. Where required and where the valve design permits, they may also be located over valves, although such arrangements are much more common in larger gas pipeline and storage compressors. These pockets are easy to actuate while the compressor is operating, and the approach is commonly used for automatic capacity control. Most manufacturers offer a selection of fixed volume clearance pockets for their cylinders.

R.2.4.3 Automatic Variable Volume Clearance Pockets

Several types of automatic variable volume clearance pockets have been developed and are gaining field experience for field gas applications. Each of these come with unique application requirements and/or trade-offs. In one type, the clearance piston positioning motor requires three-phase electrical power, which is typically not a readily available utility in remote locations. In another type, the clearance piston positioning motor requires pressurized air or gas, which is then vented to the atmosphere. Compressed air is not always available in field gas installations, and venting of natural gas is increasingly restricted to reduce greenhouse gas emissions. In another type, a hydraulic system is required for positioning the clearance piston, which adds some complexity and maintenance. Another unique type, the gas operated pocket, uses very small amounts of gas for actuation, which is then vented to atmosphere or back to suction. As these and potentially other advanced devices gain more experience, they promise significant potential for better, more optimal, and efficient, automatic capacity control.

R.2.4.4 Valve Clearance Spacers

Most compressor manufacturers offer optional valve clearance spacers that can be placed under suction and/or discharge valves, along with shorter valve cages (or retainers) on top of the valves, to space the valve farther from the cylinder bore to add fixed clearance volume. These can be added initially to tune the cylinder to better fit the application range, or they can be added or removed periodically to tweak the cylinder performance when needed. The changes in capacity for each spacer are small compared to clearance volume pockets, however the effects can add up to be significant when spacers are applied to all valves in the cylinder. Valve spacers added under the crank end valves can help reduce the amount of required head end clearance volume addition for a specific operating condition. This reduces the potential for low volumetric efficiency issues that can reduce valve reliability. The compressor must be stopped, depressurized, partially disassembled and then reassembled in order to add or remove valve spacers, making this a practical alternative only when operating conditions change slowly over time.

R.2.4.5 Cylinder Head Spacers

Similar to valve spacers, it is often possible to install a spacer ring between the outer head and the cylinder body. This usually requires the use of longer head studs or capscrews, and it is best practice to request assistance from the compressor OEM. The compressor must be stopped, depressurized, partially disassembled and then reassembled in order to add or remove head spacers, making this a practical alternative only when operating conditions change slowly over time.

R.2.4.6 Clearance Bottles and Plugs

Although no longer common on newer high-speed compressors, some OEM cylinders are designed to accommodate clearance volume bottles attached to the head or onto a special connection on the cylinder body. These are usually mounted with a bolted flange connection. The flanged connection can be blanked off, or a volume bottle can be connected, or the bottle size (internal volume) can be changed to accommodate changing operating conditions. The compressor must be stopped, depressurized, the flanged connection separated and then reassembled in order to remove or connect clearance bottles, making this a practical alternative only when operating conditions change slowly over time.

R.2.5 Cylinder End Deactivation

Except for tandem (aka steeple) cylinders, most reciprocating compressor cylinders are double-acting, where gas is compressed by each side of the piston on alternate strokes. By deactivating one end, usually the head end, to render the cylinder single-acting, the cylinder's capacity is cut roughly in half. On field gas compressors, this is most commonly accomplished with finger-type depressors that hold the compressor valve plates or poppets open. Plug type unloaders, rotary or linear poppet valve unloaders, and head end bypass unloaders are also used for end deactivation. Each of these unloaders has relative benefits and limitations, and not all are applicable to every cylinder. Manufacturers typically offer options for deactivating the cylinders in their line-up.

In all cases, the cylinder's capacity is reduced by about 50% with end deactivation, however valve-type deactivators have parasitic losses that are often very significant. It is important that this effect is taken into account as the reduction in required power will be less than the reduction in flow rate. Other than for short periods of operation associated with start-up, typically only one end of a cylinder can be safely be deactivated. Simultaneously deactivating both ends usually leads to rapid over-heating of the cylinder, although there are certain situations where removing all the suction valves will allow both ends to be deactivated. It is recommended that the compressor manufacturer be consulted before attempting to operate with both cylinder ends deactivated simultaneously.

End deactivation requires a predetermination that it will not cause problems with insufficient crosshead pin reversal or excessive rod load. These risks are typically higher when the crank end is deactivated, so it is most common to deactivate the head end. In most cases, this can be accurately pre-calculated with the OEM's or other proven performance modeling software, which will also indicate whether operation of the compressor will be within permissible limits at the intended speed and operating conditions.

Additional considerations are an awareness of the package's torsional and mechanical natural frequencies that could be excited by single-acting cylinder operation that changes the pulsation signature and torque effort characteristics of the compressor. This is normally examined by detailed vibration analysis in the package design phase and confirmed by testing of the complete package.

R.2.5.1 Suction Valve Removal

Another method of cylinder end deactivation involves the removal of all the suction valves from the head end of the cylinder. This is a very efficient form of deactivation, as there is very little parasitic power required to move the gas back and forth through the large valve ports to the cylinder's suction muff. The compressor must be stopped, depressurized, partially disassembled and then reassembled in order to remove or reinstall the valves, making this a practical alternative only when operating conditions change slowly over time. The effects and concerns are otherwise the same as discussed in Annex R.2.5.

R.3 Effects of Various Types of Reciprocating Compressor Capacity Control

As pointed out in Annexes R.2.3 and R.2.3, respectively, suction pressure throttling and bypass are inefficient methods of control. Nevertheless, because of the simplicity of implementation and operation, they are commonly used for capacity control on field gas compressor packages. The effects on performance vary with the system design and it's important that the packager review and determine the effects on a case-by-case basis, in consultation with the compressor manufacturer and the end user.

