Petroleum, Petrochemical, and Natural Gas Industries—Air-cooled Heat Exchangers

API STANDARD 661

~~SEVENTH~~ EIGHTH EDITION, XXXXXX ~~2012~~202X

POST SPRING 2023 CRE

MANY EDITOR'S NOTES TO BE SORTED

INCLUDES MOST OF INPUT FROM IOGP/API COMPARISON SPREADSHEET

MANY COMMENTS ADDED WHERE CLARIFICATION REQUIRED

CROSS REFERENCES AND CHECKLIST NOT YET UPDATED

INCORPORATE ACTIONS: 14, 15, 29, 39 (NO CLEAR CHANGE), 66, 89, 100, 102, 105, 106 (NO CHANGE), 108, 113, 114

WORKING THROUGH EDITOR'S NOTES – GOT TO **7.2.8.4**

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energy API

AMERICAN PETROLEUM INSTITUTE

Petroleum, Petrochemical, and Natural Gas Industries—Air-cooled Heat Exchangers

Downstream Segment

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AMERICAN PETROLEUM INSTITUTE

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Shall: As used in a standard, "shall" denotes a minimum requirement to conform to the standard.

Should: As used in a standard, "should" denotes a recommendation or that which is advised but not required to conform to the standard.

May: As used in a standard, "may" denotes a course of action permissible within the limits of a standard.

Can: As used in a standard, "can" denotes a statement of possibility or capability.

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Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001, standards@api.org.

Contents

page

Table of Contents will be generated with Final Page Proofs.

Introduction

Users of this standard need to be aware that further or differing requirements can be needed 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 applicable where there is innovative or developing technology. Where an alternative is offered, it is the responsibility of the vendor to identify any variations from this standard and provide details.

This standard requires the purchaser to specify certain details and features.

A bullet [•] at the beginning of a section or subsection indicates a requirement for the purchaser to make a decision or provide information (for information, a checklist is provided in Annex B).

In this standard, where practical, U.S. customary (USC) or other units are included in parentheses for information.

Petroleum, Petrochemical, and Natural Gas Industries—Air-cooled Heat Exchangers

1 Scope

This standard gives requirements and recommendations for the design, materials, fabrication, inspection, testing, and preparation for shipment of air-cooled heat exchangers for use in the petroleum, petrochemical, and natural gas industries.

This standard is applicable to air-cooled heat exchangers with horizontal bundles, but the basic concepts can also be applied to other configurations.

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.

AGMA 6001 [1], *Design and Selection of Components for Enclosed Gear Drives*

ANSI/AGMA 6010, *Spur, Helical, Herringbone and Bevel Enclosed Drives*

API Recommended Practice 932B, *Design, Materials, Fabrication, Operation, and Inspection Guidelines for Corrosion Control in Hydroprocessing Reactor Effluent Air Cooler (REAC) Systems*

~~API Recommended Practice 2003, *Protection Against Ignitions Arising Out of Static, Lightening, and Stray Currents*~~

ASME PTC 30 [2], *Air-Cooled Heat Exchangers*

ICC I-CODE IBC [3], *International Building Code*

ISO 76 [4], *Rolling bearings — Static load ratings*

ISO 281, *Rolling bearings — Dynamic load ratings and rating life*

ISO 286 (all parts), *Geometrical product specifications (GPS) — ISO code system for tolerances on linear sizes*

ISO 1081, *Belt drive — V-belts and V-ribbed belts, and corresponding grooved pulleys — Vocabulary*

ISO 1461, *Hot-dip galvanized coatings on fabricated iron and steel articles — Specifications and test methods*

[1] American Gear Manufacturers Association, 500 Montgomery Street, Suite 350, Alexandria, Virginia 22314, www.agma.org.
[2] American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5990, www.asme.org.
[3] International Code Council, 500 New Jersey Avenue, NW, 6th Floor, Washington, DC 20001, www.iccsafe.org.
[4] International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, www.iso.org.

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ISO1813 Belt drives -- V-ribbed belts, joined V-belts and V-belts including wide section belts and hexagonal belts - Electrical conductivity of antistatic belts: Characteristics and methods of test

ISO 2491, *Thin parallel keys and their corresponding keyways (dimensions in millimeters)*

ISO 4183, *Belt drives — Classical and narrow V-belts — Grooved pulleys (system based on datum width)*

ISO 4184, *Belt drives — Classical and narrow V-belts — Lengths in datum system*

ISO 5287, *Belt drives — Narrow V-belts for the automotive industry — Fatigue test*

ISO 5290, *Belt drives — Grooved pulleys for joined narrow V-belts — Groove sections 9N/J, 15N/J and 25N/J (effective system)*

ISO 8501-1, *Preparation of steel substrates before application of paints and related products — Visual assessment of surface cleanliness — Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings*

ISO 9563, *Belt drives — Electrical conductivity of antistatic endless synchronous belts — Characteristics and test method*

ISO 15156 (all parts), *Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production* *action Colin check if should now be moved to the bibliography*

NACE MR0103 [5], *Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments*

NACE SP0472, *Methods and Controls to Prevent In-Service Environmental Cracking of Carbon Steel Weldments in Corrosive Petroleum Refining Environments*

NFPA77 *Recommended Practice on Static Electricity*

RMA IP-3-3 *Technical Bulletin defines the measuring procedure as well as the maximum allowable resistance*

RMA– IP--27-[6], *Specifications for Drives Using Curvilinear Toothed Synchronous Belts*

3 Terms, Definitions and Abbreviations

For the purposes of this document, the following terms, and definitions and abbreviations apply.

3.1 Terms and Definitions

3.1.1
bank
One or more items arranged in a continuous structure.

[5] NACE International (formerly the National Association of Corrosion Engineers), 1440 South Creek Drive, Houston, Texas 77218-8340, www.nace.org.
[6] Rubber Manufacturers Association, 1400 K St., N.W., Suite 900, Washington, D.C. 20005, www.rma.org.

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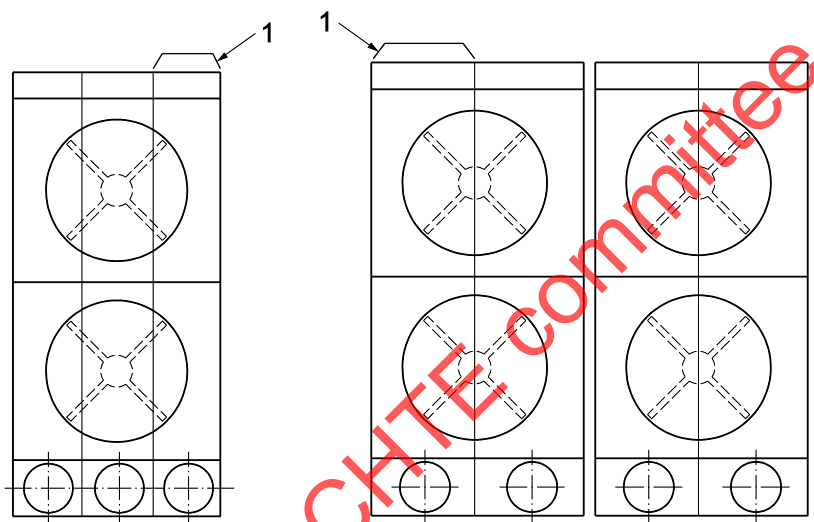
3.1.2
bare tube surface
Total area of the outside surfaces of the tubes, based on the length measured between the outside faces of the header tubesheets excluding the finned surface area if any.

3.1.3
bay
One or more tube bundles, serviced by two or more fans, including the structure, plenum, and other attendant equipment.

NOTE Figure 1 shows typical bay arrangements.

3.1.4
critical process temperature
Temperature related to important physical properties of a process stream.

EXAMPLES Freezing point, pour point, cloud point, hydrate formation temperature, and dew point.



a) One-bay **b) Two-bay**

Key
1 tube bundle

Figure 11, —Figure 1 —Typical Bay Arrangements

3.1.5
cyclic service
Process operation with periodic variation in temperature, pressure, and/or flowrate.

3.1.6
exhaust air
Air that is discharged from the air-cooled heat exchanger to the atmosphere.

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3.1.7
external recirculation
Process that uses an external duct to carry recirculated air to mix with and heat the inlet air. (Note: Review when working on the winterization section to ensure consistency)

3.1.8
finned surface
<Of a tube> total area including effective base tube area of the outside surface of a finned tube exposed to air. (Note: Slingerland to follow-up with HTRI [potential issue on input vs. output areas] & Aspen on how they calculate surface area) (may need updated of API datasheet depending on results from software providers) HTRI Confirmed on 6/6/2022 that the base tube area is included. Also merged with the std clause version.

3.1.9
forced-draftdraught exchanger
Exchanger designed with the tube bundles located on the discharge side of the fan.

3.1.10
geometric center
Location at the center of a bay on a plane midway between the air inlet and the air outlet for both forced-draft and induced-draft units.

NOTE The geometric center is also considered the acoustic center of a bay for calculations.

Add high temperature hydrogen service

3.1.11
hail screen
Is xxxxa metal or fiber net attached to the air cooler designed with openings to protect the fins from damage due to falling ice

3.1.12A
Hhigh temperature hydrogen attack
HTHA
Damage mechanism affecting carbon and low-alloy steels due to the exposure to hydrogen at elevated temperatures and pressures, resulting in the loss of carbides and strength of the materials and cracking.

3.1.13B
high temperature hydrogen service
HTHS
Services with operating hydrogen partial pressure above 350 kPa (50 psi) absolute and operating temperatures above 200 °C (400 °F).

3.1.14
hot air recirculation baffle
HAR baffle
Optional vertical barrier below an air-cooled heat exchanger bundle that minimizes the effect of wind, often used as part of a winterization system.

3.1.151
hydrogen service (to match API 660 addendum definition and API 663)
Services that contain hydrogen at a partial pressure exceeding greater than 700 350 kPa (100 50 psi) absolute.

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3.1.162
induced-draftdraught exchanger
Exchanger designed with the tube bundles located on the suction side of the fan.

3.1.173
inlet air
Atmospheric or ambient air that enters the air-cooled heat exchanger.

3.1.18
insect screen
lint screen
A xxxxxmetal or fiber net attached to the air cooler with openings sized to prevent lint or insects from entering the air cooler bundle

3.1.194
internal recirculation
Process that uses fans (possibly with louvers) to recirculate air from one part of the process bundle to the other part, often used as part of a winterization system. (Note: address with winterization topic)

3.1.2015
item
One or more tube bundles for an individual service.

3.1.216
item number
Purchaser's identification number for an itemair-cooled heat exchanger.

3.1.22X
Mmaximum process operating temperature
Specified maximum inlet temperature considering normal operation, startup, shutdown, upset conditions (e.g. power failure), and steam out.

3.1.2317
measurement surface
Surface of the bay or the cylinder or sphere on which sound- pressure level is measured.

3.1.2418
minimum design air temperature
Specified inlet air temperature that is used for winterization.

3.1.2519
minimum design metal temperature
Lowest metal temperature at which pressure-containing elements components can be subjected to design pressure.

3.1.260
octave bands
Preferred frequency bands.

Editor note add plenum depth definition (extra related clauses 3.2.3.4 rejected, also impacts figure).

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3.1.27
plenum depth
For, forced draft units: straight vertical, distance between the bottom of the bundle frame (or steam coil frame) and the top of fan ring.

For induced draft units: the straight vertical distance between the bottom of fan ring and the top of tube bundle (or top of louver frame).

3.1.281
pressure design code
Recognized pressure vessel standard specified or agreed to by the Ppurchaser.

EXAMPLE ASME *BPVC*, *Section VIII*, *Division –1*, EN 13445 (all parts)

3.1.292
recirculated air
Air that has passed through the process bundle and is redirected to mix with and heat the inlet air, often used as part of a winterization system. (Note: address with winterization topic) – HAR as possible clarification [hot air recirculation], desired vs. undesired

3.23
specified minimum tube-wall temperature
Critical process temperature plus including a safety margin.

Note: See annex table C.1

3.24
structural code
Recognized structural standard specified or agreed by the Purchaser.

EXAMPLES AISC M011 and AISC S302.

3.25
tube bundle
Assembly of headers, tubes and frames.

3.1.3026
seal-welded
Weld of unspecified strength applied between the tubes and tubesheet Tube-to-tubesheet joint weld of unspecified strength applied between the tubes and tubesheets for the sole purpose of reducing the potential for leakage. (Note: verify matches API 660/663 now per 663)

3.1.31
sheave
sprocket
Pulley for hoisting or hauling, having a grooved rim for retaining a chain, wire, or rope.

3.1.32X
Sslinger
Device attached to the top of a shaft which uses centripetal force to prevent water from flowing down the shaft and affecting the drive assembly bearings and/or motor.

[TASK GROUP REVIEW]Add new definition, a.k.a. shaft slinger

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3.1.3327
sound level
Sound- pressure level when frequency is weighted according to the standardized A, B, or C weighting used in sound- level meters.

NOTE Only A-weighted readings [dB(A)] are referenced in this standard.Note: move into normative section of document

3.1.3428
Ssound -power level
Ten times the logarithm to base 10 of the ratio of the total acoustic power radiated by a sound source to the reference power of 10^{-12} W.

3.1.3529
sound- pressure level
Twenty times the logarithm to base 10 of the ratio of the root mean square sound pressure to the reference sound pressure of 2×10^{-5} N/m^2.

3.1.36
specified minimum tube-wall temperature
Critical process temperature including a safety margin.

NOTE: See C.2.7Table C.1.

3.1.370
strength-welded
Tube-to-tubesheet joint welded so that the design strength is equal to, or greater than, the axial tube strength specified by the pressure design code. (Note: verify matches API 660/663)

3.1.38
structural code
Recognized structural standard specified or agreed by the purchaser.

EXAMPLES AISC M011 and AISC S302.

3.1.39
tube bundle
Assembly of headers, tubes, and frames.

3.1.40
thrust-block
Directional anchor that is installed in the ground.

3.1.4131
unit
One or more tube bundles in one or more bays for an individual service.

3.1.4132
wind skirt (recirculation hot air recirculation baffle?) define name function and purpose
Optional vVertical barrier either above or below an air-cooled heat exchanger bundle that minimizes the effect of wind, often used as part of a winterization system.

Editors note: discussion on 5.18.21 was to delete reference to winterization, skirts not part of winterization. Figure C3, C4, C5 points to wind skirt (used to promote mixing of hot/cold air). Consider renaming device use to promote mixing something other than "wind skirt". In the current annex do we keep it in or out. If in,

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do we rename the device. Also do we need an informative section on devices (skirt/screen) used to address HAR, HAM (hot air migration) or high winds during the design phase. Large installations, large banks of air coolers? Editor note, update "wind skirt" to "hot air recirculation baffle" throughout document

Editor note: New definitions

Action Item: Define HAR, Wind Screen, Hail Screen, insect screen. Verify effect on Annex figure changes: R. Hill. S. Edwards to help if drawings are needed

3.1.4233
winterization
Provision Dof design features, procedures, or systems for air-cooled heat exchangers to avoid problems with the process fluid as a result of low-temperature inlet air. (Note: address air recirculation with this topic)

NOTE Problems related to low-temperature inlet air include fluid freezing, cooling to the pour point, wax formation, hydrate formation, laminar flow, and condensation at the dew point (which can initiate corrosion).

Editor Acronyms to be added per IOGP

3.2 Acronyms and Abbreviation

DN nominal diameter

HBW Brinell hardness

HRC Rockwell hardness, C scale

HV Vickers hardness

NPS nominal pipe size

4 General

● **4.1** The pressure design code shall be specified or agreed to by the Ppurchaser. Pressure components shall comply with the pressure design code and the supplemental requirements given in this standard.

Pressure components shall comply with the pressure design code and the supplemental requirements given in this standard.

NOTE A bullet (●) at the beginning of a subclause indicates a requirement for the Purchaser to make a decision or provide information (see checklist in Annex B).

4.2 The air-cooled heat exchanger shall be either a forced-draftdraught exchanger or an induced-draft-draught exchanger and shall include the components shown in Figure 2 and any auxiliaries such as ladders, walkways and platforms (see A.2).

4.3 Annex A, which may be consulted if required, includes for information some recommended mechanical and design details for information. Annex A also includes precautions for consideration when specifying certain design aspects, including temperature limitations, type of extended surface, tube support methods, types of air-cooled heat exchanger, materials of gasket construction and operational considerations such as walkway access.

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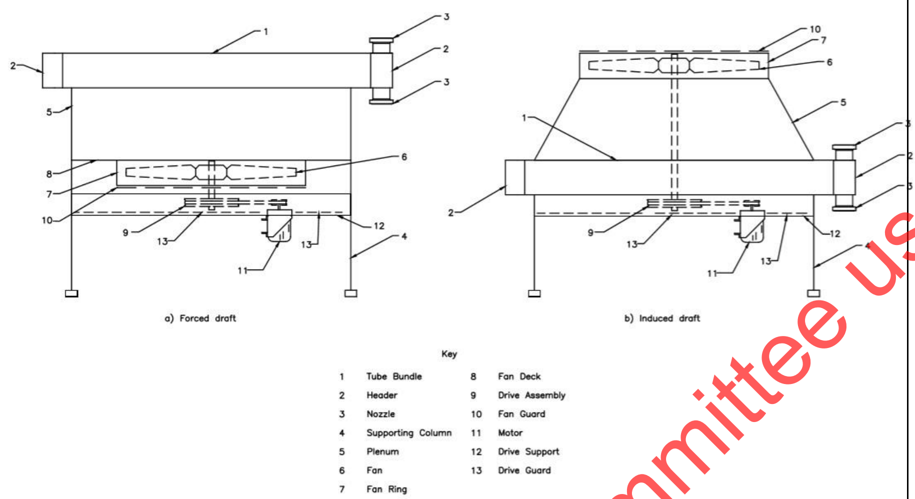
● **4.4** The ~~V~~vendor shall comply with the applicable local regulations specified by the ~~P~~purchaser.

4.5 Annex B provides a checklist that can be used by the purchaser to ensure that bulleted items in this standard are addressed. ~~In this standard, where practical, US Customary (USC) and other commonly used units are included in brackets for information.~~



~~a) Forced draft~~ **draught** ~~b) Induced draft~~ **draught**

~~Key~~

~~1 tube bundle~~ ~~6 fan~~
~~2 header~~ ~~7 fan ring~~
~~3 nozzle~~ ~~8 fan deck~~
~~4 supporting column~~ ~~9 drive assembly~~
~~5 plenum~~ ~~10 fan guard~~

Figure 22 — ~~Figure 2 —~~ Typical Components of an Air-cooled Heat Exchanger ~~(Note: Kelvion-Mike to provide sketch to update item #9 to be generic belt driven drive)~~

● **4.6** The ~~P~~purchaser shall specify if the service is designated as sour in accordance with ~~ISO 15156~~NACE MR0175 (all parts) for oil and gas production facilities and natural gas ~~sweetening~~ processing plants, or designated as wet hydrogen sulfide service in accordance with NACE MR0103 for other applications (e.g. petroleum refineries, LNG plants, and chemical plants), in which case all materials in contact with the process fluid shall meet the requirements of the applicable ~~NACE~~ standard to mitigate the potential for sulfide stress cracking (SSC). Identification of the complete set of materials, qualification, fabrication, and testing specifications to prevent in-service environmental cracking is the responsibility of the user (~~P~~purchaser). See A.2.2 for guidance on sour or wet hydrogen sulfide service.