Cylinder end deactivation and clearance volume changes are also common means of capacity control that can be readily automated. Figures R.2 through R.6 illustrate the relative effects of these methods of capacity control, aka unloading, on compressor flow and power as functions of suction pressure at constant speed and constant discharge pressure.

R.3.1 Effects of Cylinder End Deactivation on Compressor Performance

The graphs in Figure R.2 are for a six-throw, single-stage compressor with head end deactivators on each cylinder. The upper graph is flow or capacity as a function of suction pressure; the lower graph is the compressor power required as a function of suction pressure. The graphs are for constant speed, suction temperature and discharge pressure. In both graphs, the top curve, identified as LS 1 (load step 1) is with all six cylinder ends fully active (i.e., no unloading). Moving down, the next curve, LS 2, is with one cylinder head end deactivated, which results in a significant reduction in flow and power. The next lower curve, LS 3, is with two cylinder head ends deactivated, etc. on down to the bottom curve, LS 6, which is with five cylinder head ends deactivated. Although not shown, the head end of the sixth cylinder could also be deactivated, which would produce another curve below LS 6.

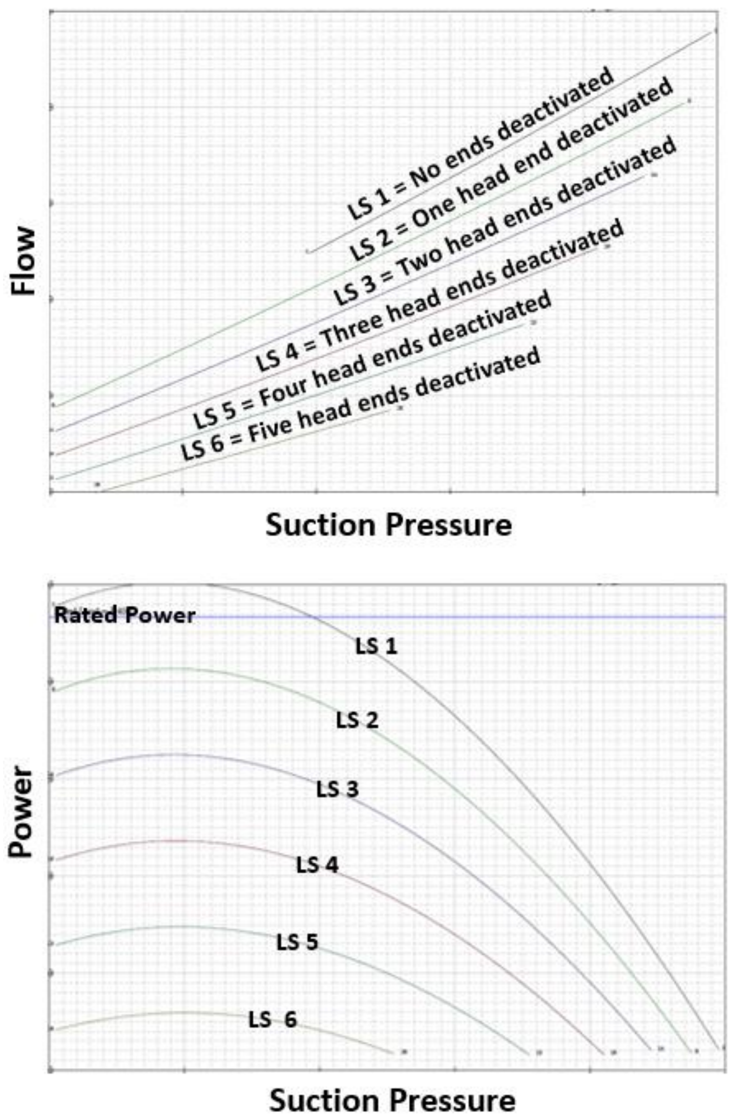


Figure R.2: Effect of deactivating cylinder head ends on a 6-throw single-stage compressor.

The horizontal line in the (lower) power graph, labeled Rated Power, shows the maximum available driver power. It can be seen that at the discharge pressure for which these curves were generated, no unloading is required when the compressor is operated with high suction pressure. The compressor can be operated on LS 1 with no cylinder ends deactivated, until the suction pressure decreases to the lower 40% of the suction pressure range shown in the graph. Below about 40%, the maximum permissible power would be exceeded unless some unloading is introduced. In this example, deactivating one cylinder end, LS 2, reduces the required power so that it does not exceed the rated power over the entire range of suction pressures. However, as shown in the (upper) flow graph, operating on LS 2 results in significantly lower compressor flow/capacity. Cylinder end deactivation can be used for reducing both the flow and the power.

As the lower graph demonstrates, reciprocating power curves are parabolic, so that decreasing suction pressure may either increase or decrease the required power, depending on which side of the peak the pressure is on.

R.3.2 Effects of Fixed Volume Clearance Pockets on Compressor Performance

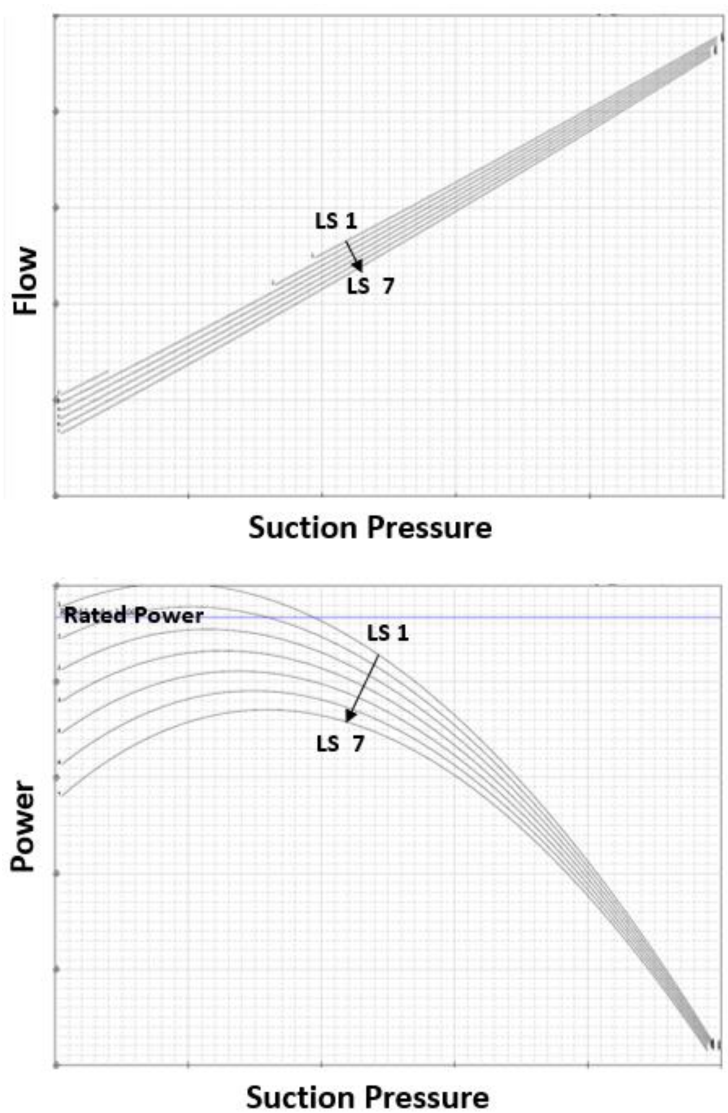


Figure R.3: Effect of cylinder head end fixed volume clearance pockets on a 6-throw single-stage compressor.

The graphs in Figure R.3 are for a six-throw, single-stage compressor with equal head end fixed volume clearance pockets on all cylinders. The upper graph is flow or capacity as a function of suction pressure; the lower graph is the compressor power required as a function of suction pressure. The graphs are for constant speed, suction temperature and discharge pressure. In both graphs, the top curve, identified as LS 1 (load step 1) is with no head end fixed volume clearance pockets open (i.e., all closed) on any cylinders.

The bottom curve, LS 7, is with head end fixed volume clearance pockets open on all six cylinders, showing a significant reduction in flow and power. The curves in between, from top to bottom, are with head end fixed volume clearance pockets open on two, three, four and five cylinders in succession.

The horizontal line in the (lower) power graph, labeled Rated Power, shows the maximum available driver power.

Fixed volume clearance pockets can be used for reducing both the flow and the power. It can be seen that at the discharge pressure for which these curves were generated, no unloading is required when the compressor is operated with high suction pressure. However, as explained in Figure R.4, it is necessary to open one or two head fixed volume clearance pockets, LS 2 and LS 3, respectively, at lower suction pressures.

A comparison of Figure R.2 and Figure R.3 shows that cylinder end deactivation causes relatively large power (and flow) changes, and clearance volume pockets result in comparatively smaller changes in power and flow. For compressor optimization, both types of unloading may be needed to safely manage performance over a wide range of operating conditions as is typical in upstream field gas compression applications. For this example, Figure R.4 shows how the multiple fixed volume clearance pocket load steps of Figure R.3 can be managed to maximize flow rate, while keeping the required compressor power from exceeding the rated driver power.

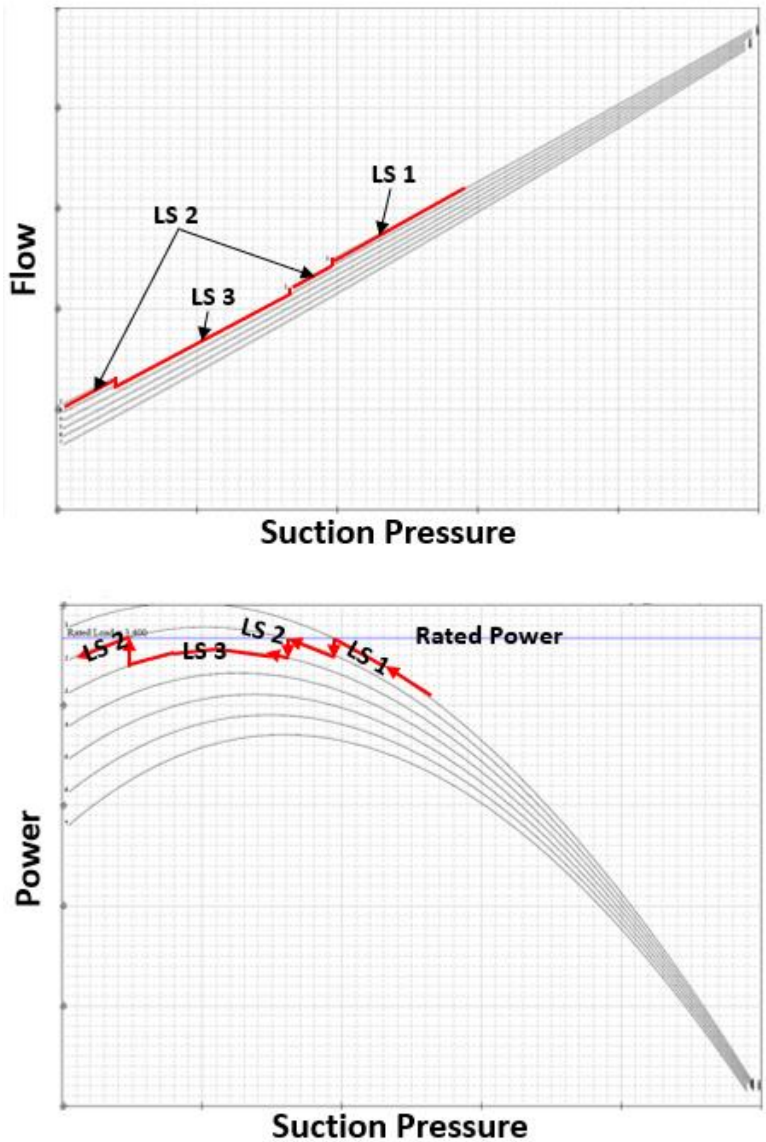


Figure R.4: Example of managing required compressor power using cylinder head end fixed volume clearance pockets on a 6-throw single-stage compressor [44].