~~Note: Update to correct NACE~~

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NOTE For the purpose of this provision, NACE MR0175 is equivalent to ISO 15156 (all parts).

4.7 The requirement for winterization and its type shall be specified by the ~~P~~purchaser. Annex C contains guidance on various methods of winterization for air-cooled heat exchangers.

4.8 Annex G provides examples of datasheets.

4.9 The purchaser shall specify if cyclic service design is required.

4.10 If cyclic service is specified, the purchaser shall specify the type and magnitude of variation in pressure, temperature, different modes of operation and flow rate, the time for the variation (hours, weeks, months, etc.) and the number of cycles or frequency for this variation expected during the life of the equipment. The extent and acceptance criteria of any required analysis shall be subject to the agreement of the purchaser. See A.2.1 for guidance on cyclic service.

4.11 The purchaser shall specify if the tube bundle is in hydrogen service.

4.12 The purchaser shall specify if the supplemental requirements of Section 12 apply to the tube bundle.

4.13 The purchaser shall specify if the requirements of high temperature hydrogen service, as included in Section 13, apply~~ to the shell and/or tube side~~.

5 Proposal~~s~~ Information Required

5.1 ~~T~~For each heat exchanger unit, the ~~V~~vendor's proposal shall include ~~a~~ completed data sheets ~~for each item (see example~~ similar to those appearing in Annex G~~B~~).

5.2 A proposal drawing that shows the major dimensions in plan and elevation, and the nozzle sizes, location, and their orientation, shall be furnished.

5.3 The proposal shall state whether vertically mounted electric motors shall be shaft up or shaft down.

5.4 The proposal shall fully define the extent of shop assembly and include a general description of the components for assembly in the field.

5.5 A~~ny~~ proposal for a design that is not ~~fully~~ described in this standard, the design code or purchaser's documents, shall include additional drawings, ~~sufficient to describe the details of~~ construction details and a description of design methods, for the proposed design.

5.6 The proposal shall include a detailed description of ~~any~~ all exceptions to the ~~specified~~ requirements of the purchaser's inquiry.

5.7 ~~The proposal shall include noise data.~~ The proposal shall include a noise data~~-~~sheet (see example in Annex G~~B~~) if specified by the ~~P~~purchaser.

5.8 The proposal shall include fan performance characteristic curves with the design point marked on the curves.

5.9 The proposal shall include details of the method used to secure the fin ends; see 7.1.11.7.

5.10 The proposal for an air-cooled exchanger with winterization /~~a~~ recirculation system (as described in Annex C) shall include drawings showing the duct and plenum sizes; net free flow area; louver type and arrangement; drive location; and proposed control schematic.

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Commented [CW21]: 660 also says "or if a datasheet is included in the inquiry, a statement indicating complete compliance with that datasheet". But we do not have this is 667! There is also a 2nd (longer) proposed wording for this clause in std clause spreadsheet.
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5.11 The Ppurchaser shall specify if tube and tube end protection is required. ~~Note: add bullet – review when reviewing IOGP paragraphs~~

5.12 The vendor shall supply a recommended spare parts list for each air-cooled heat exchanger.

6 Drawings and Other Required Data~~Documentation~~

6.1 Outline Drawings and Other Supporting Data~~Approval Information~~

6.1.1 ~~6.1.1~~The vendor shall submit, for review by the purchaser, outline drawings for each heat exchanger unit. The drawings shall include at least the following information~~For each item number, the Vendor shall produce documents that include the following information. The Purchaser shall specify which documents shall be submitted and which of them shall be subject to approval~~:

a) ~~Purchaser's~~ service, item number, ~~service,~~ project name and location, ~~P~~purchaser's order number, ~~and~~ ~~V~~vendor's shop order number and other special identification numbers;

b) design pressure, ~~maximum allowable working pressure,~~ test pressure, maximum design temperature, ~~and~~ minimum design metal temperature (MDMT)~~,~~ and any restriction on testing or operation of the heat exchanger;

c) specified corrosion allowance;

~~b)~~d) maximum allowable working pressure (MAWP) in the corroded condition and at the design temperature or when requested by the ~~P~~purchaser the maximum allowable corrosion allowance. ~~(Editor note: bullet) (Editor note: include a section in the annex giving guidance on when/why specify which method) (Bob – 2016PVP63075Ron actoon))~~

~~c)~~e) fan performance characteristic curves with the design point marked on the curve, including fan critical speeds for use with variable-frequency drives;

~~d)~~f) ~~any~~ references to the applicable codes and the purchaser's specifications ~~of the Purchaser~~;

~~e)~~g) material specifications ~~and~~ including grades for all ~~pressure parts~~components;

~~f)~~h) overall dimensions of the heat exchanger including location, dimensions of walkways, platforms, ladders and stairways; ~~Editor note Include IOGP with clarification of overall dimensions including walkways, etc. Also need to have overview of what goes where~~

~~g)~~i) dimensions and locations of supports and sizes of holding-down bolts;

j) ~~nozzle~~ connection sizes, ~~rating, facing,~~ location, projection beyond header surface, allowable ~~loadings~~ (forces and moments), ~~and~~ direction of flow and, if flanged the rating and facing, or if welded to the connecting piping the weld bevel preparation;

k) coupling sizes, rating and orientation;

l) general arrangement drawings showing header box lateral movements including any required cold set;

m) when provided, thrust-blocks between multiple bundles ~~when thrust blocks are provided~~;

~~h)~~

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Commented [CW27]: In other standards says "all components".
Commented [CW28R27]: I have changed to components as also req'd for structural members, bolting, etc.
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i)n) drive mount detailssuspension assembly details including fans, bearings, pulleys, belts, etc.; editor note expand per IOGP 6.1.2.g

j)o) masses of the tube bundle, the exchanger empty and full of water, and the mass of the heaviest component or combination of components intended by the Vvendor for handling in a single lift;

k)p) column reactions for each load type listed in 7.3.3;

l)q) requirements for postweld heat treatment requirements;

m)r) U-bend heat treatment or annealing procedure;

s) requirements for nondestructive examination (NDE)radiographic and other non-destructive examination requirements;

n)t) requirements for material impact testing;

u) requirements for surface preparation and painting requirements;

o)v) gasket materials;

p)w) maximum and minimum allowable design exposure temperatures for mechanical and instrumentation components;

x) location of nameplate, lifting lugs, grounding

q)y) clips, or other attachmentsand its position;

r)z) tube-to-tubesheet joints and details of joint preparation;

s)aa) maximum and minimum plug torque values with recommended thread lubrication;

t) when sour or wet sulfide service is specified by the Purchaser, a certified material test report (CMTR) shall be supplied for all carbon steel materials in contact with the process fluid.

bb) recommended spare parts for startup/commissioning and recommended spare parts for operation; Editor note – outstanding action re different set for startup and commissioning vs. run time (do have action item to review))

cc) pickling and passivation;

dd) positive material identification;

ee) tube welding and/or expansion into tubesheet;

ff) lifting and handling, including a lifting diagram;

gg) non-destructive examination personnel qualification records; Editor note – proposed that this is covered as part of 6.3)

hh) sub-vendor list.

6.1.2 The vendor shall recommend the tools required for the assembly and maintenance of the heat exchanger. If torquing or tensioning of bolting on cover plate headers or plugs on plug headers is required, the vendor shall provide applicable procedures.

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Commented [CW34]: This is in the wrong section so moved to 6.3.f. Should be moved to Reports and Records, and re-worded to: Certified material test reports (CMTRs) for all pressure-retaining parts, including tubes (each material test report shall be identified by a part number). For wet hydrogen sulfide service, CMTRs shall comply with the requirements of 8.2.2;

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6.2 Information Required After Outline Drawings Are Reviewed

6.2.1 Upon receipt of the purchaser's review comments on the outline drawings, the vendor shall submit copies of all detailed (nonproprietary) drawings and relevant documentation for the purchaser's review. These shall fully describe the heat exchanger and shall include at least the following information:

6.~~1~~2.2 If specified by the purchaser, the vendor shall submit details for the following:~~The Vvendor shall also furnish~~ submit gasket details drawings, field assembly drawings, and drawings for all auxiliary equipment and controls furnished. Drawings shall show electrical and control connections, including those of motive and signal air for any pneumatically actuated louvers or fans. The gasket details shall include type and material, and shall be shown on a separate drawing. This drawing shall not be marked with any restrictions for use. Editor note re IOGP, will be expanded into a list of more drawings and details required for review.~~

a) Gaskets including the type and material and shall not be marked with any restrictions for use;

b) tube bundle and tube bundle frame; ~~Editor note under review – see action as might separate~~

c) field assembly;

d) auxiliary equipment when applicable, such as lubricating system, vfd controllers, steam coils, vibration in Bently Nevada system, actuators for louvers, junction box for wiring, piping manifolds, acoustic baffles, and electrical and control connections including those of motive and signal air for any pneumatically actuated louvers or fans. Also, any other parts that are specified in the purchase order;~~and controls including cable trays and junction boxes;~~

e) structure, walkways, platforms, ladders and stairways;

f) motor suspension assembly including fans, bearings, pulleys, belts, etc.;

g) plenum chamber including plenum beams;

h) fan ring including support;

i) fan screens and guards;

j) header guard, for personnel protection and hot surfaces.

6.~~1~~2.3 If specified by the ~~P~~purchaser, the vendor shall submit ~~copies of~~ the following calculations:~~, required by the pressure design code shall be provided for the design of pressure components, including header boxes, tubes and tube joints. Sufficient detail shall be supplied for any non-standard pressure boundary components, such as swage type transition nozzles. Calculations shall also be provided for restraint relief in accordance with 7.1.6.1.3, and also for the defined external moments and forces on nozzles in accordance with 7.1.10.~~

a) calculations required by the pressure design code for design of pressure components, including header boxes, tubes, tube to tubesheet weld joints, inlet and outlet process nozzles and other non-standard pressure boundary components such as swage nozzles;

b) structural calculations to evaluate column reactions for each load types listed in 7.3.3;

c) thermal and hydraulic design calculations;

d) restraint relief calculations in accordance with 7.1.6.1.3;

e) local load analysis due to external forces and moments on nozzles in accordance with 7.1.10.

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● **6.~~1~~2.4** If specified by the ~~P~~purchaser, the vendor shall submit copies of applicable welding procedure specifications, welding procedure qualifications and weld map for review or record.~~weld maps, all proposed welding procedures,~~ These shall includ~~eing~~ tube-~~-~~to-~~-~~tubesheet welding procedures and ~~qualifications (including~~ if applicable, impact test results~~, if applicable~~) If specified by the purchaser these shall be submitted for approval prior to fabrication and/or for final record. ~~(Review after standardization discussion)~~

6.~~1~~2.5 If a hot air recirculation system is ~~utilized~~ used for winterization, documents showing duct and plenum sizes; net free flow areas; louver types and arrangement; louver drive location(s); heating coil and heating medium consumption; and control scheme schematic shall be provided.

● **6.~~1~~2.6** Further engineering information required from the ~~V~~vendor for installation, operation, maintenance, or inspection shall be a matter of agreement between the ~~P~~purchaser and the ~~V~~vendor.

~~**6.1.7** The vendor shall recommend the tools required for the assembly and maintenance of the heat exchanger. If torqueing or tensioning of bolt on cover plate headers or plugs on plug headers is required, the vendor shell provide applicable procedures. (Editor note: move 6.1.7 to be after current 6.1.5)~~

~~6.2~~6.3 ~~Final~~ Reports and Records

~~**6.2.1** The Vendor shall maintain records of the materials used and fabrication details for at least 10 years.~~

● ~~**6.2.2**~~ After the heat exchanger is completed, the vendor shall furnish the purchaser with the following documents in the format and quantities specified by the purchaser~~The Purchaser shall specify which of the following shall be furnished, and shall specify if any of them shall be in an electronic medium~~:

a) "as-built" data-sheet, including material specifications and grades for all ~~pressure~~ component~~parts~~; ~~(Note: discuss/align on as-built definition for all HX standards)~~

b) as-built shop drawings including certified outline and details of headers and tube bundles; as-built shop drawings shall also be provided for any heating coils; The drawings shall show the corrosion allowance of the header box plates and nozzles, and the minimum nominal wall thickness of the nozzles. All marked "CERTIFIED AS-BUILT".

c) all calculations as required by the pressure design code, including nozzle load confirmation, restraint relief and any finite element analysis, marked "CERTIFIED AS-BUILT";

d) certified motor drawing and completed motor data-sheet for each size and type of motor;

e) completed manufacturer's data report in accordance with the pressure design code;

f) certified material test reports (CMTR) for all pressure-retaining- ~~parts~~- parts, including tubes (each material test report shall be identified by a part number). For wet hydrogen sulfide service, CMTRs shall comply with the requirements of 8.2.2;

g) certified record of all impact tests performed;

~~f)~~h) complete certified bill of materials suitable for obtaining all replacement parts, including quantity, description, material specification, and identification of each part;

~~g)~~i) fan and hub data, including shaft bore and keyway dimensions and coupling and sheave data;

~~h)~~j) schematic diagram for automatically controlled fan pitch or louver blade adjustment, if the controller is furnished by the ~~V~~vendor;

~~i)~~k) installation, operation and maintenance instructions, including lifting and the type of lubrication ~~furnished~~ for gears and bearings;

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Commented [CW43R42]: Done, but has additional sentences that need to be considered.

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Commented [CW46]: I deleted 'furnished'. Is this in the vendor's supply? If required say 'supplied by'.

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~~j)~~l) parts list;

~~k)~~m) certified noise data~~-~~sheet for the air-cooled heat exchanger with the fans operating at rated speed and at design conditions;

~~l)~~n) fan performance characteristic curves showing the operating point and shaft power consumption;

~~m)~~o) louver characteristic performance curve;

p) temperature ~~recorder~~ charts ~~made during~~of all postweld heat treatments of the headers;

q) shop run-in test report, including all recorded test results;

~~n)~~r) thermal and hydraulic design calculations;

s) non~~-~~destructive ~~testing records~~examination (NDE) map;

t) all associated NDE reports, including radiographic, magnetic-particle, liquid-penetrant, ultrasonic, hardness, impact, positive material identification (PMI), and any other reports as applicable;

u) non-destructive examination personnel qualification records;

~~o)~~v) hydrostatic test records in the form of a chart or certification;

~~p)~~w) nameplate rubbing or facsimile.

7 Design

7.1 Tube Bundle Design

7.1.1 General

7.1.1.1 Tube bundles shall be rigid, self-contained, and designed for handling as a complete assembly.

7.1.1.2 The ~~V~~vendor shall make provision for lateral movement of exchanger tube bundles of at least 6 mm (1/4 in.) in both directions or 12.7 mm (1/2 in.) in only one direction, unless the ~~P~~purchaser and the ~~V~~vendor agree on a different value. –Cut outs in the bundle side frames shall not be used to allow for lateral movement without the approval of the ~~P~~purchaser.

~~**7.1.1.x** When specified by the Purchaser, preferential offset of the bundle shall be provided.~~

~~A cold set may be required to preferentially offset the bundle from its neutral position.~~
~~Editor note: need to reword 7.1.1x to remove may~~

~~Action item: S. Radovcich & A. Miller. Create informative section for 7.1.1.2 covering how a purchaser may account for higher piping movements~~

7.1.1.3~~y~~ When specified by the ~~P~~purchaser, thrust~~-~~blocks between headers of adjacent tube bundles shall be provided to minimize friction loads at piping takeoffs and anchors, and applied nozzle loads. See A.3.1 for additional guidance on higher piping movements and thrust-blocks. ~~*(editor note: bullet)*~~

7.1.1.~~4~~3 Provision shall be made to accommodate thermal expansion of tubes.

7.1.1.~~5~~4 All tubes shall be supported to prevent sagging and meshing or deformation of fins. Tube supports shall be spaced not more than 1.83 m (6 ft) from center to center.

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Commented [CW48R47]: Added as new clause 8.1.6

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7.1.1.65 A hold-down member (tube keeper) shall be provided at each tube support. Hold-down members shall be attached to side frames by bolting.

7.1.1.76 Tubes of single-pass condensers shall be sloped downward at least 10 mm/m ($^1/_8$ in./ft) towards the outlet header.

7.1.1.87 The last pass of tubes in multi-pass condensers shall be sloped downward at least 10 mm/m ($^1/_8$ in./ft) towards the outlet header (see A.3.1).

7.1.1.98 Air seals shall be provided throughout the tube bundle and the bay to minimize air leakage and bypassing. Any air gap that exceeds 10 mm ($^3/_8$ in.) in width shall be sealed.

7.1.1.109 The minimum thickness of metal used for air seal construction shall be 2.7 mm (12 gauge USS); 0.105 in.) within the bundle side frame and 1.9 mm (14 gauge USS; 0.08 in.) outside the bundle side frame.

NOTE USS is US Standard for sheet and plate iron and steel.

7.1.1.110 Bolts for removable air seals shall be at least 10 mm ($^3/_8$ in.) nominal diameter.

● **7.1.1.121** The exchanger shall be designed for an internal steam-out operation at the temperature, pressure, and operating conditions if specified by the Ppurchaser.

● ~~**7.1.1.12** The Purchaser shall specify if cyclic service design is required. If cyclic service is specified, the Purchaser shall specify the type and magnitude of variation in pressure, temperature and flowrate, the time for the variation (hours, weeks, etc.) and the number of cycles or frequency for this variation expected during the life of the equipment. The extent and acceptance criteria of any required analysis shall be subject to the agreement of the Purchaser (see A.2).~~

7.1.2 Heating Coils

7.1.2.1 Heating coils provided to protect the tube bundle against freeze-up shall be in a separate bundle, and not part of the tube bundle.

7.1.2.2 Heating coils shall cover the full width of the tube bundle.

7.1.2.3 The tube pitch of the heating coil shall not exceed the smaller of twice the tube pitch of the tube bundle or 4.75 times the nominal heating coil tube diameter.

7.1.2.4 If steam is used as heating fluid, heating coils shall be single pass, and the tubes shall be sloped downward at least 10 mm/m ($^1/_8$ in./ft) towards the outlet.

7.1.2.5 Pipe-type headers with welded-in tubes may be used for steam service.

7.1.3 Design Temperature

● **7.1.3.1** The purchaser shall specify a maximum design temperature and a minimum design metal temperature ~~The maximum and minimum design temperatures~~ for pressure parts. ~~shall be as specified by the Purchaser.~~

NOTE The design temperature chosen may not be the same as the material selection temperature for high temperature hydrogen service.

● **7.1.3.2** The Ppurchaser shall ~~separately~~ specify the maximum operating temperature to apply for fin type selection (the fin design temperature). The design temperatures for pressure parts are not intended to govern fin type selection or to apply in determining exposure temperatures of mechanical and instrumentation components. ~~(Note: steam out consideration)~~

Commented [CW49]: This is moved to section 4 as per our other stds (joins all the other special selection sections e.g. sour.

Commented [CW50]: There is some confusion throughout on specifying minimum design temperature and/or MDMT. In other standards this clause relates to metal temperatures!

Commented [CW51R50]: I have changed to the 663 clause re metal temperatures.

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7.1.4 Design Pressure

- The design pressure shall be as specified by the ~~P~~purchaser.

7.1.5 Corrosion Allowance

- **7.1.5.1** The corrosion allowance shall be as specified by the ~~P~~purchaser for all surfaces exposed to the process fluid, except that no corrosion allowance shall be provided for tubes, gaskets or gasket contact surfaces. If not specified by the purchaser as none, a ~~minimum~~ corrosion allowance of 3 mm (1/8 in.) shall be provided for carbon and low-alloy steel components.

7.1.5.2 The corrosion allowance shall be provided on each side of pass partition plates or stiffeners.

7.1.5.3 A thickness equal to the depth of the pass partition groove may be considered as available corrosion allowance on grooved cover plate and tubesheet surfaces.

- **7.1.5.4** When specified by the ~~P~~purchaser, once the required thicknesses of the header components and tubes have been determined based on design pressure and temperature, specified corrosion allowance, and other required criteria, then the maximum available corrosion allowance shall be determined for each component~~. Maximum available corrosion allowance shall be determined by calculation~~ based on the actual material thickness used and the required thickness in accordance with the following:~~. (editor note: make bullet) (editor note: include a section in the annex similar to 6.1.1.c) (note: wording of this paragraph to be reviewed at next meeting)~~

a) ~~a) Maximum available corrosion allowance value shall be~~ determined for tubes, and each tubesheet, plug-sheet, top, bottom, end, and partition/stiffener plate in header;~~.~~

b) ~~b) For~~ removable cover plate headers and removable bonnet headers, maximum available corrosion allowance for each flange shall also be determined;~~.~~

c) ~~c) The~~ as-built maximum available corrosion allowance for each plate or header flange shall be included on the equipment drawing and manufacturer's data report. The limiting component shall be noted;~~.~~

d) ~~d) Maximum available corrosion allowance shall be~~ determined at least to the nearest 0.1 mm (0.005 in.).

7.1.6 Headers

7.1.6.1 General

- **7.1.6.1.1** Headers shall be designed to prevent excessive ~~warpage~~ stresses of ~~tubesheets~~ header box(s) and/or leakage at tube joints. The analysis shall consider maximum operating temperature and other operating cases as specified by the purchaser~~maximum cooling conditions at minimum ambient air temperature. If specified by the Purchaser, the analysis shall~~ ~~c~~considering including alternative operations such as ~~low process flow at~~ low ambient air temperature, low process flow rate, freezing of fluids in tubes, steam-out, loss of fans due to power failure, and cyclic conditions specified in the ~~A~~additional p~~P~~rocess ~~I~~information ~~D~~datasheet~~alternative operating condition datasheet.~~.

7.1.6.1.2 If the fluid temperature difference between the inlet and the outlet of a multi-pass bundle exceeds 110 °C (200 °F), U-tube construction, split headers, or other methods including calculations, of restraint relief shall be employed. ~~The difference between inlet and outlet temperatures shall be calculated for the cold and clean condition and include abnormalnormal operating conditions (e.g. start-up, upset, loss of cooling). Editor's note: Action: Datasheet to incorporate table with upset conditions, etc., as per 660~~

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7.1.6.1.3 The requirement for restraint relief in single- or multi-pass exchangers shall be investigated regardless of the fluid temperature difference between the inlet and outlet of the exchanger. The Vvendor shall provide calculations to prove the adequacy of the design. Some of the stresses are additive, and tube-to-tubesheet joint efficiency shall be considered. Calculations shall consider the following stress combinations:

a) for tube stress and/or tube-to-tubesheet joint stress:

   1) stress caused by differential tube expansion between rows/passes in the coil sections in both clean and fouled conditions,

   2) stress caused by pressure,

   3) stress caused by nozzle forces and moments,

   4) stress caused by lateral header movement;

b) for header and nozzle stress:

   1) stress caused by temperature and pressure,

   2) stress caused by nozzle forces and moments,

   ~~NOTE Forces and moments can induce movement of the header; see note in 7.1.10.2.~~

   3) stress caused by differential tube expansion between rows/passes in the coil sections;

c) for header attachments and supports (including coil side frames and cooler structure):

   1) stress caused by mass of the header full of water,

   2) stress caused by nozzle forces and moments,

   ~~NOTE Forces and moments can induce movement of the header; see note in 7.1.10.2.~~

   3) stress caused by tube expansion.

NOTE There can be additional loads and stresses imposed on the tube bundle that have not been mentioned above (e.g. seismic).

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7.1.6.1.4 Headers shall be designed so that the corresponding cross-sectional flow area of each pass is at least 100 % of the flow area in the following tube pass.

7.1.6.1.5 The lateral velocity in the header inlet compartment shall not exceed the velocity in the inlet nozzle. Multiple nozzles or an increased header cross-sectional area can be required.

7.1.6.1.6 The ~~minimum~~ nominal thickness of header components shall not be less than as shown in Table 1.

Table 1 — ~~Minimum~~ Nominal Thickness of Header Components

Component	~~Minimum~~ Thickness	
	Carbon or low-alloy steel mm (in.)	High-alloy steel or other material mm (in.)
Tubesheet	19 (3/4)	16 (5/8)
Plug-~~-~~sheet	19 (3/4)	16 (5/8)
Top, bottom and end plates	12 (1/2)	10 (3/8)
Removable cover plates	25 (1)	22 (7/8)
Pass partition plates and stay plates	12 (1/2)	6 (1/4)

NOTE The thickness indicated for any carbon or low-alloy steel component includes a corrosion allowance of up to 3 mm (1/8 in.). The thickness indicated for any component of high-alloy steel or other material does not include a corrosion allowance. The thickness is based on an expanded tube-to-tubesheet joint with one groove.

7.1.6.1.7 Pass partitions used as stay plates for the tubesheet and plug-~~-~~sheet shall be made of one integral plate. Partition plates shall be provided with a minimum of two holes for drain or vent of 5 mm (3/16 in.) diameter. Drain holes shall be at least one nozzle internal diameter away from the process nozzle centerline.

7.1.6.1.8 Header types other than those described in 7.1.6.2 or 7.1.6.3 may be proposed as an alternative design (see Clause 12).

7.1.6.1.9 Header boxes shall be supported from the side frames by the use of angles, or similar devices, upon which the header rests. ~~Headers shall not be supported from cantilevered connections off of the side frames.~~

7.1.6.1.10 For alloy headers when slide pads are not used, the support mating surface shall be of compatible chemistry as the header box material.~~Where stainless steel headers are applied, the support mating surface shall be of similar chemistry.~~

7.1.6.2 Removable Cover Plate and Removable Bonnet Headers

7.1.6.2.1 The cover plate header design shall permit removal of the cover without disturbing header piping connections. Figure 3 a) shows the typical construction of tube bundles with removable cover plate headers. Cover plate headers shall not be used where the tube side design pressure is above 3000 kPa gauge (435 psig) or in hydrogen, sour, or wet hydrogen sulfide service. ~~Editor note add IOGP clause and modify A.3.8.1 (outstanding action)~~

7.1.6.2.2 The bonnet header design shall permit removal of the bonnet with the minimum dismantling of header piping connections. Figure 3 b) shows typical construction of tube bundles with removable bonnet headers.

7.1.6.2.3 Bolted joints shall be designed using through bolts with either confined joint gaskets or ~~unconfined~~ non-confined joint full-face gaskets. Stud bolt construction may be used if approved by the ~~P~~purchaser. Gasket contact surfaces on cover plates, matching header box flanges and tubesheets shall be machined. For the gasket types specified in Table A.3, the gasket contact surface finish of header box

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flanges, cover plates and pass partition plates shall be in accordance with Table A.4 The surface finish shall be appropriate for the type of gasket (See also A.3.12). Typical constructions are shown in Figure 4.

7.1.6.2.4x For hydrogen, sour, or wet hydrogen sulfide service, only confined joint gasket construction shall be used [see Figure 4 a) or 4 b)]. Editor note, update wording to match updated figure 4Editor note 6.1.6.1 will change to incorporate this following IOGP to some extent.

7.1.6.2.54 Either jackscrews or a minimum clearance of 5 mm ($^3/_{16}$ in.) shall be provided at the cover periphery to facilitate dismantling.

7.1.6.2.65 Stay-bolts shall not be used.

7.1.6.2.76 For stud type construction, provision (e.g. sliding pins) shall be made to prevent damage to the studs during handling of the cover plate.

7.1.6.2.87 The minimum nominal diameter of through-bolts shall be 16 mm ($^5/_8$ in.). The minimum nominal diameter of stud bolts shall be 20 mm ($^3/_4$ in.).

7.1.6.2.98 The maximum spacing between bolt centers shall be in accordance with the pressure design code.

7.1.6.2.109 The minimum spacing between bolt centers shall be as shown in Table 2.

7.1.6.2.110 Spacing between bolts straddling corners shall be such that the diagonal distance between bolts adjacent to the corner does not exceed the lesser of the spacing on the sides or the ends.

7.1.6.2.121 Allowable stresses that have been established on the basis of short-time tensile strength shall not be used for the design of flanges and gasketed flat covers.

NOTE 1 These allowable stresses can cause permanent deformation.

NOTE 2 In ASME *BPVC, Section II*, the allowable stresses of some stainless steel alloys and high-nickel alloys have been established in this way.

7.1.6.2.13x The area of the pass partition ribs shall be included in the calculations for determining the cover plate bolting requirements. (Note: Slingerland to reach out to other manufactures for input; review with task group at next meeting)

7.1.6.3 Plug Headers

7.1.6.3.1 Threaded plug holes shall be provided opposite the ends of each tube for access. Holes shall be threaded to the full depth of the plug- sheet. Figure 5 shows typical construction of a tube bundle with plug headers.

7.1.6.3.2 The nominal thread diameter of the plug holes shall be equal to the outside diameter of the tube plus at least 3 mm ($^1/_8$ in.).

7.1.6.3.3 Gasket contact surfaces of plug holes shall be spot-faced. The edges of the facing shall be free of burrs.

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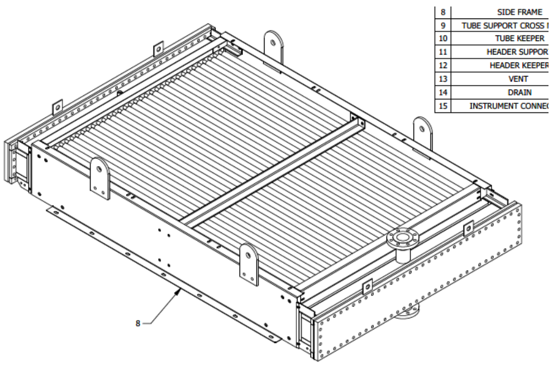

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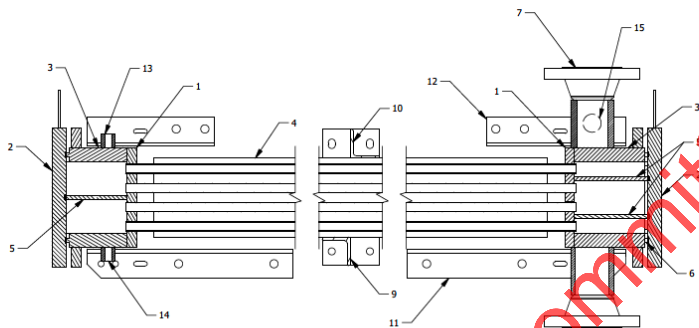

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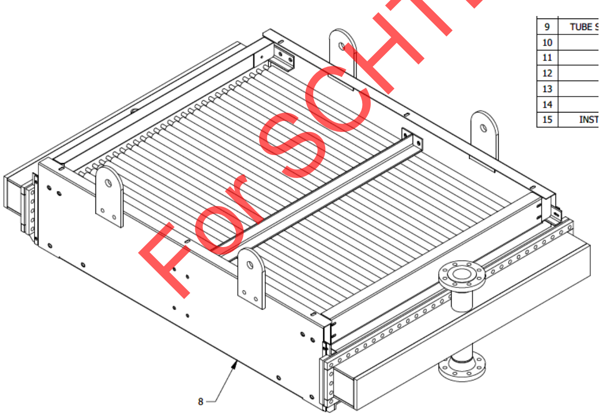
a) Removable cover-plate header



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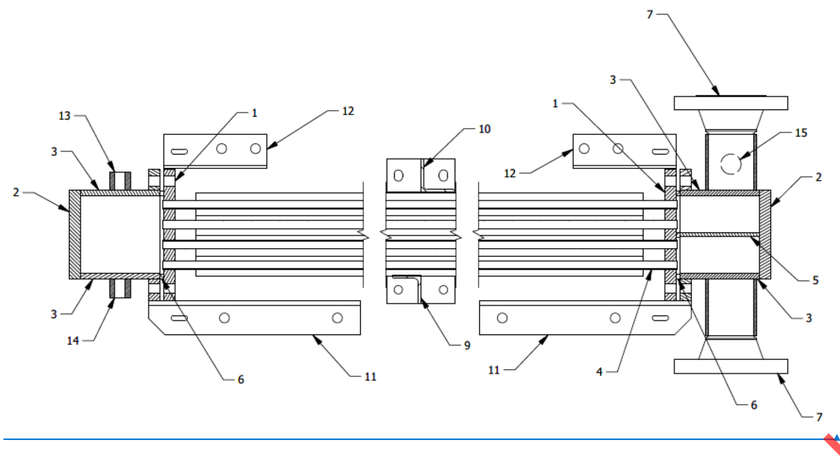


b) Removable bonnet header

Key

1 tubesheet

2 removable cover plate or removable bonnet

3 top and bottom plates removable bonnet

4 tube top and bottom plates

5 tubepass partition

6 gasket pass partition

7 nozzle gasket

8 side frame nozzle

9 tube support cross-member side frame

10 tube keeper tube spacer

11 header supporttube support cross-member

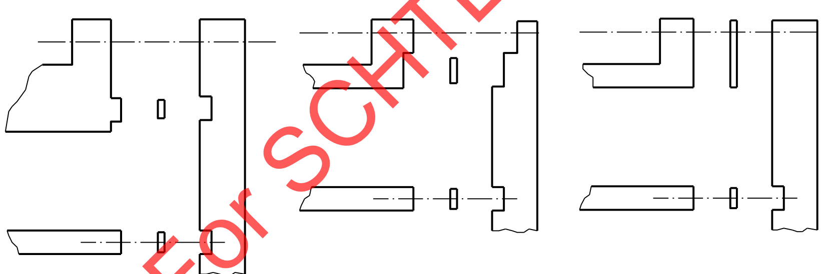
12 headertube keeper

13 vent

14 drain

15 instrument connection

Figure 33 —Figure 3 —Typical Construction of Tube Bundles with Removable Cover Plate and Removable Bonnet Headers (Editor note: check if native files exist)



a) Confined joint tongue and groove styleFlanged construction, confined gasket

b) Flanged construction, semiconfined gasketConfined joint

c) Flanged construction, nonconfined Non-confined gasketjoint

Figure 44 —Figure 4 —Typical Flanged JointConfined and Full-faced Gasket Joint Construction Details

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Table 2 — Minimum Flange Bolt Spacing

Nominal Bolt Diameter mm (in.)	Minimum Bolt Spacing mm (in.)
16 (5/8)	38 (1 1/2)
19 (3/4)	44 (1 3/4)
22 (7/8)	52 (2 1/16)
25 (1)	57 (2 1/4)
29 (1 1/8)	64 (2 1/2)
32 (1 1/4)	71 (2 13/16)
35 (1 3/8)	76 (3 1/16)
38 (1 1/2)	83 (3 1/4)
41 (1 5/8)	89 (3 1/2)
44 (1 3/4)	95 (3 3/4)
48 (1 7/8)	102 (4)
51 (2)	108 (4 1/4)

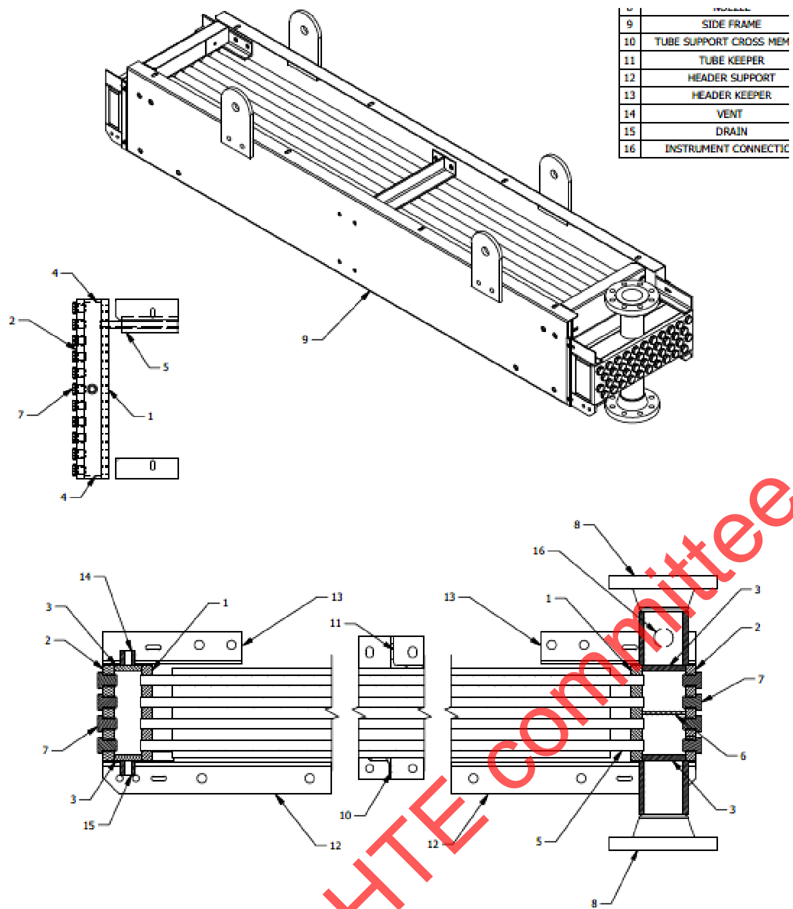
7.1.7 Plugs for Tube Access

7.1.7.1 Plugs shall be the shoulder type with straight-threaded shanks.~~Action Item – Task Group – Review need to call out alternative plug types e.g. two-piece plugs can be used with agreement by purchaser~~

7.1.7.2 Hollowed plugs shall not be used.

7.1.7.3 Plugs shall have hexagonal heads. The minimum dimension across the flats shall be at least equal to the plug shoulder diameter.