The compressor can be operated on LS 1 with no volume pockets open until the suction pressure decreases to the lower 40% of the suction pressure range shown in the graph. Below about 40%, the maximum permissible power would be exceeded unless some unloading is introduced. In this example, opening one head end clearance volume pocket, LS 2, reduces the required power so that it does not exceed the rated power until the suction pressure decreases to about 34% of the maximum. However, to avoid overloading the driver as the suction pressure decreases further, it is necessary to move to LS 3 with two head end clearance volume pockets open. Near the lower end of the suction pressure range, the machine could continue to operate on LS 3, however, switching back to LS 2 in the lower 10% of the suction pressure range results in higher flow rates without exceeding the rated power.

Figure R.4 shows that the compressor could be operated on LS 3 over the entire suction pressure range, however this would result in less than an optimal flow rate over a significant part of the suction pressure range. This figure is a simple example of how careful selection and automatic control of unloading devices can be used to maximize the throughput of a compressor as operating conditions change.

A best practice during the specification and bidding phase, or even during the design phase, of a project is to evaluate whether the higher cost of automatic unloaders can be justified by the value of the increased gas delivery from being able to better utilize the compressor's capability as operating conditions change. This is especially important when efficiency improvement and carbon footprint reduction are goals of the project.

R.3.3 Effects of Variable Volume Clearance Pockets on Compressor Performance

Variable volume clearance pockets are very commonly applied on reciprocating compressors for field gas applications, however most are manually actuated and therefore not very practical for optimizing the performance.

Automatic variable volume pockets have been less commonly applied, as they are more complex systems that add to the initial cost. However, they are gradually being used more frequently as operators want to improve compressor efficiency, flexibility and full capacity utilization.

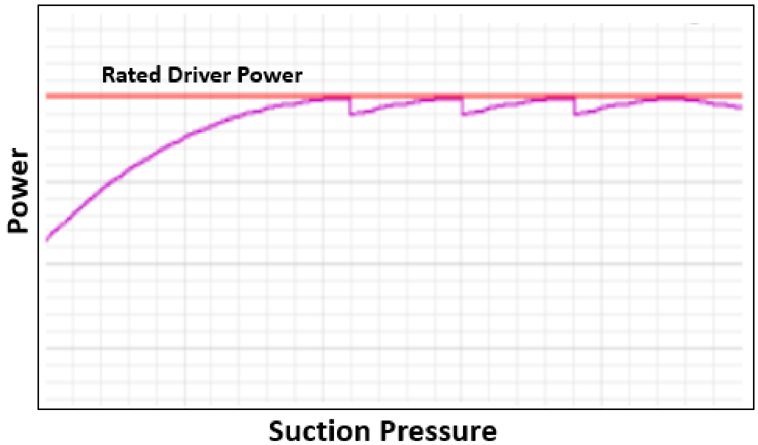


Figure R.5: Effect of a cylinder head end variable volume clearance pocket[44].

Figure R.5 demonstrates how a single variable volume clearance pocket can be used to maintain operation close to, but not exceeding, the rated driver power, which maximizes the compressor capacity. This type of unloader is automated. Although in theory, with precision control, the variable pocket could maintain operation exactly at full power, in reality there is a tolerance in the controllability.

In addition, it is typically not desirable to adjust the pocket unnecessarily often, which would wear it our prematurely. Accordingly, the automatic adjustment tolerances are set with these considerations in mind, erring on the safe side with respect to avoidance of over-powering the driver, as small steps are made. Typically, on a multi-cylinder compressor, it might be applied to only one cylinder in conjunction with multiple fixed volume clearance pockets on the other cylinders. However, it also could be applied to all cylinders, whether single- or multi-stage.

R.3.4 Effects of the Combination of End Deactivators and Fixed Volume Clearance Pockets on Compressor Performance.