7.1.7.4 The pressure seal shall be maintained by means of a gasket between the flange of the plug and the plug- sheet.



Key

1 tubesheet
2 plug- sheet
3 top and bottom plates
4 end plate
5 tube
6 pass partition
7 plug stiffener
8 nozzle plug
9 side frame nozzle
10 tube support cross-member side frame
11 tube keepertube spacer
12 tube support cross-member header support
13 headtube keeper
14 vent
15 drain
16 instrument connection

Figure 55 — Figure 5 — Typical Construction of a Tube Bundle with Plug Headers (item 2 is not pointing clearly to the plug sheet vs. plug; update if figures are available) (item 7 should show holes to be different than item 6 in upper figure; update if figures are available) (connection of item #10 in lower figure to be updated based on new requirement above/remove side frame from the lower figure) (update by: Scott Edwards)

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7.1.7.5 Positive means (such as a self-centering taper) shall be provided to ensure seating of the gasket in the spot-faced recess.

7.1.7.6 Plugs shall be long enough to fill the plug--sheet threads, with a tolerance of ± 1.5 mm (1/16 in.), except for galling materials or if the nominal plug--sheet thickness is greater than 50 mm (2 in.), for which alternative designs may be used with the approval of the Ppurchaser. Additional factors to consider in selecting the plug design are thread interference, erosion, crevice corrosion and retention of fluid in cavities.

7.1.7.7 The thickness of the plug head from its gasket surface to the top face shall be at least 50 % of the nominal tube outside diameter. Greater thickness can be required due to pressure rating and material considerations.

7.1.7.8 Threads of plugs having nominal diameters 30 mm (1 1/4 in.) and smaller shall be fine series threads.

7.1.7.9x Two-piece plugs (i.e. utilizing a threaded plug and a separate insert/gasket compressor) may also be used.– The design details and materials of the two-piece plug shall be agreed upon between Ppurchaser and Vvendor.

7.1.8 Gaskets

7.1.8.1 Gaskets shall not contain asbestos.

7.1.8.12 Plug gaskets shall be of the solid-metal type. The material of the plug gasket shall be the same type as that of the plug, unless otherwise agreed by the Ppurchaser and Vvendor. Plug gasket hardness shall be a minimum of 20 BHN less than that of the plug and the plug-sheet materials. Nominal representative samples of 0.5 %, with a minimum of 2, shall be tested. Editor's note: Last sentence to be moved into testing section

7.1.8.3a Plug header Kammprofile gasket information (width, thickness, profile, metallurgy) (Draft paragraph by Paul Wehmer & Allen Miller)

Feedback: ACTION: Liaison with gasket manufacturers by Scott, Theresa and Carter

7.1.8.4X When plug gaskets are provided as grooved metal style with a soft gasket-sealing faces, they shall comply with the following:

The gasket shall have a flat smooth profile.

a) There shall be a minimum of two full grooves (i.e. 3 peaks) across each face of the gasket;.

b) The a metallic core shall havewith a minimum core thickness of 1.53 mm (1/168 in.) after machining of the grooves;. Action - this number to be confirmed

d)c) Thea metallic core material shall with a corrosion resistance at least equal to that of the gasket contact surface material.be equivalent to that of the plug sheet.;

e) The a facing material shall beof graphite with a minimum thickness of 0.5 mm (0.02 in.) on each side of the gasket, unless otherwise specified by the purchaser.

7.1.8.5b Plug gaskets of types other than solid-metal shall be agreed upon between the Ppurchaser and Vvendor. (note: review wording at next meeting)

7.1.8.62 Plug gaskets shall be flat and free of burrs.

7.1.8.73 The minimum thickness of solid metal plug gaskets shall be 1.5 mm (0.060 in.).

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7.1.8.84 For the joint type shown in Figure 4 a), cover plate and bonnet gaskets shall be of the double-metal-jacketed, filled type or solid metal with a soft gasket seal facing, unless otherwise specified by the purchaser. Filler material shall be non-asbestos and shall be suitable for sealing, exposure resistance and fire safety performance. Editor's note: Action: Doug will bring into line with 660 on double-metal-jacket use

7.1.8.95 For the joint type shown in Figure 4 b), double-metal-jacketed, filled type gaskets or [at design pressures of 2100 kPa gauge (300 psig) or less] compressed sheet composition gaskets suitable for the service shall be used, unless otherwise specified by purchaser. Gaskets shall be non-asbestos and shall be suitable for sealing, exposure resistance and fire safety performance.

7.1.8.106 For the joint type shown in Figure 4 c), compressed sheet composition gaskets suitable for the service may be used at design pressures of 2100 kPa gauge (300 psig) or less. Gaskets shall be non-asbestos and shall be suitable for sealing, exposure resistance and fire safety performance.

7.1.8.117 The width of removable cover plate and removable bonnet gaskets shall be at least 10 mm ($^3/_8$ in.).

7.1.8.128 Gaskets shall be of one piece. Where welds are used they shall meet the following.

a) Welds in the perimeter portion of the gasket shall be continuous and full-penetration. The cross-section, finish and flatness of these welded areas shall match the remainder of the perimeter gasket.

b) Welds shall not inhibit the sealing or compression of the perimeter gasket or pass ribs.

7.1.8.139 Double-jacketed gaskets shall not be used for the peripheral portion of the gasket in the following services:

a) hHydrogen service,;

b) oOperating temperature above 205 °C (400 °F),;

c) cCyclic service,;

d) Ssour or wet hydrogen sulfide service,;

e) dDesign pressure equal to or greater than 2100 kPa gauge (300 psig);.

7.1.8.9140 Tables in Annex A may be consulted for further guidance on gaskets. Action need specific reference

7.1.97.1.8 Nozzles and Other Connections

7.1.89.1 Flanges shall be in accordance with the pressure design code unless otherwise specified by Ppurchaser.

7.1.89.2 Connections of nominal size DN 32 (NPS 1$^1/_4$), DN 65 (NPS 2$^1/_2$), DN 90 (NPS 3$^1/_2$), DN 125 (NPS 5) or less than DN 20 (NPS ¾) shall not be used.

7.1.89.3 Connections DN 40 (NPS 1$^1/_2$) and larger shall be flanged.

7.1.89.4 In hydrogen service, sour, or wet hydrogen sulfide service, all connections shall be flanged. Slip-on and lap joint flanges shall not be used.

7.1.89.5 If design conditions require the equivalent of PN 150 (ASME Class 900) or higher flange ratings, all connections shall be flanged.

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7.1.89.6 The nominal thickness of the nozzle neck, of carbon steel and low-alloy steel flanged connections shall not be less than specified in Table 3.

Table 3 — Minimum Nozzle Neck Nominal Thickness

Pipe Size DN (NPS)	**Nozzle Neck Thickness** mm (in.)
20 ($^3/_4$)	5.56 (0.219)
25 (1)	6.35 (0.250)
40 (1$^1/_2$)	7.14 (0.281)
50 (2)	8.74 (0.344)
80 (3)	11.13 (0.438)
100 (4)	13.49 (0.531)
150 (6)	10.97 (0.432)
200 (8)	12.70 (0.500)
250 (10)	15.09 (0.594)
300 (12)	17.48 (0.688)

NOTE The data in this table are taken from ASME B36.10M, using schedule 160 for sizes up to DN 100 (NPS 4) and schedule 80 for the larger sizes.

- **7.1.89.7** The facing of process flanges shall be in a horizontal plane unless another arrangement is specified by the Ppurchaser.

7.1.89.8 Flanged connections shall be one of the following types:

a) A forged or centrifugally cast, integrally flanged welding neck.

b) A pipe welded to a forged or centrifugally cast welding neck flange.

c) A seamless transition piece attached to a forged or centrifugally cast welding neck flange.

d) A fabricated transition (e.g. nozzle necks that are fabricated by rolling and welding of plate), if agreed by the purchaser.

e) A casting, if agreed by purchaser.

f) A lap joint stub-in (except for carbon steel and low-alloy), if agreed by purchaser.

7.1.89.9 If a transition is used, stay bars, greater header thickness or greater nozzle thickness can be required to provide adequate mechanical strength.

7.1.8.10 Threaded connections shall not be used in hydrogen, sour, or wet hydrogen sulfide service. This includes auxiliary connections, such as vents, drains, instrument connections, and chemical cleaning connections.

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7.1.8~~9~~.11~~0~~ Threaded connections shall ~~be~~ not be less than DN 25 (NPS 1), except that pressure gauge connections shall ~~be~~ not be less than DN 20 (NPS $^{3}/_{4}$). This includes auxiliary connections such as vents, drains, instrument connections, and chemical cleaning connections.

7.1.8~~9~~.12~~1~~ Threaded connections shall be one of the following types and shall comply with the pressure design code:

a) forged steel full-coupling threaded one end only, with a suitable rating (e.g. ASME B16.11, class 6000);

b) forged steel fitting with integral reinforcement;

c) tapped holes for vent and drain connections, where header plate thickness permits;

d) equivalent boss connection.

● **7.1.8~~9~~.13~~2~~** The size and type of thermowell connections, if any, shall be specified by the ~~P~~purchaser. When specified~~If a thermowell connection is specified~~, it shall be located in the nozzle unless the nozzle is smaller than DN 100 (NPS 4), in which case the connection shall be located on the header adjacent to the nozzle. ~~(editor note: bullet)~~

● **7.1.8~~9~~.14~~3~~** The size and type of pressure gauge connections, if any, shall be specified by the ~~P~~purchaser. ~~If a pressure gauge connection is~~When specified, it shall be located on the nozzle unless the nozzle is smaller than DN 80 (NPS 3), in which case the connection shall be located on the header adjacent to the nozzle. ~~(editor note: bullet)~~

7.1.8~~9~~.15~~4~~ Pipe threads shall be taper pipe threads (e.g. ASME B1.20.1) and shall comply with the pressure design code.

● **7.1.8~~9~~.16~~5~~** The size, type, and location of chemical cleaning connections, if any, shall be specified by the ~~P~~purchaser.

7.1.8~~9~~.17~~6~~ If specified, instrument connections shall be located in at least one inlet and outlet nozzle per bundle, except that none is required in intermediate nozzles of stacked bundles.

7.1.8~~9~~.18~~7~~ All threaded piping connections shall be closed with a round-headed solid plug.

7.1.8~~9~~.19~~8~~ Flanged auxiliary connections, if any, shall be closed with blind flanges. The gasket and bolting materials shall be suitable for the specified operating conditions.

7.1.8~~9~~.20~~19~~ Vent and drain connections shall be provided at high and low points, respectively, on each header. Header nozzles installed at high and low points may serve as vents and drains. Connections serving as vents and drains shall not extend into the header beyond the inside surface. When split header boxes are provided, the details of the vent and drain connections shall be agreed~~ment~~ between the ~~P~~purchaser and ~~V~~vendor.

7.1.8~~9~~.21~~0~~ If the header thickness does not permit minimum thread engagement of vent and drain plugs, couplings or built-up bosses shall be installed.

7.1.8~~9~~.22~~1~~ Bolts between connecting nozzles of stacked tube bundles shall be removable without moving the bundles.

7.1.8.23 Set-in nozzles shall be flush with the inside surface of the header box plates.

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7.1.8.24 The inside corners of all set-in nozzles shall be rounded to a minimum radius of 3 mm (1/8 in.).

7.1.8.25 Nozzles shall be self-reinforced without the use of reinforcing pads.

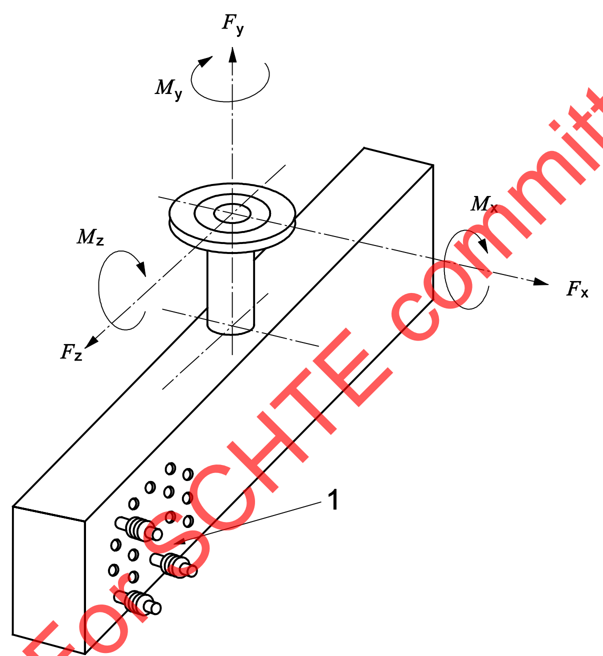
7.1.8.26 The use of stay bars for added mechanical strength or reinforcement of nozzles shall not be allowed.

~~7.1.10~~7.1.9 Maximum Allowable Moments and Forces for Nozzles and Headers

7.1.9~~10~~.1 Each nozzle, in its design corroded condition, shall be capable of withstanding the simultaneous application of the moments and forces defined in Figure 6 and Table 4.

New bullet clause – allow for 2x allowable loads in table 4 and 2x multiplier is also applied to values in 7.1.10.2. Extend RP section A.3.6 to guide limiting large load values on the air cooler nozzles and apply to 7.1.10.2 paragraph as well.

Editor Note: Check with Sarah on how calculations have been done



Key
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Figure 66 ~~—Figure 6 —~~Nozzle Loads

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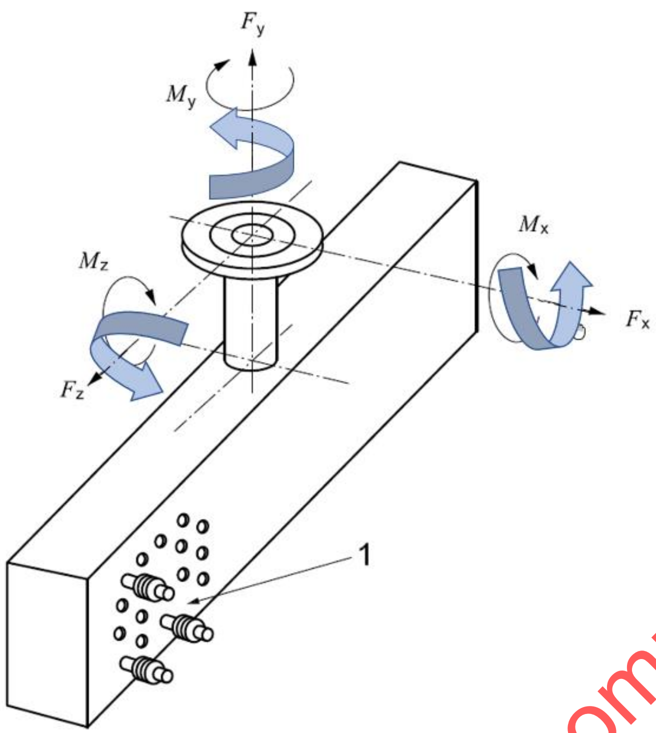

Key

1 fin tubes

Figure 6 — Nozzle Loads

Table 4 — Maximum Allowable Nozzle Loads

Nozzle Size DN (NPS)	Moments N·m (ft·lbf) M_x	M_y	M_z	Forces N (lbf) F_x	F_y	F_z
40 (1[1]/2)	110 (80)	150 (110)	110 (80)	670 (150)	1020 (230)	670 (150)
50 (2)	150 (110)	240 (180)	150 (110)	1020 (230)	1330 (300)	1020 (230)
80 (3)	410 (300)	610 (450)	410 (300)	2000 (450)	1690 (380)	2000 (450)
100 (4)	810 (600)	1220 (900)	810 (600)	3340 (750)	2670 (600)	3340 (750)
150 (6)	2140 (1580)	3050 (2250)	1630 (1200)	4000 (900)	5030 (1130)	5030 (1130)
200 (8)	3050 (2250)	6100 (4500)	2240 (1650)	5690 (1280)	13,340 (3000)	8010 (1800)
250 (10)	4070 (3000)	6100 (4500)	2550 (1880)	6670 (1500)	13,340 (3000)	10,010 (2250)
300 (12)	5080 (3750)	6100 (4500)	3050 (2250)	8360 (1880)	13,340 (3000)	13,340 (3000)
350 (14)	6100 (4500)	7120 (5250)	3570 (2630)	10,010 (2250)	16,680 (3750)	16,680 (3750)

7.1.9~~10~~.2 The design of each fixed or floating header, the design of the connections of fixed headers to side frames, and the design of other support members shall ensure that the simultaneous application (sum) of all nozzle loadings on a single header does not cause any damage. When the component summation load exceeds the values listed below, agreement on either the individual loads or component loads between the manufacture and purchaser is required~~The components of the nozzle loadings on a single header shall not exceed the following values~~:

M_x 6100 N·m (4500 ft · lbf)

M_y 8130 N·m (6000 ft · lbf)

M_z 4070 N·m (3000 ft · lbf)

F_x 10,010 N (2250 lbf)

F_y 20,020 N (4500 lbf)

F_z 16,680 N (3750 lbf)

~~NOTE The application of the moments and forces shown in Table 4 will cause movement that will tend to reduce the loads to the values given above.~~

7.1.9~~10~~.3 The total of all nozzle loads on one multi-bundle bay shall not exceed three times that allowed for a single header.

~~**7.1.10.4** See 7.1.6.1.3 for further details.~~

~~7.1.11~~7.1.10 Tubes

7.1.10~~1~~.1 The outside diameter of cylindrical tubes should be at least 25.4 mm (1 in.).

• **7.1.10~~1~~.2** The maximum tube length when there are plot limitations shall be as specified by the ~~P~~purchaser.

7.1.10~~1~~.3 The wall thickness for tubes with an outside diameter of 25.4 mm (1 in.) to 51 mm (2 in.) shall not be less than that specified in Table 5.

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Table 5 — Minimum ~~Required Wall~~ Thickness of Tubes

Tube Material	Minimum ~~Required Wall~~ Thickness[a] mm (in.)
Carbon steel or ferritic low-alloy steel (max. 9 % chromium)	2.11 (0.083)
High-alloy [austenitic, ferritic and austenitic/ferritic (duplex)] steel	~~1.65 (0.065)~~1.47 (0.058)
Non-ferrous material	~~1.65 (0.065)~~1.47 (0.058)
Titanium	~~1.24 (0.049)~~1.07 (0.042)

[a] For embedded fin tubes, this thickness shall be measured from the bottom of the groove to the inner wall.

7.1.10~~1~~.4 Tubes shall be furnished on either a minimum wall basis or an average wall basis, provided the wall thickness is ~~nowhere~~ not less than that specified in 7.1.11.3.

7.1.10~~1~~.5 Tubes may be finned or unfinned.

7.1.10~~1~~.6 For a finned tube, the total unfinned length between tubesheets after assembly shall not exceed 1.~~,~~5 times the thickness of one tubesheet.

7.1.10~~1~~.7 Any finned tube construction shall be ~~a matter of~~ agreement between the ~~P~~purchaser and the ~~V~~vendor. The ~~V~~vendor shall demonstrate that the type of construction furnished is suitable for the intended service conditions (taking into account factors such as metal temperature, cycling, loss of cooling, effect of environment and any specified abnormal operating conditions). The fin selection temperature shall be in accordance with Table 6~~A.1~~. The following are descriptions of several types of commonly used finned tube construction. ~~Editor note: remove Bullet/update first sentence to match standard wording.~~ ~~Takeaway as an action to update wording (Colin)~~

a) Embedded — rectangular cross-section aluminum fin wrapped under tension and mechanically embedded in a groove 0.25 mm ± 0.05 mm (0.010 in ± 0.002 in.) deep, spirally cut into the outside surface of a tube. Tube wall thickness is measured from the bottom of the groove to the inside diameter of the tube. The fin end at each end of the tube shall be secured to prevent loosening or unravelling of the fins; the ~~V~~vendor shall indicate the method used.

b) Extruded (integral) — an aluminum outer tube from which fins have been formed by extrusion, mechanically bonded to ~~an inner~~the tube ~~or liner~~. For extruded fins, the thickness of the remaining sleeve of aluminum between fins shall be at least 0.51 mm (0.02 in.).

c) Overlapped footed — L-shaped aluminum fin wrapped under tension over the outside surface of a tube, with the tube fully covered by the overlapped feet under and between the fins. The fin end at each end of the tube shall be secured to prevent loosening or unravelling of the fins; the ~~V~~vendor shall indicate the method used.

d) Footed — L-shaped aluminum fin wrapped under tension over the outside surface of a tube, with the tube fully covered by the feet between the fins. The fin end at each end of the tube shall be secured to prevent loosening or unravelling of the fins; the ~~V~~vendor shall indicate the method used.

e) ~~Externally b~~Other bond~~inged~~ — tubes on which fins are bonded to the outside surface by hot-dip galvanizing, brazing, or welding. ~~Editor Note: Action to verify if hot-dip galvanizing is possible (Nicolas bBilbault)~~

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f) Knurled footed — L-shaped aluminum fin wrapped under tension over the outside surface of a tube, while the foot of the fin is simultaneously pressed into the ribbed outer surface of the tube. The fin end at each end of the tube shall be secured to prevent loosening or unravelling of the fins; the Vvendor shall indicate the method used.

7.1.101.8X The maximum process operating temperature for various types of fin bonding shall be as given in Table 6X.

Note: Create an RP to discuss how to come up with maximum process operating temperature and include shutdown/upset/steam out considerations.
Note: Ensure datasheet has maximum process operating temperature input

Table 6XX — Maximum Process Operating Temperature for Fin Bonding Types

Fin Bonding Type	Maximum Process Operating Temperature °C (°F)
Embedded fins	400 (750)
Hot-dip galvanized steel fins	360 (680)
Extruded fins	300 (570)
Footed fins (single L) and overlap footed fins (double L)	130 (270)
Knurled footed fin, either single L or double L	200 (390)
Welded or brazed fins	> 400 (750) (maximum should be agreed by Ppurchaser)
Except where stated otherwise, the above limits are based on a carbon steel tube and aluminum fins; different materials for the tube and/or the fins may result in a different temperature limit and the manufacturer shall be consulted.	

f) Editor's note: Action: Doug will check alternate material suitability with manufacturers

7.1.101.98 For fins wrapped under tension or embedded, the minimum pre-formed (stock) thickness shall be as follows:

— for fin heights less than 12.7 mm (1/2 in.), the minimum pre-formed (stock) thickness shall be 0.35 mm (0.014 in.);

— for fin heights equal to and above 12.7 mm (1/2 in.), the minimum pre-formed (stock) thickness shall be 0.40 mm (0.016 in.);

— the minimum fin tip thickness for integral or extruded fins shall be 0.2 mm (0.008 in.).

7.1.101.10X For extruded fins, the minimum dimensional requirements shall be asin accordance with Figure V and Table 7 follows: Editor note use IOGP as a guide for this. Lose list.

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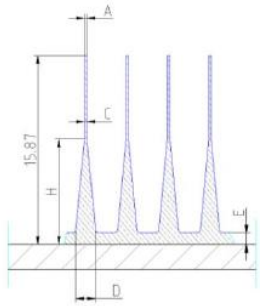

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Figure 77 — 1Fin Dimensional Geometry

Table 11 — Fin Geometries

Base tube Diameter (inch)	Fin height	FPI	Extuded type	H (mm)	A (mm)	C (mm)	D (mm)	E (mm)
1 inch	15.87 mm 5/8 inch	8	Extruded	8.87	0.20	0.20	1.70	1.00
			Heavy ext.		0.30	0.30	1.80	1.00
			Extra Heavy Ext.		0.40	0.40	1.90	1.00
1 inch	15.87 mm 5/8 inch	10	Extruded	5.8	0.25	0.50	1.100	1.00
			Heavy ext.		0.30	0.60	1.110	1.00
			Extra Heavy Ext.		0.37	0.70	1.120	1.00
1 inch	15.87 mm 5/8 inch	11	Extruded	6.8	0.24	0.24	1.00	0.80
Nearly the same dimensions on H to E values for higher base tube diameter								

Note 2. The minimum remaining thickness of the extruded liner material under fins 0.5 mm (0.02 in.).

~~fin height~~
~~fin base thickness~~
~~minimum thickness of the extruded line under fins 0.51 mm (0.02 inch)~~

7.1.10.11(14)y. Fin density under-tolerance shall not exceed 3 %.

7.1.10.12(15)z. The minimum gap between fins on adjacent tubes shall be 3 mm (1/8 in.).

7.1.10.136(aa) When extruded finned tubes are used, the purchaser shall specify if the unfinned area shall be protected taking into account ~~considering~~the tube material and/or environment of the air cooler. The method and details shall be agreed between the purchaser and ~~supplier~~vendor and may include such methods as:

a) metallizing/thermal spray;

b) sleeves;

c) coating.

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— Editor's note: Action: Extruded fin thickness requirements base and fin tip dimensions & shape? Kelvion. Also need to add inspection criteria for checking number of fins per inch. Also says RP on piping tolerances from IOGP spreadshe t ? Also see IOGP spreadsheet comment

Editor note: Action for Greg to confirm HTRI's ability to correctly model extruded fin profile

Note: Aspen EDR calculation method: Aspen Air Cooled program provides two inputs for tube length (Tube length and Effective tube length). Tube length is the total length of tube including the ends fitted into the tubesheets and where the tube comes into contact with tube supports. Effective tube length is the length of tube that is exposed to heat transfer. Inactive parts of a tube are where it fits into the tubesheets and comes into contact with tube supports. The user has option to enter effective tube length or let the program to calculate it based on the information on tube supports and tubesheets. The program would use effective tube length to perform thermal calculation. Thus, the calculated area does not include tube support location.

Note: HTRI Calculation method (v9.1 & 9.2) are correctly modeling extruded fins.

7.1.101.149 Flattening in the bend of U-tubes shall not exceed 10 % of the nominal outside diameter of the tube.

7.1.101.150 For U-tubes, design calculations shall be based on the reduction in wall thickness associated with bending. The thickness of the tubes need not be increased to meet the requirements in Table 5 provided the wall thickness in the U-bends meet the minimum requirements of the pressure design code and any specified tube corrosion allowance. The minimum tube wall thickness at the U-bend shall be calculated in accordance with Equation (1).

$$t_0 = t_1\left[1+\frac{d_o}{CR}\right] \qquad t_b = \frac{t}{\left[1+\frac{D_o}{4R_m}\right]} \tag{1}$$

where

t_0 t_b is the required tube wall thickness prior to bending, mm (in.)minimum tube wall thickness after bending;

t_1 t is the minimum tube wall thickness calculated by code rules for a straight tube subjected to the same pressure and metal temperature, mm (in.)before bending;

d_0 D_o is the tube outside diameter, mm (in.);

C is the thinning constant:
= 4, typical for the following materials: carbon steel, low alloy, ferritic stainless, austenitic stainless, other relatively non-work-hardening materials, and copper alloys.
= 2, typical for the following materials: martensitic stainless, duplex stainless, super austenitic stainless, titanium, high nickel alloys, and other work-hardening materials.

Mm (in.)

Note: different constants may be used based upon other considerations foof tube thinning and previous experience.

R_m is the mean radius of U-bend, mm (in.).

More than one tube gauge, or dual gauge tubes, may be used in a tube bundle. Flattening at the bend shall not exceed 10% of the nominal tube outside diameter. For tube bends with R < 2do, flattening may exceed 10 % when the material is highly susceptible to work hardening or when the straight tube thickness is < 2do/12. Special consideration, based upon bending experience, may be required. Special consideration may also be required for materials having low ductility.

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~~[TASK GROUP REVIEW]~~

~~The calculated thickness, t_b, shall not be less than the specified minimum required tube wall thickness as specified in 7.1.11.3.~~

~~**7.1.11.11** If U-bends are formed from tube materials that are relatively non-work-hardening and are of suitable temper, tube-wall thinning in the bends shall not exceed 17 % of the original tube wall thickness.~~

7.1.10~~1~~.15X The mean radius of U-bends shall not be less than 1.5 times the nominal outside diameter of the tube. For martensitic stainless steels, super austenitic stainless steels (>6 wt ~~-~~ % ~~-~~ Mo) duplex stainless steels, titanium, and high nickel alloys (>30 wt % Ni), the mean radius of U-bends shall not be less than 2.0 times the nominal outside diameter of the tube.

7.1.10~~1~~.16~~2~~ Requirements for heat treatment after bending of the U-tubes shall be specified by the ~~P~~purchaser. The procedures and extent of heat treatment shall be in accordance with the pressure design code and shall be agreed between ~~P~~purchaser and ~~V~~vendor.

7.1.10~~1~~.17~~3~~ Elliptical tubes shall not be used unless agreed between ~~to by~~ the purchaser and the vendor. See A.3.3.5 to A.3.3.7.

7.1.10~~1~~.17A When U-tubes are provided, the U-bends shall be provided with a support baffle or similar device which allows thermal expansion thru the support while minimizing air leakage. The details shall be agreed between the purchaser and manufacturer.

7.1.11 Tube-to-Tubesheet Joints

7.1.11.1 Tube-to-tubesheet joints shall be expanded with a groove, or two grooves, unless a strength-welded tube-to-tubesheet joint is specified by the purchaser. See A.4.2 for additional guidance on the selection of tube-to-tubesheet joints.

7.1.11.2 For expanded joints, tubesheets less than 25 mm (1 in.) thick shall be provided with one groove. A second groove shall be provided for tubesheets 25 mm (1 in.) or greater in thickness.

7.1.11.3 If welded tube-to-tubesheet joints are specified, the joint shall be welded by one of the following methods:

a) strength-welded only;

b) strength-welded and expanded

c) seal-welded and expanded.

7.1.11.4 When strength welds are applied, the degree of expansion and use of grooves shall be specified or agreed to with the purchaser.

7.1.11.5 When a strength welded joint is used without groove(s), light expansion may be used (with 1 % to 3 % wall reduction).

7.2 Air-side Design

7.2.1 General

7.2.1.1 Factors such as weather, terrain, mounting, environment and the presence of adjacent structures, buildings and equipment influence the air-side performance of an air-cooled heat exchanger. The ~~P~~purchaser shall supply the ~~V~~vendor with all such environmental data pertinent to the design of the exchanger. These factors shall be taken into account in the air-side design.

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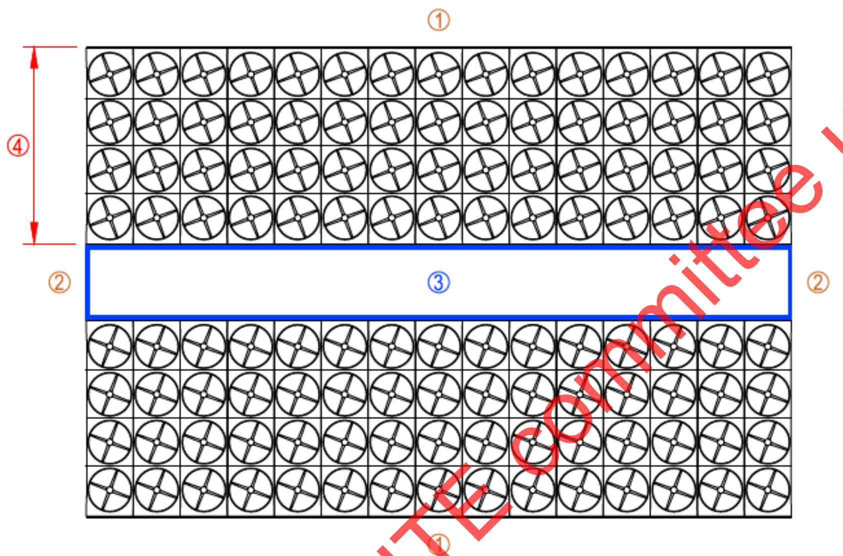
Expand the information required from the purchaser to the vendor including weather conditions, wind speed and direction (e.g. locations with high prevailing wind velocities – is HAR mitigation needed? Add guidance to A.3.10 as well?): Action Nicolas Bilbault

Feedback from Nicolas:

I propose to keep the wording above as is, but to add some specifics about the change in quantity of ACHE sitting next to each other and even facing each other especially on large LNG trains where we can have 900 ft long ACHE sitting side by side in to lines leading to up to 140 ft wide ACHE lay out with 6 to 8 fans to feed only from both ends as per below sketches:



Key:
1 Air inlet to improve feed to central fans
2 Air inlet
3 Sealing plates (No air inlet)
4 Up to approximately 20 m (65 ft)

Figure 88 — Typical multiple bundle configuration

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7.2.1.2 All air-cooled heat exchangers, whether they are located inas a single stand-alone unit orientation or in a bank of several bays located side by side, require adequate clearance below the fan plenum for forced draft units, or below the tube bundle for induced draft units, to allow an adequate quantity of air to enter the bay and traverse the tube bundle. A typical configuration for a grade-mounted installation is shown in Figure X.

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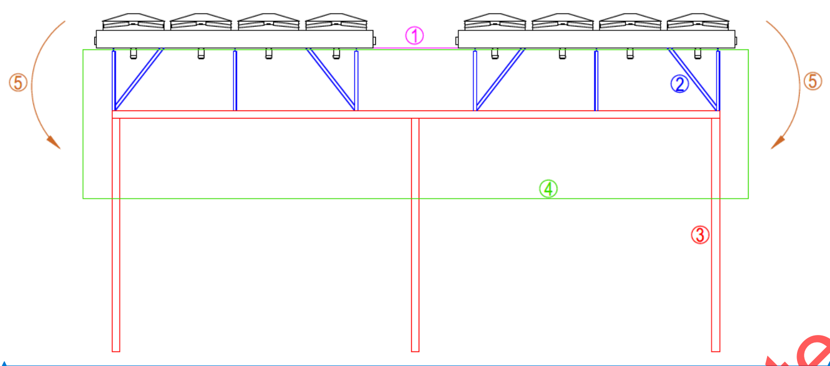
7.2.1.3 The air approach velocity (*k*) to ~~of the air approaching~~ the air-cooled heat exchanger (approach velocity) shall not exceed a nominal value of 3.6 m/s (700 ft/min) for forced draft units, or 4.1 m/s (800 ft/min) for induced draft units at the perimeter of the bay and/or bank. ~~EDITORS NOTE: Consider moving last 2 sentences to informative.~~ Adjusting the column height is the normal way that the approach velocity is attained on grade-mounted installations. Consideration shall also be given to providing adequate head clearances for mechanical equipment maintenance when adjusting the column heights. See A.3.~~9~~110.



Key:
1 Sealing plate to avoid hot air recirculation
2 Air cooler supporting structure
3 Client supporting pipe rack
4 Typical required free space for proper air inlet
5 Air inlet

Figure 99 — Typical Configuration of Grade-mounted Installations

7.2.1.4~~3~~ The minimum height above grade for grade-mounted installations shall be calculated in accordance with Equation (2):

$$h = \frac{q_v}{l_p \times k} \qquad (2)$$

where

h is the minimum height above grade to the bottom of the fan ring inlet ~~plenum chamber~~ for forced draft type units, or to the bottom of the tube bundle side frames for induced draft type units, expressed in meters (feet);

q_v is the total actual volumetric flow rate of air that the air-cooled heat exchanger(s) are design to use at design conditions, expressed in actual cubic meters per second (actual cubic feet per minute);

l_p is the length of the perimeter of the bay or bank, expressed in meters (feet), from which air will be free flowing into the air-cooled heat exchanger(s). [Include only the perimeter of which no air is being blocked or hindered by other structures or bays from entering the air-cooled heat exchanger(s)];

k is the maximum allowable approach velocity~~a constant~~, which is 3.6 m/sec (700 ft/min) for forced draft units and 4.1 m/sec (800 ft/min) for induced draft units.

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7.2.1.54 For forced draft units, the kinetic energy of the air entering through the perimeter air (ambient air density multiplied by the square of the air approach velocity) shall be less than that of the discharge air exiting the tube bundle (exit air density multiplied by the square of the average bundle exit face velocitynominal air discharge velocity). Editors note: wordsmith later…..

7.2.1.65 For units with air inlet louvers at the perimeter, the gross louver area (inside the louver frames) shall be used to determine the approach velocity. Where screens are provided at the perimeter, the area used to calculate the approach velocity shall be discounted by accounting for the area blocked by the screen mesh.

7.2.1.76 The requirement for air-flow control shall be as defined by the Ppurchaser on the basis of specific process operation requirements, including the effect of weather.

7.2.1.87 Fan selection 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 pressure increase. Since tT39pecthis requirement is to prevent stall and inefficient operation of the fan., Iit is not necessary that the resulting increased power requirement govern the driver rating, unless specified by the purchaser. Action: Ron will give corrected wording.

● **7.2.1.98** If requested by the Purchaser, the Vendor shall estimate the design exposure temperatures for mMechanical components and instruments shall be designed and manufactured for the exposure temperature based on each purchaser specified operating mode (start-up, normal operation, shutdown, loss of power, stagnated air flow, one fan inoperable, etc.) and ambient temperature rangesusing conventional heat transfer analyses and shall submit the estimate to the Purchaser for approval.

For items using air recirculation systems, design exposure temperatures for each operating mode (start-up, normal operation, shutdown, loss of power, stagnated air flow, one fan inoperable, etc.) shall be examined.

Editors Note: this clause needs to be reworked. S-710 specifically revised it, "Mechanical components and instruments shall be designed and manufactured based on design exposure temperatures for each operating mode (start-up, normal operation, shutdown, loss of power, stagnated air flow, one fan inoperable, etc.)".