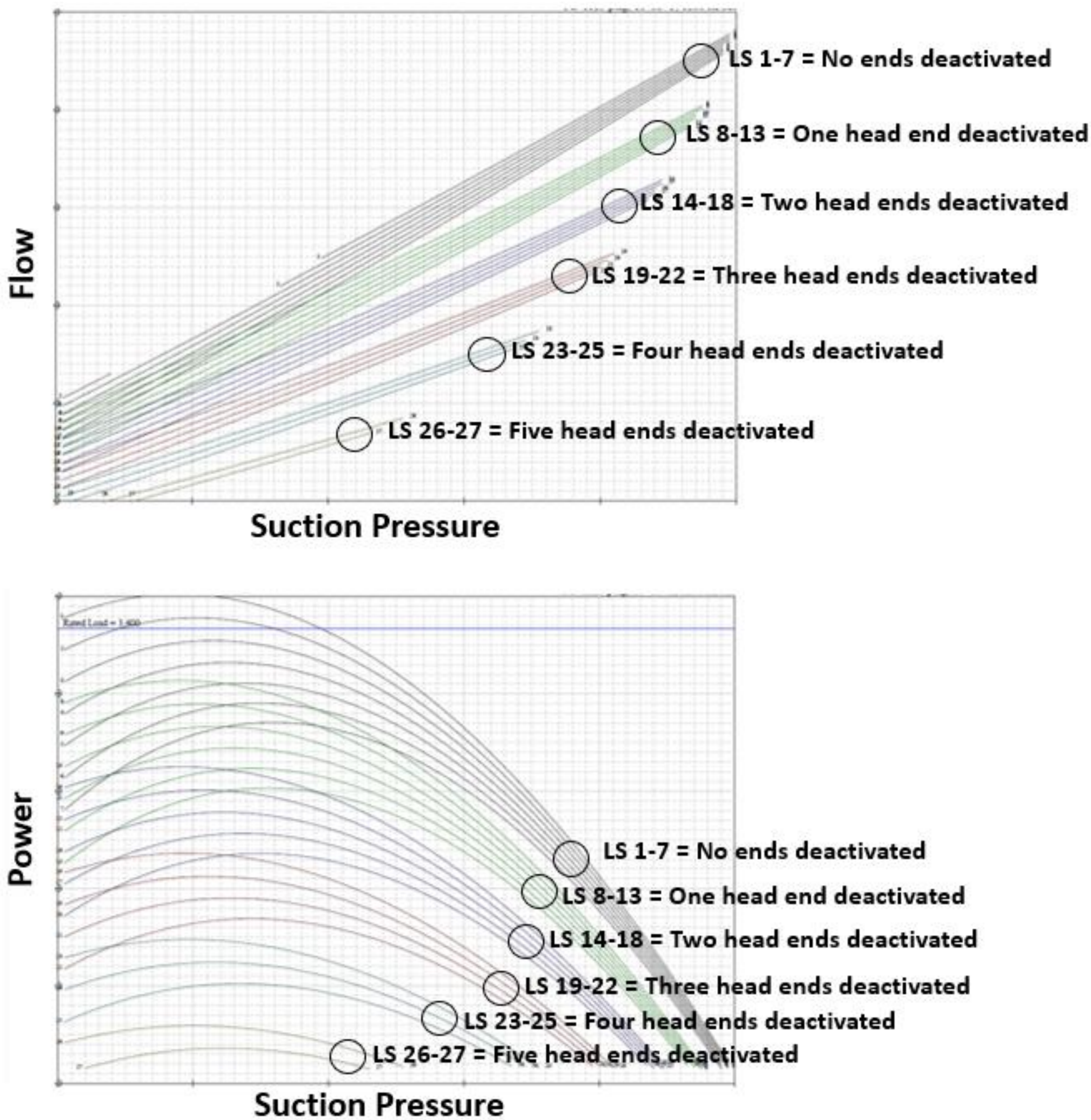


Figure R.6: Effect of cylinder head end deactivators and fixed volume clearance pockets on a 6-throw single-stage compressor.

As mentioned in Annex R.3.2, cylinder end deactivation provides a relatively large step change in flow and required power. Fixed volume clearance pockets provide smaller step changes in flow and power, being most effective at higher pressure ratios (and lower suction pressures). In many instances, a combination of clearance volume changes and end deactivation is required to effectively cover a broad operating range as shown in Figure R.6. In this example, six cylinders in a single-stage configuration have both head end deactivators and head end fixed volume clearance pockets. Since both devices are on the head end, only the deactivator or the volume pocket on a specific cylinder can be used at any given time.

Although the arrangement shown in Figure R.6 is more typical of a pipeline compressor, the same philosophy can be applied (with fewer load steps) on field gas compressors that have two or more cylinders in parallel on the same stage of compression.

R.4 Unloading Scheme Specification and Design

Once the compressor and driver have been defined and a decision made whether to utilize speed, various unloading devices, and/or suction pressure throttling for controlling flow, the compressor unloading scheme can be configured to provide the required operational flexibility.

Design of a safe and efficient capacity control scheme is one of the more complex challenges of gas compression systems. It is typically the obligation of the end user to determine the required control parameter(s), such as suction pressure, discharge pressure, flow rate or power. In addition, it is important for the end user to define a required range of operating conditions plus key design points (gas compositions, flow rates, suction line pressures and temperatures, and discharge line pressures). This includes expected intentional, as well as unexpected, but potentially possible, operating ranges over which the equipment could be operated. Ideally, this definition is part of the pre-order process, but as a minimum, it is important that it be completed very early in the design process.

The timing and frequency of operating condition changes (e.g., fluctuating, gradual, seasonal or random) is an important factor. The timing and frequency of condition changes dictate whether manual unloading (e.g., manual head end variable volume clearance pockets or shutting down and pulling valves for end deactivation) or automatic unloading must be provided to accommodate frequently changing conditions. Ideally, some automatic unloading and control is preferred in order to maximize the safe and efficient utilization of the available driver power. Otherwise, with only manual adjustments available, units tend to be underutilized, operating at less than rated power most of the time.

The compressor OEM's or other proven performance modeling software is used to generate the performance for the selected compressor configuration, including the initially selected unloading devices. It is important to compute the performance for each specified operating point and load step over the entire range of operating conditions that the compressor will be required to operate. Maps of power and flow, plotted against suction pressure, are most useful in assessing the suitability of the compressor configuration. It is prudent to compare the performance at actual operating conditions over the entire intended operating range of suction and discharge pressures, speeds and load steps with safe operating limits for all parameters. For a reciprocating compressor, these operating limits include rated compressor and driver power, rated and minimum allowable speed, cylinder maximum allowable pressure, rod load, crosshead pin reversal, volumetric efficiency and discharge temperature.

It is important for the capacity control scheme and the required devices to be clearly defined in the packager's proposal, along with performance provided for the specified and required operating ranges of the compressor. There are numerous trade-offs to consider in the design of a safe and optimal compression system. Best practice is for the unloading scheme to be determined, or at least validated, by experienced professionals and reviewed by the compressor manufacturer before the final design is released.