7.2.2 Noise Control Editors note: per fan drive, per bay, per unit?

● **7.2.2.1** The purchaser shall specify For a heat exchanger operating in the specified service with fans operating at design speed and pitch, either or both of the following noise limits shall be specified by the Purchaser:

a) the maximum allowable sound- pressure level (L_p) values per fan drive assembly at a specified distance..at the location designated by the Purchaser; See Annex E for guidance on measurement of noise levels.

b) **7.2.2.2** If specified by the purchaser sound- power level (L_W) values per fan drive assembly shall be provided. (all fans running?)

NOTE A typical noise data sheet is shown in Annex BG.

7.2.2.3 The Vendor shall submit sSound- power and sound- pressure levels of the equipment, shall takieng into account relevant information, e.g. plenum geometry, inlet shape (type and dimension of bell or cone), obstructions (identified by purchaser?), etc. Reference to fan includes driver, speed reducer, etc. Editors note: test with complete bay running or single fan? Each fan drive assembly should have sound pressure limit at a distance. Sound– power level is useful for generating near/far field sound map, which can be used in overall noise map for the installation, e.g. large LNG plants, balance between single fan

Commented [CW78]: Need consistent spelling. Propose "airflow control" when it is the system, and "stagnated air flow" when related to the flow of air.

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Commented [CW79]: Unclear if this was the intent. TG review suggested. Probably 2nd paragraph can be deleted.

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drive and total sound- power level. ACTION:Allen to reword 7.2.2.1, 2, 3 with considerations from datasheet.

7.2.2.2 The order of preference for obtaining the required noise data shall be as follows:

a) actual testing of a representative bay installed either in an environment remote from other noise sources (shop or field tests) or installed in an operating plant;

a) derivation of noise data by testing similar equipment and adjusting the data for the actual equipment size and operating conditions. Both the measured data and the correction procedure shall be reported.

7.2.2.3 Guidance for determining noise levels is included in Annex E. Editors note: move to appropriate spot. Added to 7.2.2.1

7.2.3 Fans and Fan Hubs

7.2.3.1 Two or more fans aligned in the direction of tube length shall be provided for each bay, except that single-fan arrangements may be used if agreed by the Ppurchaser.

7.2.3.2 Fans shall be of the axial flow type.

7.2.3.3 Each fan shall be sized such that the area occupied by the fan is at least 40 % of the bundle face area served by that fan (the bundle face area being the nominal width of the bundle or bundles multiplied by the nominal tube length).

7.2.3.4 Each fan shall be located such that its dispersion angle shall not exceed 45 degrees at the upper most or lower most tube row depending on the fan type selected. Bundle centerline, as shown in Figure 7. Editors note; consider adding minimum plenum depth requirement, see S 710

Action item: S. Edwards. Update figure 7 to show upper and lower most tube for definition in 7.2.3.4. C. Weil has base Autocad files.

7.2.3.5 The fan tip speed shall not exceed the maximum value specified by the fan manufacturer for the selected fan type. Fan tip speed shall not exceed 60 m/s (12,000 ft/min) unless approved by the Ppurchaser. In no case shall the fan tip speed exceed 80 m/s (16,000 ft/min). Noise limitations can require lower speeds.

7.2.3.6 The radial clearance between the fan tip and the fan orifice ring shall be as shown in Table 6.

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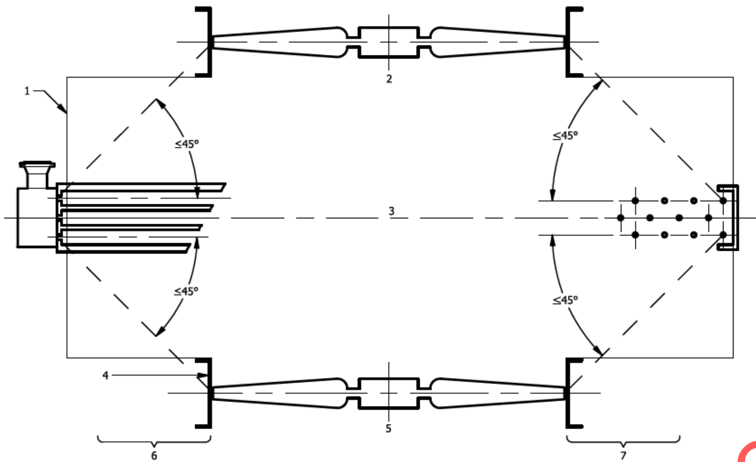

Key

1 plenum
2 induced draft~~draught~~
3 centerline of bundle
4 fan ring
5 forced draft~~draught~~
6 side
7 front

Figure 10~~10~~ — Figure 7 — Fan Dispersion Angle

Table 6 — Radial Clearances

Fan Diameter		**Radial Clearance** mm (in.)	
m	(ft)	Minimum	Maximum
≤ 3.0	(≤ 9)	6.35 (1/4)	12.7 (1/2)
> 3.0 and ≤ 3.5	(> 9 and ≤ 11)	6.35 (1/4)	15.9 (5/8)
> 3.5	(> 11)	6.35 (1/4)	19.05 (3/4)

7.2.3.7 Detachable fan blades shall be moment-balanced against a master blade.

7.2.3.8 Each fan assembly shall be balanced by one of the following means:

a) dynamic balancing as an assembly;

b) dynamic balancing of the hub and static moment-balancing of the blades.

7.2.3.9 The fan assembly shall be designed to minimize reverse air flow at the hub e.g. using a center hub disc. ~~Editors note: bad sentence. Needs to be modified or deleted. See S-710.~~

7.2.3.10 For fans having a diameter larger than 1.5 m (5 ft), individual fan blades shall be manually adjustable for varying blade pitch.

7.2.3.11x The PThe purchaser shall specifyic if the Use of automatic control for varying the blade pitch is required.shall be as specified by the Purchaser. Editors note: get input from suppliers: how often is auto variable pitch used?

ACTION; Ron to get with Doug and debrief including when action items should be completed.

Stopped here: 5/18/2021

Start here 11/16/2021

7.2.3.121 Fans equipped for pneumatically actuated, automatically controlled pitch adjustment of blades shall comply with the following.

a) If a single controller operates more than one actuator, the Ppurchaser shall provide an isolating valve in the control signal line for each actuator, to allow maintenance.

b) The pneumatic actuator may be equipped with a positioner or a bias relay.

c) If provided, the positioner or bias relay shall be designed to operate on a 20 kPa to 100 kPa gauge (3 psig to 15 psig) pneumatic control signal. Each change in the control signal shall result in a corresponding change in the fan blade pitch. The operating range of the positioner shall be adjusted so that the maximum pitch obtained is equal to the selected design blade angle setting. The fan manufacturer shall set maximum and minimum blade pitch limit stops. Unless otherwise specified by the Ppurchaser, the minimum blade pitch limit shall result in an essentially zero air flow.

d) The Vvendor shall furnish a flexible tubing connection approximately 300 mm (12 in.) long for connecting to the Ppurchaser's control-air line. The tubing shall connect to a rigid steel or alloy pipe or tube that terminates outside the fan enclosure. A terminal fitting for connection to the Ppurchaser's control-air line shall be DN 8 (NPS ¼1/4). Pipe threads shall be taper pipe threads.

● e) The Ppurchaser shall specify the direction of change of the fan pitch with loss of control-air pressure.

7.2.3.132 Hub and fan assemblies with automatically controllable pitch adjustment employing lubricated joints shall be designed to minimize lubrication maintenance through the use of bearings not requiring periodic re-lubrication.

7.2.3.143 The fan characteristic performance curve shall relate static or total pressure, rate of flow, blade pitch, and fan input shaft power, for dry-air standard conditions as stated in Table 7. The operating point and power for the specified design conditions shall be shown on the fan characteristic performance curve.

Table 7 — Dry-air Standard Conditions

Dry-bulb temperature	21.1 °C (70 °F)
Pressure	101.3 kPa (29.92 in. of mercury)
Density	1.2 kg/m^3 (0.075 lb/ft^3)

7.2.3.154 The natural frequency of the fan or fan components shall not be within 10 % of the blade-pass frequency. Blade-pass frequency (in passes per second) equals the number of blades multiplied by the fan speed (in revolutions per second). Slipping drive belts, low power supply voltage or variable fan-speed

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control operation cause fan speeds lower than design values; if the blade pass frequency exceeds the natural frequency of the fan or component, the effect of such operation shall be evaluated.

7.2.3.165 No materials (fan blades, hubs, blade retainers and any elastomeric material, etc.) shall be exposed to temperatures above the manufacturer's recommended operating limit, regardless of whether the fan is at rest or in operation.

7.2.3.176 The fan design for the exchanger shall take into account the additional pressure drop associated with the air flowing across insect screens and lint screens, plus an additional allowance for fouling that takes place on the screens. The estimated additional fouling pressure drop component shall be equal to two (2) times the clean pressure drop through the screens. The fan and motor shall be designed to account for an increased pressure drop across the screens due to fouling at least 10 % of the static pressure drop across the tube bundle. The pressure drop from air flowing across hail screens shall also be taken into account, although it is not necessary to add additional fouling pressure drop due to the location of the hail screens.

7.2.3.18 When glass fiber reinforced plastic (GFRP) blades are used, they shall be provided with ultra-violet protection.

7.2.3.19 Induced draft fan mounting and bearing arrangements shall be designed to allow fan and hub removal and re-installation without disturbing the tube bundle or shaft.

Editors note: Define screen/skirt? Consider addressing wind screens and other devices used to mitigate HAR.

7.2.4 Fan Shafts and Bearings

7.2.4.1 Anti-friction shaft bearings shall have a calculated rating life, L_{10}, of 50,000 h at maximum load and speed in accordance with ISO 281 and/or ISO 76, where L_{10} is the number of hours at rated bearing load and speed that 90 % of a group of identical bearings will complete or exceed before the first evidence of failure.

7.2.4.2 The bearing housing design shall incorporate seals to prevent lubricant loss during operation and when the shaft is idle.

7.2.4.3 The bearing housing design shall incorporate a grease release for all bearing housings to prevent overfilling.

7.2.4.4X The bearing housing design shall incorporate seals to prevent and entry of water or foreign materials during operation and when shaft is idle. The bearing mounting and housing design shall incorporate a device such as a "slinger plate" or "deflector plate".The bearing design shall incorporate seals to prevent loss of lubricant and entry of foreign materials.

● **7.2.4.5Y** When specified by the purchaser, an external conical slinger shall be fitted to the fan shaft to prevent water from entering the housing along the shaft. (Editor note, make bullet)

7.2.4.3 The fan shaft diameter shall suit the bearings. Bearings shall be sized in accordance with 7.2.4.1.

7.2.4.64 Fan shaft stresses shall not exceed the values given in AGMA 6001.

7.2.4.75 Fan shafts shall have key seats and fits in accordance with ISO 2491 and ISO 286 (all parts) (tolerance N8).

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7.2.4.~~8~~6 Fan bearing exposure temperatures above 127 °C (260 °F) require one or more special features such as high-temperature seals, heat stabilization, retainers or modified internal clearances. Lubricants shall be suitable for the design exposure temperature plus any temperature due to friction and loading.

7.2.4.~~9~~7 The upper fan shaft (radial) bearing shall be a single row ball bearing with metal retainer. Alternate bearing designs may be proposed by the vendor subject to the approval of the ~~P~~purchaser.

7.2.4.~~10~~8 The lower fan shaft (thrust) shall be a double row spherical roller bearing in a flange block housing. Alternate bearing designs may be proposed by the vendor subject to the approval of the purchaser.

7.2.4.~~11~~9 The radial run-out tolerance, expressed as TIR (total indicator reading), of the supplied fan shaft shall not exceed 0.05 mm (0.002 in.) for forced draft fans and 0.13 mm (0.005 in.) for induced draft fans.

7.2.4.1~~2~~0 The radial run-out tolerance of the sheave attached to the fan shaft, at its outer edge, shall not exceed the values permitted by RMA IP-27.

7.2.4.1~~3~~1 The axial run-out tolerance of the sheave attached to the fan shaft shall not exceed the values permitted by RMA IP-27. The axial run-out may be measured on both the top and bottom faces of the sheave, with the smaller of the two readings being used.

~~Editor note: sheave definition needed (include in definition commonly referred to as pullies and sprockets)~~

7.2.5 Lubrication Facilities~~Feedback~~

7.2.5.1 Bearing houses shall be designed to allow for the greasing of fan and motor bearings (when required) while the equipment is in operation and without having to remove protective guards.

7.2.5.2 Grease lines shall be provided ~~as necessary~~ so that all connections are accessible from the~~a~~ service platform(s) or grade.

7.2.5.3 Separate grease lines shall be provided for each injection point.

7.2.5.4 Grease lines shall utilize stainless steel tubing unless otherwise specified by the purchaser.

Note: In marine or coastal environments, materials with a higher chloride cracking resistance ~~(e.g. Alloy 800)~~ are sometimes used.

7.2.5.5 Grease lines shall have an outside diameter of at least 6 mm (1/4 in.). The length of the grease lines should be minimized.

~~Connections shall be provided outside the fan guards to permit grease lubrication of fan shaft bearings without shutdown of the equipment. Stainless steel tubing with an outside diameter of at least 6 mm (1/4 in.) shall be used for grease lines. The connections shall be accessible from grade or service platforms. The length of the grease lines should be minimized.~~Potential Note/RP section to guide the purchaser in certain environments may require increased metallurgy. Action: L. Pasnik

~~Action item to reword 7.2.5.1-7.2.5.3 for better flow: A. Miller~~

7.2.6 Fan Guards

7.2.6.1 Removable steel fan guards shall be ~~furnished on forced-draught exchangers~~provided.

~~**7.2.6.2** The materials of fan blades and fan guards shall be a non-sparking combination.~~

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Commented [CW80]: Unclear what req'd here. Note clause above. Potential Note/RP section to guide the purchaser in certain environments may require increased metallurgy. Action: L. Pasnik
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7.2.6.23 Flattened expanded metal for fan guards shall not exceed 50 mm (2 in.) nominal mesh size.

7.2.6.34 The minimum thickness of expanded metal mesh shall be as shown in Table 8.

Table 8 — Minimum Thickness of Expanded Metal Fan Guard Mesh

Nominal size mm (in.)	Minimum thickness mm (in.)
40 (1 1/2)	2 (0.070)
50 (2)	3 (0.110)

7.2.6.45 The openings in woven or welded mesh for fan guards shall not exceed an average area of 2600 mm^2 (4 in.^{2}) if the wire spacing in both directions exceeds 25 mm (1 in.).

7.2.6.56 The thickness of wire for welded or woven mesh shall be at least 2.77 mm (12 BWG; 0.109 in.).

NOTE BWG is Birmingham Wire Gauge.

For REVIEW:

"The thickness of the _____(carbon steel component) shall be XX gauge.

Note: XX gauge is equivalent to Y.YYY mm (0.ZZZZ in)."

7.2.6.67 Fan guards shall be designed with stiffening members so that a concentrated load of 1000 N (200 lbf) on any 0.1 m^2 (1 ft^2) shall not cause fastener failure or stiffener deflection greater than L/90, where L is the length of the span between points of support.

7.2.6.78 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 the lesser.

7.2.6.89 Gaps between the fan guard and equipment or between sections of the fan guard shall not exceed 12 mm (1/2 in.).

7.2.6.9 Fan guards shall provide maintenance access i.e. removable or hinged section.

7.2.7 Drivers

7.2.7.1 General

● **7.2.7.1.1** The purchaser shall specify the type of drive system and the Vvendor's scope of supply.

7.2.7.1.2 For electric motor drivers, the rated shaft power available at the motor shaft shall be the greater of the terms on the right sides_ of the following expressions.

$P_{dr} \geq$ 1.05C1 (P_{f1}/E_m) Equation (X1)

$P_{dr} \geq$ 1.10C2 (P_{f2}/E_m) Equation (X2)

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Commented [CW81]: Not sure how this relates to the previous sentence.

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Wwhere:

P_{dr} is driver rated shaft power;

P_{f1} is fan shaft power operating at design blade angle; specified minimum design temperature with blade angle set for design dry-bulb temperature;

E_m is mechanical efficiency of separate power transmissions;

P_{f2} is fan shaft power operating at design dry-bulb temperature.

These requirements apply to fixed-pitch, variable-pitch and variable-speed fans unless otherwise specified.Equation X1 is only applicable to non-variable-speed operation with fixed or variable-pitch fans. For units provided with variable-speed fans, see RP section XXXX.
Action: R. Hill. Create/update RP section to give guidance when shaft power margin is required.

C1 = 1.05 when considering operation at the minimum design temperature

C2 = 1.10 when considering operation at the design dry-bulb temperature

The Ppurchaser may specify larger values for C1 and C2.

New RP section for variable speed fans including guidance for startup in cold environments. Action: P. Harte to create RP and update normative text (Backup- A. Miller)

7.2.7.2 Electric Motor Drivers

● **7.2.7.2.1** Electric motors shall be three-phase, totally enclosed, fan-cooled motors suitable for service in petrochemical installations and capable of full-voltage starting, full-phase inversion, continuous duty and designed for an 80 °C (140 °F) temperature rise over 40 °C (104 °F) ambient temperature at nameplate rating. The purchaser shall specify the voltage and frequency, the applicable motor specification, the hazardous area classification, the temperature classification and the insulation class.

7.2.7.2.2 The motor manufacturer shall be advised that the motor is intended for air-cooled heat exchanger service and operation outdoors, unprotected against the weather. If the motor operates vertically, the motor manufacturer shall verify in writing that the motor is suitable for vertical operation, either shaft up or shaft down.

7.2.7.2.3 Unless otherwise agreed by the Ppurchaser, motor frames shall be of cast steel or corrosion-resistant cast iron, with integrally cast support feet.

7.2.7.2.4 The motor design loading shall exclude the service factor allowance.

7.2.7.2.5 Motors shall have grease-lubricated bearings designed for an L_{10} life of at least 40,000 h under continuous duty at rated load and speed (see 7.2.4.1 for the definition of L_{10}). If the motor is mounted vertically, the bearing lubrication system and seals shall be suitable for a vertically mounted motor.

7.2.7.2.6 If the motor is mounted in the shaft-up position, the belt sheave shall be designed as a shield to prevent water from accumulating and being directed down the motor shaft while the motor is either idle or running. Alternatively, an external conical slinger may be fitted to the shaft to prevent water from entering the housing along the shaft.

7.2.7.2.7 Motors shall have drains at the lowest point of the frame as mounted on the air-cooled heat exchanger.

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Commented [CW83]: New RP section for variable speed fans including guidance for startup in cold environments. Action: P. Harte to create RP and update normative text (Backup- A. Miller
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7.2.7.2.8 Standard motors are designed for 40 °C (104 °F) ambient temperature and altitudes not exceeding 1000 m (3280 ft). Higher temperatures and/or altitudes (resulting in reduced air density) can require improved insulation or an increase in motor frame size. If it is required that the motor be suitable for service exceeding the standard conditions, the motor manufacturer shall be notified.

- **7.2.7.2.9** If specified by the Purchaser, aA self-actuating braking device shall be installed to prevent reverse rotation of an idle fan.