R.5 Control Algorithm Specification and Design

While requiring a full review of unit potential before purchase can quickly identify the strengths and shortcomings of that unit when compressing within a specified operating map, many end users also need the ability to implement performance modeling in PLCs (programmable logic controller). This is so that the PLC can safely control the compressor while optimizing it for load, flow, fuel usage and/or environmental compliance. Failure to model a unit very close to how the OEM would model that unit can lead to operation at potentially unsafe operating conditions as well as warranty disputes.

The main safety-related performance control items for reciprocating compressors are: pressure, discharge temperature, rod load, and crosshead pin reversal. Of these, standard real-time sensors can readily identify high pressure and high temperature. There are devices currently available for measuring dynamic internal cylinder gas pressures and thus inferring real-time rod load and crosshead pin forces. However, these devices are not yet in common use for control of reciprocating compressors in upstream gas compression.

While a simple pressure differential can be useful in keeping most low-speed reciprocating compressors out of rod load problems, this method is generally insufficient for high-speed units. Most high-speed compressor OEMs base rod load and pin reversal calculations on cylinder internal gas pressures, which vary with speed and gas density due to the pressure drops associated with valve velocities and gas passageways. Furthermore, regardless of whether the OEM uses inertia forces for rod load calculations, high-speed compressor OEMs do use inertia for crosshead pin non-reversal calculations. Inertia forces are a function of reciprocating weights and rotational speed. Thus, simple pressure differentials fail to cover potential safety issues related to pin non-reversals.

With high-speed compressors, therefore, it is very important for control systems to calculate the rod load and pin reversal calculations in the same way that the compressor OEM software models them. This ensures that calculated values are compared properly with the OEM rating limits. Valve losses must also be estimated in the way that OEMs estimate them, so that correct internal cylinder pressures are used in dynamic rod load calculations. The old practice of using flange pressures to calculate rod load is not adequate or safe enough for high-speed compressors.

In short, for these types of safety items, it’s important to know actual reciprocating weights and rod load limits and how those items are used in determining if the unit can be safely operated at a specific operating point, at a specific speed, and at a specific load step configuration.

As shown in Figure R.6, in some areas of the operating map, the load step curves overlap or cross over each other. In these cases, it’s desirable to include program logic that selects the most efficient safe load step. Normally, the volume pockets, rather than the end deactivation steps, result in higher efficiency.

When compressor packagers lack suitable experience in developing automatic load step control algorithms and programs, suggested practice is to rely on experienced compressor automation companies for designing automatic unloading control systems, or as a minimum, to use a qualified high-speed reciprocating compressor expert to assist with the development of the control algorithms and the programming logic used within the PLC for selection of optimal safe load steps.

Annex S
(Informative)

Guidelines for Selection, Design and Application of Air-Cooled Heat Exchangers

This Annex S provides additional guidance and tutorial information that supplements the specified requirements of Section 10.

S.1 Air-Cooler Design Parameter Typical Default Values

Air-cooler application design parameter typical default values are listed below in brackets [] that may be used where required parameters have not been specified.

a) Compressor performance calculations at the specified design conditions - where varying conditions are specified, it is important that the extents of the operating range are provided, considering suction pressures, discharge pressures, inlet gas temperatures, and gas compositions. [This includes providing multiple operating cases basis actual gas compositions rather than computer generated compositions based on generic gas compositions; suction gas temperature of 32.2 °C (90 °F) as default.]

b) Maximum design inlet air temperature at air-cooler [37.8 °C (100 °F) as default]

   NOTE 1: Air-cooler air inlet temperatures may be elevated above the maximum ambient air temperature as a result of site conditions.

c) Minimum design inlet air temperature at air-cooler [no minimum as default]

d) Site altitude [457 m (1500 ft) as default]

e) Each gas interstage (IC) cooler tube bundle maximum design outlet temperature [54.4 °C (130 °F)] or maximum design approach temperature [16.7 °C (30 °F)] [greater of for default]

f) Final stage gas aftercooler (AC) tube bundle maximum design outlet temperature [120 °F (48.9 °C)] or maximum design approach temperature [11.1 °C (20 °F)] [greater of for default]

g) Minimum interstage cooler (IC) and/or aftercooler (AC) gas tube bundle outlet temperature [no minimum as default]

h) Gas outlet temperature control design (manually actuated louvers, automatic air or electric actuated louvers, warm air recirculation system, variable speed fan, etc.) [manually actuated independent air flow louvers on warm air-side of tube bundles as default]

i) Maximum Allowable Working Pressure (MAWP) for gas tube bundle(s) [minimum default value for Maximum Allowable Working Pressure (MAWP) to be the greater of 10% or 345 kPa (50 psi) above the maximum specified operating pressure]

j) Maximum allowable fan parasitic horsepower (hp) for engine-driven fans [5% of engine rated hp as default]

k) Fan sound level limits, where applicable [none as default]

l) Fan tip speed [fan manufacturer's limit as default]

   NOTE 2: Air-cooler manufacturer provides the calculated fan sound level if specified; sound level tests are not required.

m) Fan air flow draft of forced-draft (fan on cold air-side of tube bundles) or induced-draft (fan on warm air-side of tube bundles) [forced as default]

n) Any specification for gas cooler tube bundle tube materials of construction, where applicable [welded ASME SA214 carbon steel as default]

o) Any specification for gas cooler tube bundle header materials of construction, where applicable [ASME SA516-70 carbon steel as default]

p) Any specification for gas cooler tube bundle minimum corrosion allowance and/or non-destructive examination (NDE) above ASME Section VIII Division 1 requirements, where applicable [none as default]
q) Engine and/or compressor coolant type and percentage composition [50% ethylene or propylene glycol and 50% demineralized water as default engine coolant, in year-round warm climates no less than 10% glycol or inhibitor, or per engine manufacturer's guidelines]
r) Packager to specify the process gas tube bundle nozzle locations and/or orientations, when predetermined [none as default]

   NOTE 3: It is important that the Packager or Purchaser specifies if nozzle locations or orientations are to be predetermined as this may affect the thermal design of an air-cooler.