- **7.2.7.2.10X** When specified by the Ppurchaser, emergency shutdown switch shall be installed for each fan local to the unit.

Editor note, add bullet above

7.2.7.3 Variable-speed Drive Systems

- Requirements for variable-speed drive systems (VSDS) shall be agreed between the Ppurchaser and the Vvendor. This shall include the range of speeds required.

7.2.8 Couplings and Power Transmissions

7.2.8.1 General

7.2.8.1.1 Bushings and couplings shall be either split taper or cylindrical fit and shall be keyed.

7.2.8.1.2 Power transmission components shall have a rated power for continuous service that is at least equal to the rated power of the actual driver multiplied by the component service factor.

7.2.8.1.3 Fan shaft and gear shaft couplings shall be the non-lubricated type and shall have a minimum service factor of 1.5.

7.2.8.1.4 Exposed moving parts shall have guards in accordance with 7.2.8.4.

7.2.8.1.5 Figure 8 shows typical drive arrangements.

7.2.8.2 Belt Drives

7.2.8.2

7.2.8.2.1 Belt drives shall be either conventional V-belts or high-torque type positive-drive belts. Belt selection has to consider the environmental conditions it will be exposed to and the operating conditions.

Add new clause: Belt . Editor Note: Add RP to guide the purchaser around conditions. drives shall be selected for a minimum of 2 years continuous use in the operating environment.

7.2.8.2.2 Belt drives exposed to the exhaust air streamin a heated air stream (such as mounted above the tube bundletop-mounted drives) shall not be used unless approved by the Ppurchaser. If so approved, the belt design temperature shall take into account the maximum air temperature near the belt (or the maximum belt temperature possible due to radiation) under all conditions; decreased fan efficiency shall also be taken into account. The Vvendor shall indicate how the driver is suspended; the driver should not be located in the exhaust heated air stream (see also 7.2.7.2.8 and 7.2.8.2.13).

7.2.8.2.3 Belt drives shall be provided with guards in accordance with 7.2.8.4.

7.2.8.2.4 Belt drives shall be provided with jack screws or an equivalent means of initial belt-tensioning and/or re-tensioning.

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7.2.8.2.5 V-belt drives shall be in accordance with ISO 1081, ISO 4183, ISO 4184, ~~ISO 5287,~~ ISO 5290, and/or ISO 9563 as applicable. ~~Action item: Jey to verify if all external references are still valid. Jerry Allison to verify vendors are using/in compliance with all external references~~

7.2.8.2.6 V-belts shall be either matched sets of individual belts or a multiple-belt section formed by joining a matched set of individual belts.

7.2.8.2.7 High-torque type positive-drive belts may be either one belt or a pair of matched belts.

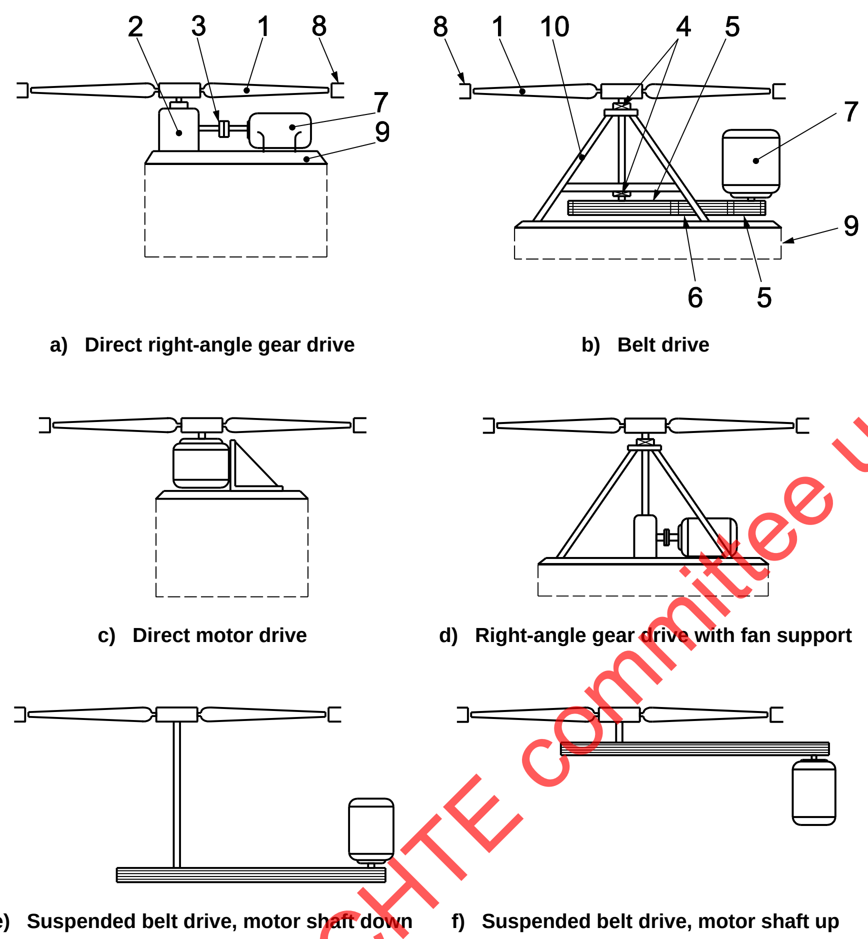
7.2.8.2.8 V-belts shall have a minimum service factor of 1.4 based on driver rated power.

7.2.8.2.9 High-torque type positive-drive belts shall have a minimum service factor of ~~1.8~~2.0 based on driver-rated power.

7.2.8.2.10~~X1~~ High-torque type positive-drive-belt drive assemblies shall be used with motor drivers rated up to and including 45 kW (60 hp).

7.2.8.2.11~~10~~~~X2~~ V-belt drive assemblies ~~suspended from the structure~~ may be used with motor drivers rated ~~not higher than~~up to and including 30 kW (40 hp) with the agreement of the purchaser.

~~**7.2.8.2.11** High-torque type positive-drive-belt drive assemblies suspended from the structure may be used with motor drivers rated not higher than 45 kW (60 hp).~~



Key

1	fan	6	belt ~~drive~~
2	gear box	7	motor
3	coupling	8	fan ring
4	bearing	9	base plate
5	sheave	10	fan support

Figure 11~~11~~ — ~~Figure 8 —~~ Typical Drive Arrangements

7.2.8.2.12 The drive-belt jacket shall be oil resistant.

7.2.8.2.13 Standard driveDrive-belt materials shall be suitable for a temperature range from the minimum specified ambient temperature are limited to an exposure temperature of to 60 °C (140 °F). When the maximum exposure temperature is greater than 60 °C (140 °F), agreement between purchaser and manufacturer is required. Note: Verify ambient temperature is specified by purchaser. (7.2.1.1)

7.2.8.2.14X2 Drive belts, both V-belt and HDT styles, shall comply with ISO 9563 for electrical conductivity. Action: Jerry & Scott

7.2.8.2.14.1 Drive belts shall comply with RMA Bulletin IP-3-3 maximum resistance requirements for static conductive belts limiting to six mega-ohms when an electrical potential of 500 volts is applied to a clean, dry surface of the belt through electrodes spaced 215 mm (8.5 in) apart.

Note: A belt with a measured resistance greater than six mega-ohms is considered non-conductive. Action: S. Edwards to verify if bulletin to see if applicable to API 661.

7.2.8.2.14.2 For synchronous power transmission belting (positive engagement of belt teeth), the reference document is ISO 9563, which describes a test procedure and fixture specific to synchronous belting, where the electrodes are machined to match the specific tooth profile of the belt. The maximum allowable resistance, measured with an applied potential of 500 Volts, is calculated as follows:

R = 6x105L

where R = resistance in ohms

L = distance between electrodes

7.2.8.2.15 Spare belts shall be suitable for a six-year shelf life when stored in accordance with RMA bulletin IP 3-4. ACTION Replace with new clause from Raj

Action: Jay will liaise with manufacturers of motors and belts (suggest get names from a/c manufacturers) on the values, etc., of 14.1 and 14.2.

7.2.8.3 Gear Drives

7.2.8.3.1 Electric motors rated higher than 45 kW (60 hp) shall use gear drives; . smaller Smaller motors may use gear drives.

7.2.8.3.2 When gear drives are used, a common, rigid structure shall support both the motor and gearbox. Gear drives for electric motors rated not higher thanup to and including 45 kW (60 hp) may be suspended from the structure. Note: consider IOGP paragraph

7.2.8.3.3 Gears shall be of the spiral bevel type. They shall have a minimum service factor of 2.0 in accordance with ANSI/AGMA 6010.

7.2.8.3.4 Top-mounted gear Gear drives shall not be mounted above the tube bundleused.

7.2.8.3.5 Gear boxes shall be provided with an external oil level indicator visible from the maintenance platform.

7.2.8.3.6X1 Purchasers shall specify if the gear box requires compatibility with oil mist lubrication system. Editor note: Bullet item

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7.2.8.4 7.2.8.4 Direct Motor Drives

When specified by the purchaser, direct motor drives may be used. When applied, the requirements of the systems must be agreed by the purchaser and vendor. (Editor note: make bullet).

RP on use of direct drive systems (adv & disadv): Action for R. Hill to draft

7.2.8.47.2.8.5 Mechanical Power Transmission Guards (Editor Note: Renumber)

7.2.8.54.1 Guards shall be provided for moving components.

7.2.8.54.2 Guards shall be constructed to allow ready access for maintenance of the equipment.

7.2.8.54.3 Gaps between guards and equipment shall not exceed 12 mm ($^1/_2$ in.).

7.2.9 Vibration Cut-out SwitchesDevices (Action: A. Miller to draft rewrite of 7.2.9) Feedback

7.2.9.1 A vibration monitoring device shall be provided for each fan driver unit to measure radial vibration, and the type shall be specified by or agreed to by the purchaser. One readily accessible vibration cut-out device shall be provided for each fan driver unit if specified by the Purchaser.

7.2.9.2 When required, the type of vibration cut-out device shall be specified by or agreed to by the Ppurchaser.

7.2.9.3 When mechanical vibration switches are specified, they shall comply withinclude the following:

a) They shall be a double-throw, two-contact type of switch, suitable for the hazardous area classification.;

b) They shall be of the a manual, externally reset type that does not requireing dismantling of the switch for resetting, and shall have sensitivity adjustment.

7.2.9.4 When vibration transducers are specified, they shall complyinclude with the following:

a) They shall be a velocity transmitter or transducer (velometer) type, suitable for the hazardous area classification.;

b) Uunless otherwise specifiedagreed, they shall have a high alarm setting of 132.7 mm/s (0.5 in./s) and shutdown at 25 mm/s (1 in./s).

7.2.9.1 One readily accessible, double-throw, two-contact vibration cut-out switch shall be provided for each fan driver unit if specified by the Purchaser.

7.2.9.2 Vibration cut-out switches shall be of the manual, externally reset type not requiring dismantling of the switch for resetting and shall have sensitivity adjustment.

7.2.10 Louvers

7.2.10.1 All requirements in 7.2.10 apply to both parallel- and opposed-action louvers, unless otherwise specified.

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7.2.10.2 The thickness of louver blades manufactured from plain sheets shall be at least 1.5 mm (16 gauge USS; 0.060 in.) for carbon steel and 2.3 mm (13 gauge USS; 0.090 in.) for aluminum. The thickness of extruded hollow-shaped aluminum blades shall be at least 1.5 mm (16 gauge USS; 0.060 in.).

7.2.10.3 Frames of carbon steel shall be at least 3.5 mm (10 gauge USS; 0.135 in.) thick; frames of aluminum shall be at least 4 mm (0.160 in.) thick.

7.2.10.4 The unsupported louver blade length shall not exceed 2.1 m (7 ft).

7.2.10.5 The deflections of louver blades and side frames shall not exceed the values given in Table 9.

Table 9 — Maximum Allowable Louver Deflection

Field Code Changed

Louver Components	Maximum Deflection
Louver blades in closed position with design load of 2000 N/m^2 (40 lb/ft^2)	L/180
Louver side frames with uniform design load of 1000 N/m^2 (20 lb/ft^2)	L/360
L designates the length of the span between points of support.	

7.2.10.6 The deflection of louver blades and side frames shall be evaluated at a metal temperature equal to the higher of the following:

a) maximum process inlet temperature less 30 °C (50 °F);

b) specified air inlet dry-bulb temperature.

7.2.10.7 The gap between the louver blade and the frame at the header ends shall not exceed 6 mm (1/4 in.).

7.2.10.8 The gap between the louver blades and the frame at the louver sides shall not exceed 3 mm (1/8 in.).

7.2.10.9 Louver blade pivot pins shall be designed for their load but, in any case, shall be at least 10 mm (3/8 in.) in diameter.

7.2.10.10 ~~Bearings~~Louver bushings ~~designed for exposure temperature in accordance with 7.2.1.4~~ shall be provided at all pivot points, including control arm, torque rod and blade pivot pins. ~~Bearings~~ Bushings shall not require lubrication. The exposure temperature shall not exceed 150 °C (300 °F) for polytetrafluoroethylene (PTFE) base composite ~~bearing~~ material in accordance with 8.4.2. Higher-temperature ~~bearing~~ materials are available but may be used only with the approval of the ~~P~~purchaser.

7.2.10.11 Louver linkages shall be designed so that equal movement of all louver blades results from a change of actuator position. The maximum allowable deviation shall be 3 mm (1/8 in.), measured as a gap between any two blades with louver actuator in the fully closed position. The means of transmitting force between the louver actuator and the blades shall be adequate to withstand, without damage, the maximum possible force that can be applied by the actuator in any blade position and in either direction.

7.2.10.12 Actuation of louver sections shall require a torque of not more than 7 N·m for each square meter (6 in.-lbf for each square foot) of face area to achieve full travel. The handling force to operate the louvers shall not exceed 250 N (56 lbf)

7.2.10.13 The travel of louver blades from fully closed to fully open shall be at least 70 degrees.

7.2.10.14 All shaft connections shall be attached at adjustable linkage points by keys, splines, or equivalent positive methods. Set-screw connections shall not be used.

● **7.2.10.15** If used for automatic control, the purchaser shall specify either pneumatic or electronic control and actuation and shall comply with the following requirements:. (Editor note: bullet paragraph

~~7.2.10.15~~a) When pneumatic is used for control and actuation ~~If used for automatic control~~, louver actuators shall be designed to operate with a 20 kPa to 100 kPa gauge (3 psig to 15 psig) pneumatic control signal. If supplied with design motive-air pressure, actuators shall be sized to supply at least 150 % of the necessary force for full-range louver blade travel. Design motive-air pressure shall be 410 kPa gauge (60 psig) unless otherwise specified.

b) When electronic is used for either control or actuation, agreement between the purchaser and vendor is required.

7.2.10.16 A positioner shall be provided at each actuator unless otherwise specified.

7.2.10.17 If a single controller operates more than one actuator, the ~~P~~purchaser shall provide an isolating valve in the signal line for each actuator to allow maintenance.

7.2.10.18 The location of the actuator and positioner assembly shall not interfere with access to the header, and both shall be ~~readily~~ accessible for maintenance ~~from a service platform (if available)~~. The assembly shall not be in the hot-air stream if the exit air temperature at any condition exceeds 70 °C (160 °F). Alternative materials shall be selected for higher exposure temperatures.

● **7.2.10.19** The louver position upon loss of control-air pressure shall be specified by the ~~P~~purchaser.

7.2.10.20 All louvers not automatically or otherwise remotely operated shall be provided with extensions or chains to permit manual operation from grade or platform, except that extensions or chains shall not be used if longer than 6 m (20 ft). Handles for manual operators shall not project into walkways or access ways in any operating position.

● **7.2.10.21**~~Y1~~ When specified by the purchaser, automatically controlled, pneumatically actuated louvers shall be equipped with a manual hand wheel override for control on loss of air. (Editor note: bullet item) Action: D Slingerland – send to Paul Harte to review if any concern with wording

End on 11/16/2021

Start on 2/2/2022

7.2.10.22~~1~~ A locking device shall be provided for manual operators to maintain louver position. Set-screw or thumb-screw locking devices shall not be used. A means shall be provided to indicate whether the louvers are open or closed.

7.2.10.23~~2~~ The louver characteristic performance curve shall relate the percentage of air flow to the angle of the louver blade.

7.2.10.24~~3~~ Due to the nature of their design, louvers are vulnerable to damage during handling. Spreader bars and anti-racking procedures should be used. Specific handling instructions shall be included on the louver assembly drawing and shall be marked on the louver at a lift point. Revisit this item at next meeting

7.2.10.25~~4~~ Pin-type retainers shall be used to hold manual control levers of louvers in a set position; butterfly-type locking nuts shall not be used.

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7.2.10.265 All linkage joints shall comply with the following requirements:

a) will not require routine maintenance;

b) All linkage joints shall be through-bolted or pinned;–

c) not have friction-type joints; shall not be used. The

d) –not have bolting or pinning shall be done after final linkage adjustment.

7.2.11 Screens

7.2.11.1 General

● The purchaser shall specify if screens are required and, if so, shall specify the type (hail screens, insect and/or lint screens).

7.2.11.2 Insect/lint Screens

7.2.11.2.1 The purchaser shall approve the screen location and design. In general, it is desirable to locate the screens for low air velocity at the exchanger periphery where velocity is lowest, normally typicallylocated on the columns below the tube bundle or plenum chamber. The screens shall not impede the actuator or louver stroke.

7.2.11.2.2 Screens shall be removable for cleaning, maintenance and off-season storage. They should be sized to facilitate ease of handling.

7.2.11.2.3 Screen mesh shall be wire cloth. The mesh size shall be number 8 for galvanized or number 16 for stainless steel. Other materials may be used if agreed with the purchaser.

NOTE Mesh number is openings per linear inch, e.g. number 8 has 8 openings per linear inch (which is 315 openings per meter). Follow-up B. Drazner to check on international specification. Follow-up D Slingerland: Remove SI units if mesh size is standard size. Also address 7.2.11.3.2 with resolution of 7.2.11.2.3 Resolution: Values are in US units only.

7.2.11.3 Hail Screens

7.2.11.3.1 In forced draft units, hail screens, if specified, shall be located directly above the tubes in the tube bundle and shall cover at least the finned portion of the tubes. In induced draft units, hail screens, if specified, shall be located directly above the fan in the fan ring. The screens shall not impede the actuator or louver stroke.

7.2.11.3.2 Screens shall be either lightweight galvanized grating or galvanized wire cloth. The mesh size shall be number 8. The wire thickness shall be at least 0,017 in0,43 mm (27 ASWG; 0,017 in.).

NOTE ASWG is American Standard Wire Gauge.

7.3 Structural Design

7.3.1 General

● **7.3.1.1** The structural code shall be specified or agreed by the Ppurchaser. Structural steel design, fabrication and erection shall be in accordance with the structural code.

7.3.1.2 Bolts for load-bearing members shall be designed and installed in accordance with the structural code.

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7.3.1.3 Weld-metal design stress shall conform to the structural code.