   NOTE 4: Air-cooler pass plate arrangements can be designed with either crossflow (side by side passes with short span pass plate) or counterflow (above and below passes with long span pass plate). Even pass plate arrangements result in both inlet and out nozzles on the same end of tube bundle. Odd pass plate arrangements result in nozzles on opposite ends of tube bundle. Counterflow pass plate arrangements will limit nozzle orientation with the inlet at the top and the outlet at the bottom of headers for horizontally oriented tube bundles. Crossflow pass plate arrangements may limit the ability to split flow through multiple inlet and/or outlet nozzles.

s) Any dimensional limits for transportation and/or installation, where applicable [none as default]

S.2 Mechanical Design Considerations for Reducing Heat Transfer in Cold Weather

S.2.1 Minimum Air and Gas Temperature Limits

It is important that Purchaser defines any required minimum air-cooler inlet air and gas discharge temperatures to prevent excessive condensation, hydrates, or other conditions. There are multiple options in the air-cooler design and operation to increase the approach temperature (difference between inlet air and gas discharge temperatures), for example, warm air-side tube bundle louvers, cold air-side tube bundle louvers, variable fan speed, variable fan blade pitch, fan blade removal, warm air recirculation system, etc. There are also package design options, for example, variable hot-side tube bundle bypass. Best practice is for Purchaser or Packager to consult with the air-cooler supplier to determine whether an increased approach temperature design is recommended or will be required to minimize the risk of freezing, hydrate formation, and/or excessive condensation in individual gas tube bundles.

S.2.2 Hot-Side Bypass

Variable flow hot-side gas bypass will reduce gas flow through tube bundle and reduce the air-cooler gas outlet temperature which may result in increased gas condensation and/or hydrate formation and may cause fluid freezing.

S.2.3 Inlet Air Flow Restrictions

Restricting inlet air flow such as blocking off fan air inlets may cause damage to the equipment; consult air-cooler manufacturer for options for inlet air flow restrictions.

S.2.4 Variable Speed Drives on Engine-Driven Fans

On engine-driven fans utilizing variable speed drives, turndown conditions may result in nonlinear reductions in heat transfer. Air-coolers are typically designed for full range air-cooler performance at warmest air-cooler inlet air temperature and maximum speed conditions. It is important that the overall air-cooler design considers the full range of thermal and mechanical performance at reduced fan speed operation.

S.3 Air-Cooler Mechanical Design Considerations for Optimization of Air Flow

It is important that the Purchaser considers intake and discharge air flow direction and restriction plus effects of inlet air preheat and warm air discharge recirculation in specifying and siting air-cooler design parameters. Best practice is that air-coolers with fans 1219 mm (48 in.) in diameter and larger are designed so that air is not drafted from or directed toward the package driver, unless approved by Purchaser.

S.3.1 Engine Silencer/Converter Mounting Elevation Above Air-Cooler

It is important that the engine silencer/converter is elevated above the air-cooler to avoid restriction in air flow and minimize heat radiation to tube bundles and that the flow area around the silencer is equal to or greater than the tube bundle discharge area below the silencer/converter. Best practice is to elevate the silencer/converter above the top most surface of the air-cooler (higher elevation of tube bundle guard or open louvers) such that the sum of the lengths of tangents from silencer/converter circumference to outer sides of air-cooler is equal to or greater than the full width of air-cooler area beneath silencer. Referring in Figure S.1, the minimum height between top of air-cooler and bottom of silencer/converter can be calculated in accordance with Equation (6).

$$H = \sqrt{\left(\frac{W + D}{2}\right)^2 - \left(\frac{W}{2}\right)^2} - \left(\frac{D}{2}\right) \tag{6}$$

Where,
H is the minimum height from top of tube bundle or louvers to bottom of silencer in m (ft);
W is the full width of top of air-cooler in m (ft);
D is the diameter of silencer/converter in m (ft).

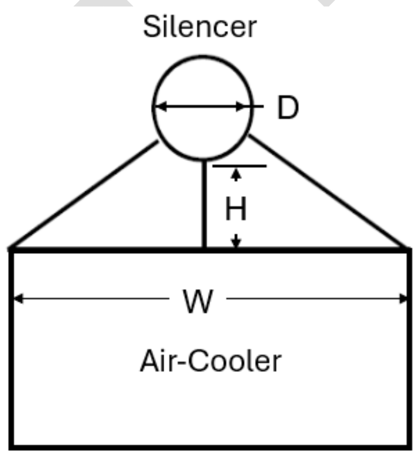


Figure S.1: Dimensions for calculating minimum permissible height of exhaust silencer above air-cooler.

S.3.2 Platform and Surge Tank Mounting Elevation Above Air-Cooler

It is important that platforms and surge tanks are elevated above the top surface of the air-cooler to minimize restrictions in air flow. Best practice is for flow areas through and around platform to be equal to the tube bundle discharge area below the platform and for elevation of platform above top most surface of air-cooler (higher of elevation of tube bundle guard or open louvers) to be such that the sum of the free area of the platform plus the platform perimeter area between the platform perimeter and the top air-cooler surface is equal to or greater than the area of the platform footprint. Best practice is also for flow areas around surge tanks to be equal to or greater than tube bundle discharge area below surge tank and for elevation of surge tank bottom above top air-cooler surface (higher of elevation of tube bundle guard or open louvers) to be such that the area of the surge tank perimeter area between the surge tank perimeter and the top air-cooler surface is equal to or greater than the area of the surge tank footprint. The minimum platform and/or surge tank height above top of air-cooler can be calculated in accordance with Equation (7).

$$H = \frac{(WxL)\ x\ (1 - OA)}{(W + L)\ x\ 2} + K \tag{7}$$

Where,

H is the minimum height from the top of tube bundle guard or open louvers to the bottom of the platform or surge tank in m (ft);

W is the width of the platform or surge tank in m (ft);

L is the length of the platform or surge tank in m (ft);

OA is the % platform grating open area, expressed as a decimal, or use a value of 0 for a surge tank.

K is a constant equal to 0.07 m for SI units or 0.25 ft for USC units.

S.4 Air-Cooler Site Layout Considerations

S.4.1 Spacing and Elevation

It is important to consider placement of air-coolers basis: prevailing summer wind directions; proximity to enclosures, walls, sloped roof lines, and other objects that may restrict or redirect air flow; proximity to heat sources, including other existing or future air-coolers, which may reject heat and reduce the heat transfer performance of the air-cooler; and providing adequate accessibility and personnel clearance for maintenance. Best practice is to locate air-coolers away from air flow obstructions a minimum distance equal to two times the plenum width. It is important for Purchaser to provide a dimensioned site layout for considerations required in the air-cooler design.

S.4.2 Inlet Air Flow Velocity

All horizontal-bundle horizontal-fan air-coolers, whether they are located in a single stand-alone orientation or in a bank of several bays located side by side, require adequate clearance below the fan guard for forced-draft units, or below the tube bundle for induced-draft units, to allow an adequate volume of lowest temperature air to enter the fan and flow through the tube bundles. Best practice is for the velocity of the air approaching the air-cooler (approach velocity) not to exceed a nominal value of 3.6 m/sec (700 ft/min) for forced-draft air-coolers, or 4 m/sec (800 ft/min) for induced-draft air-coolers at the perimeter of the individual air-cooler bay and/or bank of air-cooler bays. Adjusting the column height and/or air-cooler spacing is the normal way that the approach velocity is attained on grade-mounted horizontal-bundle and horizontal-fan air-cooler installations. It is also important to consider providing adequate personnel clearance for mechanical equipment maintenance when determining the installed height of air-coolers.

S.4.3 Spacing and Elevation Calculation

For grade-mounted air-cooler configurations with horizontal-bundle and horizontal-fan orientations, use equation (8) for height and spacing calculations for air-cooler installations.

$$h = \frac{q_v}{L_p\ x\ k} \tag{8}$$

Where,

h is the height above grade to the bottom of the fan guard for forced-draft type units, or to the bottom of the tube bundle side frames for induced-draft type units, expressed in m (ft);

q_v is the total actual volumetric flow rate of air that the air-cooler(s) is designed to use at design conditions, expressed in actual m^3/min (ft^3/min [ACFM]);

L_p is the length of the perimeter of the bay or bank, expressed in m (ft), from which air will be free flowing into the air-coolers (include only the perimeter of which no air is being blocked or hindered by other structures or bays from entering the air-coolers);

k is a constant, which is 213 m/min (700 ft/min) for forced-draft units and 244 m/min (800 ft/min) for induced-draft units.

Air-cooler configurations with engine-driven vertical-fans and horizontal-bundles normally attain recommended approach velocity by adjusting air-cooler spacing. Air-cooler configurations with vertical single fan and vertical or slanted tube bundles do not have spacing and elevation limitations to attain recommended inlet air approach velocity due to their inherent design.

S.4.4 Adjacent Enclosures and Roof Lines

Unintentional warm air recirculation can negatively impact the performance of an air-cooler. An air-cooler depends on unobstructed fresh ambient air for optimum operation. Operation within an enclosure or building or on the summer downwind side of roof lines may preheat inlet air temperature. It is important to consider the effects of locating air-coolers adjacent to walls, roof lines, other air-coolers or other heat sources. Best practice is to maintain a minimum distance nominally equal to two times the plenum width from an air flow obstruction or heat source.

S.5 Air-Cooler Motor HP Derate Factors for Site Altitude and Temperature

For increased air temperature and altitude at site conditions greater than the motor manufacturer's derate guidelines, nameplated fan motor horsepower may be derated per guidelines in Table S.1.

Table S.1 - Motor HP Derate Factors for Site Altitude and Temperature

Altitude Meters (Feet)	**Maximum Motor Inlet Air Temperature °C (°F)**				
	≤ 40 (104)	**>40 (104) and ≤ 45 (113)**	**>45 (113) and ≤ 50 (122)**	**>50 (122) and ≤ (55) 131**	**>55 (131) and ≤ 60 (140)**
≤1000 (3280)	1.00	0.96	0.92	0.87	0.82
>1000 (3280) and ≤4921 (1500)	0.97	0.93	0.89	0.84	0.80
>1500 (4921) and ≤2000 (6562)	0.94	0.90	0.86	0.81	0.77
>2000 (6562) and ≤ 500 (8202)	0.90	0.86	0.83	0.78	0.74
>2500 (8202) and ≤3000 (9843)	0.86	0.83	0.79	0.74	0.71
>3000 (9843) and ≤3500 (11,483)	0.82	0.79	0.75	0.71	0.67
>3500 (11,483) and ≤4000 (13,123)	0.76	0.73	0.70	0.66	0.62

S.6 Air-Cooler Storage

It is important that the Purchaser or Packager specifies the duration between air-cooler completion and package installation, and that the air-cooler manufacturer specifies air-cooler preservation scope for the specified storage duration if longer than three months.

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