7.3.1.4 Structural members shall be designed without the requirement for field welding.

7.3.1.5 For induced-draftdraught exchangers, tube bundles shall be removable without removing the platforms, unless otherwise specified by the Ppurchaser. For forced-draftdraught exchangers, the bundles shall be removable without separately supporting or dismantling the fan, plenum or platforms and without disturbing the structure or adjacent bays.

7.3.1.6 Suspended drives shall be attached to the structure by through-bolts to permit dismantling.

7.3.1.7 A minimum of one grounding lug shall be provided per bay.

7.3.2 Vibration Testing

7.3.2.1 Structural members shall be designed to minimize vibration. The maximum amplitude of vibration over the design fan-speed range shall be 0.15 mm (0.006 in.) from peak to peak, as measured on primary structural members and machinery mountings.

● ~~**7.3.2.2** The Purchaser shall specify if a shop test is required to verify compliance with the vibration limits.~~

7.3.2.23 Wind velocity at test conditions shall not exceed 5 m/s (10 mph).

7.3.3 Structural Design Loads and Forces

7.3.3.1 General

The design shall take into account the loads and forces defined in 7.3.3.2 through 7.3.3.13.

7.3.3.2 Dead Loads

● Dead loads shall consist of the total mass of the material furnished by the Vvendor plus the mass of any fireproofing. If fireproofing is being applied, the Ppurchaser shall state the extent and type.

Follow-up: C. Wei–l — Check how fired equipment (ex: API 560) is defining Vvendor, Mmanufacturer, etc. to clearly define scope coming from other suppliers

7.3.3.3 Live Loads

Live load designs shall consist of movable loads (including personnel, portable machinery, tools and equipment) and operating loads in equipment and piping. Design live loads on platforms, columns and walkways (exclusive of loads from piping and equipment in place) shall be a minimum of as the loadings specified in Table 10.

Follow-up: S. Edwards to confirm if OSHA limits are above below table.

Follow-up: B. Drazner to check if EU has regulations above below table.

Table 10 — Live Loads on Platforms, Columns and Walkways

Structural Component	Average Load	Concentrated Load
Floor plate or grating	4900 N/m² (100 lb/ft²)	—
Floor framing	2450 N/m² (50 lb/ft²)	2250 N (500 lb)
Columns and brackets	1200 N/m² (25 lb/ft²)	2250 N (500 lb)
Ladders ~~and stairways~~	—	2500 N (500 lb)
stairways		And a minimum of 4450 N (1000 lb) or 5 x anticipated loads

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7.3.3.4 Impact Loads

The vertical design impact load for lifting devices furnished by the ~~V~~vendor shall be two (2.0) times the mass of the heaviest piece of equipment being lifted. The lateral impact load shall be 0.35 times the mass being lifted.

7.3.3.5 Thermal Forces

Thermal forces shall include forces caused by partial or complete anchorage of piping or equipment, sliding or rolling friction of equipment and expansion or contraction of the structure. The ~~P~~purchaser and the ~~V~~vendor shall agree on acceptable thermal forces.

7.3.3.6 Test Load

The test load is that due to the additional mass of the water used for testing.

7.3.3.7 Wind Load

The wind design load shall be in accordance with the structural code.

7.3.3.8 Earthquake Forces

Earthquake design shall be in accordance with the ICC I-CODE IBC unless otherwise specified.

7.3.3.9 Nozzle Loads

Nozzle loads shall include all forces and moments applied to the nozzle face, such as deadweight of pipe, thermal forces, the mass of fluid in the piping, etc. The total magnitude and direction of these forces and moments shall be in accordance with 7.1.10 unless otherwise specified.

7.3.3.10 Fan Thrust

Fan thrust shall be based on the maximum thrust. If velocity pressure is not included, then fan thrust shall be based on the static pressure shown on the data-sheet multiplied by 1.25.

7.3.3.11 Snow Load

● The purchaser shall specify the snow load, if any, to apply to the total air-cooled heat exchanger plot area.

7.3.3.12 Other Loads

● Loads, forces and moments other than those described in 7.3.3.3 through 7.3.3.11 that are supported by, or applied to, the air-cooled heat exchanger shall be specified by the ~~P~~purchaser in terms of exact type, location, magnitude and direction. Examples of such loads are special transportation loads, auxiliary pipe supports, ladders and walkways furnished by others, and temporary scaffolding supports. Structural and nozzle loads imposed by movement of the structure or installation (e.g. floating production system) on which the exchanger is mounted shall be specified by the ~~P~~purchaser in terms of the exact type, location, magnitude, and direction (e.g. pitch, roll, yaw, heave, surge and sway).

7.3.3.13 Loading Combinations

All structural components shall be designed to support combinations of the loads and forces to which they can be subjected during erection, testing or flushing of the equipment or when operating at design conditions. The following combination of loads and forces shall be considered in the design of columns, bracing, anchor bolts and foundations and in checking stability against overturning:

~~c)~~a) erection:

1) dead load of the structure, less fireproofing;

2) the greater of the following:

   i) dead load of equipment, less piping,

   ii) dead load of equipment, less platforms supported by the equipment;

3) full wind load or earthquake load, whichever is greater;

~~d)~~b) testing or flushing equipment:

1) dead load of the structure, plus fireproofing;

2) dead load of equipment, including platforms supported by the equipment;

3) nozzle loads;

4) test loads;

5) wind load of 500 N/m^2 (10 lbf/ft^2);

6) applicable live loads from platforms and walkways specified in 7.3.3.3; however, these live loads shall not be included in either the design of anchor bolts or the check for stability against wind or earthquake;

~~e)~~c) operation at design conditions:

1) dead load of structure;

2) dead load of equipment, including platforms supported by the equipment;

3) nozzle loads;

4) operating mass of fluid in equipment;

5) unbalanced forces from impact;

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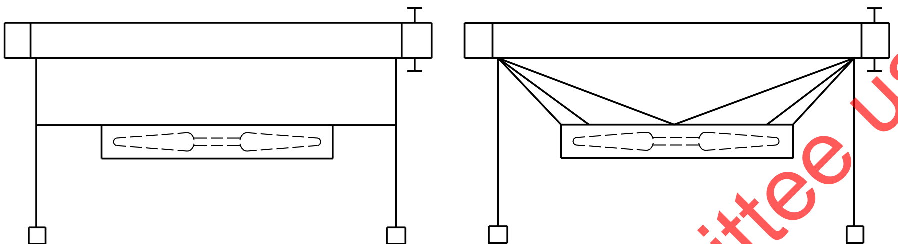
6) applicable live loads specified in 7.3.3.3; however, these live loads shall not be included in either the design of anchor bolts or the check for stability against wind or earthquake;

7) full wind load or earthquake load, whichever is greater.

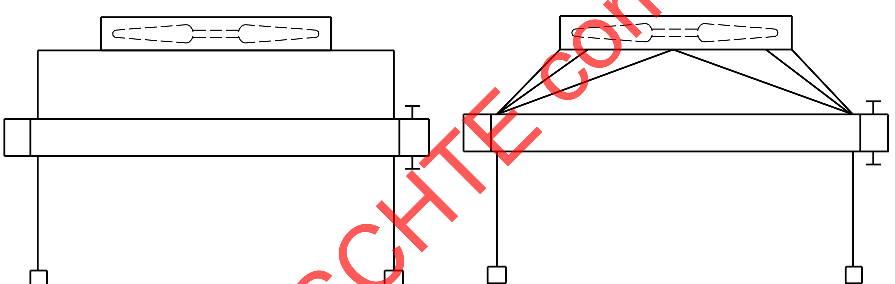
Loading conditions of a special nature shall at all times receive proper consideration. (All loads and forces are additive.)

7.3.4 Plenums

7.3.4.1 Figure 9 shows typical plenum arrangements.



a) Forced draftdraught — Box-type plenum **b) Forced draftdraught — Transition plenum**



c) Induced draftdraught — Box-type plenum **d) Induced draftdraught — Transition plenum**

Figure 1212 — Figure 9 — Typical Plenum Arrangements

7.3.4.2 Box-type plenums employing panel construction shall be designed to form an integral part of the structure.

7.3.4.3 Bank arrangements for field-assembled units may be designed with common walls between adjacent plenums.

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7.3.4.4 The plenums between the fan and the bundle shall be partitioned to prevent recirculation of air from operating fans through non-operating fans.

● **7.3.4.5** Plenum partition requirements for recirculation systems shall be as specified or agreed by the Ppurchaser. See Annex C.

7.3.4.6 The thickness of steel sheet material used in the construction of plenums shall be at least 1.3.59 mm (14 10 gauge USS; 0.13508 in.) flat, or 1.54.8 mm (16 7 gauge USS; 0.1875060 in.) ribbedcorrugated.

Editor note change gauge to gage throughout ALSO change order and have the 7 gage before the 10 gage but not the terms flat and corrugated

~~Follow-up: D. Slingerland to update all USS references back to correct conversion in US/SI.~~

Follow-up: B. Drazner to determine if gauge references should be used vs. US/SI value specification.

7.3.4.7 The minimum plenum height shall be obtained from information provided in 7.2.3.4 and Figure 7, with a minimum of 600 mm (2 ft)..

7.3.4.8 Fan decks shall be designed for a live load of 2500 N/m² (50 lbf/ft²) with a minimum thickness of 2.7 mm (12 gauge USS; 0.105 in.).

7.3.5 Mechanical Access Facilities

● **7.3.5.1** The number and location of header access platforms, interconnecting walkways and ladders shall be specified by the Ppurchaser.

7.3.5.2X Unless otherwise specified by the Ppurchaser, all floors of the walkways, platforms, etc. shall be made of steel construction.

● ~~(Bullet)~~ **7.3.5.3Y** When alternative materials of construction are specified by the purchaser (eg. GRP), the requirements for component design shall be agreed upon with the supplier

7.3.5.42 If specified, maintenance platforms shall be provided beneath each drive assembly to provide access for removal and replacement of all drive components.

7.3.5.53 All Platforms platforms and walkways shall have a clear width of at least 0.75 m (30 in.).

7.3.5.64 The floor of the walkways, platforms, etc., shall be grating, expanded metal or a raised-pattern solid plate with drain holes. If raised-pattern steel is used, the thickness shall be at least 6 mm (1/4 in.).

~~Glass-reinforced plastic (GRP) shall be used if specified by the Purchaser.~~

7.3.5.75 Ladders, railings, toe plates, safety cages, etc., shall be of steel construction or, if specified by the Ppurchaser, another metal materials or such as GRP in accordance with local regulations. The following shall apply.

a) Safety cages shall be provided for ladders over 3 m (10 ft) high.

b) Chains with safety hooks or safety gates shall be provided across ladder openings at platforms.

c) Ladders over 2 m (6 ft) high shall provide for side-step access to platforms unless otherwise specified.

7.3.5.86 Header platforms shall be provided with a toe-board on the side next to the exchanger. If the gap between the platform and the exchanger is greater than 150 mm (6 in.), a knee rail shall be fitted.

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7.3.5.97 If steel pipe railings are not galvanized, they shall be sealed to prevent internal corrosion.

- **7.3.5.108** The Ppurchaser shall specify requirements, if any, for personnel protection against high air-outlet temperatures and hot surfaces. Editor note splitting into 2 paragraphs

7.3.5.11 For forced draft units, the minimum vertical clearance between the fan ring inlet (including any inlet bell) and access platform or grade (for grade-mounted coolers) shall be 2100 mm (83 in.).

7.3.5.12 For induced draft units, the minimum vertical clearance between the tube bundle frame and access platform or grade (for grade-mounted coolers) shall be 2100 mm (83 in.).

Break 2/2/2022

7.3.6 Lifting Devices

7.3.6.1 At least two lifting lugs shall be provided on each side frame of tube bundles and each louver section side frame. Lifting lugs on side frames of adjacent bundles shall be located so as not to interfere with bundle installation.

7.3.6.2 Two lifting lugs shall be provided on each removable cover plate and each removable bonnet.

7.3.6.3 Solid-forging or plate-type lifting lugs shall be used for tube bundle side frames, louver side frames, cover plates and bonnets. The opening in the lug shall be at least 40 mm ($1^1/_2$ in.) diameter.

7.3.6.4 Sufficient lifting eyes shall be provided on each driver and gear to allow safe installation and dismantling. A structural member shall be provided with load attachment points for removal and replacement of driver components. –If a trolley I-beam is provided, trolley stops shall be provided.

Follow-up: D. Slingerland to provide HLIV details to task group

7.3.6.5 Lug or eye design shall be based on a total load equal to twice the weight of the lift.

8 Materials

8.1 General

8.1 Follow-up: P. Harte to review other unfired APIs (ex. API 660) 8.1 Materials paragraphs for potential inclusion into API 661

8.1.1 Materials for pressure components shall be in accordance with the pressure design code.

8.1.2 Cast iron shall not be used for pressure components in flammable, lethal or toxic service.

8.1.3 Structural supports, such as side frames and beams, that are part of the tube bundle and not accessible for maintenance shall be galvanized, unless otherwise specified by the Ppurchaser or not permitted by 8.1.5.

8.1.4 Galvanizing of structural steel shall be in accordance with ISO 1461.

8.1.5 Galvanized materials or zinc-containing paints, etc., shall not be used in direct contact with or directly above exposed austenitic stainless steel or high-nickel alloy pressure components. Alternative coatings and/or materials shall be used.

8.1.6 Supports, guides, and spacers in contact with austenitic stainless steel or high nickel alloy tubes, or their fins, shall be aluminum.

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8.1.67 Combinations of construction materials shall be compatible such that electrolytic (galvanic) cells are minimized.

8.2 Requirements for Carbon Steel in Sour or Wet Hydrogen Sulfide Service

Follow-up: P. Harte to review other unfired APIs (ex. API 660) 8.2 Materials paragraphs for potential inclusion into API 661

8.2.1 Materials shall be supplied in the normalized condition, unless otherwise approved by the Ppurchaser. The acceptability of hot formed material shall be subject to approval of the purchaser.

8.2.2 Pressure-retaining components shall be supplied with a certified material test report (CMTR). The CMTR shall include the unspecified elements chromium (Cr), columbium (Cb) (also known as niobium [Nb]), nickel (Ni), vanadium (V), molybdenum (Mo), and copper (Cu) that are used in the equation to calculate the carbon equivalent (CE) as defined by ISO 15156 (all parts)/MR0175 or NACE MR0103.

● **8.2.3** The maximum allowable carbon equivalent shall be agreed with the Ppurchaser, prior to purchase of materials being used in fabrication. Restrictions on other residual elements and micro-alloying elements may also apply depending on the severity of the service. The Ppurchaser shall specify any such restrictions.

8.3 Headers

8.3.1 External load-bearing parts welded to headers shall be of the same nominal composition as the material to which they are welded.

8.3.2 Welded header pass partitions and stiffeners shall be of the same material type as the header plate.

8.3.3 Tube access header plug material shall be compatible withof the same nominal composition as the header material. Cast iron shall not be used for plug material.

8.3.4 Tube access header plugs of carbon steel bar-stock material or individual forged plugs shall be of a material allowed by the pressure design code (e.g. ASME *BPVC Section II*, SA-105).

8.3.5X Where two-piece plugs are used, the wetted piece shall be of forged material.

8.3.65 When specified by the purchaser Precautions should be taken to avoid galling between the plugs and austenitic stainless steel, or high nickel alloy, plug-sheets, and the precautions should be taken which may include the use of rolled formed threads or alternative plug materials, e.g. UNS S20910 or UNS S21800.plug sheet.

NOTE 1 The use of proper lubricant and plug installation practices is often sufficient to prevent galling.

NOTE 2 Additional measures, as referred to in this clause, may be provided for further assurance but may impact cost and schedule.

Feedback

8.3.Y When specified by the purchaser, plugs for use in austenitic stainless steel plug sheets shall be of XM-19 (UNS S20910) material.

Follow-up: A. Miller to proposed modifications to address galling concerns

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8.4 Louvers

8.4.1 Louver blade pivot pins shall be austenitic stainless steel or UNS A96063 aluminum alloy in the T6 temper condition.

8.4.2 Louver bearings shall be of either polytetrafluoroethylene (PTFE) base composite material containing at least 20 % fill (exposure temperatures shall be in accordance with 7.2.10.10), or an approved alternative if required for a higher design temperature.

8.4.3 Steel louver blades and frames shall be galvanized. If mill-galvanized material is used, all cut and punched edges shall be protected by a zinc-rich coating.

8.5 Gaskets

8.5.1 Gaskets shall not contain asbestos.

8.5.2 Plug gaskets shall be of the solid-metal type. The material of the plug gasket shall be the same type as that of the plug, unless otherwise agreed by the purchaser and vendor. Plug gasket hardness shall be a minimum of 20 BHN less than that of the plug and the plug-sheet materials. Nominal representative samples of 0.5 %, with a minimum of 2, shall be tested. Editor's note: Last sentence to be moved into testing section

8.5.3 Plug header Kammprofile gasket information (width, thickness, profile, metallurgy) (Draft paragraph by Paul Wehmer & Allen Miller)

Feedback: ACTION: Liaison with gasket manufacturers by Scott, Theresa and Carter

8.5.4 When plug gaskets are provided as grooved metal style with soft gasket-sealing faces, they shall comply with the following:

a) a minimum of two full grooves (i.e. 3 peaks) across each face of the gasket;

b) a metallic core with a minimum core thickness of 1.5 mm (1/16 in.) after machining of the grooves; Action - this number to be confirmed

c) a metallic core material with a corrosion resistance at least equal to that of the gasket contact surface material.;

d) a facing material of graphite with a minimum thickness of 0.5 mm (0.02 in.) on each side of the gasket, unless otherwise specified by the purchaser.

8.5.5 Plug gaskets of types other than solid-metal shall be agreed upon between the purchaser and vendor. (note: review wording at next meeting)

8.5.6 Plug gaskets shall be flat and free of burrs.

8.5.7 The minimum thickness of solid metal plug gaskets shall be 1.5 mm (0.060 in.).

8.5.8 For the joint type shown in Figure 4 a), cover plate and bonnet gaskets shall be of the double-metal-jacketed, filled type or solid metal with a soft gasket seal facing, unless otherwise specified by the purchaser. Filler material shall be non-asbestos and shall be suitable for sealing, exposure resistance and fire safety performance. Editor's note: Action: Doug will bring into line with 660 on double-metal-jacket use

8.5.9 For the joint type shown in Figure 4 b), double-metal-jacketed, filled type gaskets or [at design pressures of 2100 kPa gauge (300 psig) or less] compressed sheet composition gaskets suitable for the

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service shall be used, unless otherwise specified by purchaser. Gaskets shall be non-asbestos and shall be suitable for sealing, exposure resistance and fire safety performance.

8.5.10 For the joint type shown in Figure 4 c), compressed sheet composition gaskets suitable for the service may be used at design pressures of 2100 kPa gauge (300 psig) or less. Gaskets shall be non-asbestos and shall be suitable for sealing, exposure resistance and fire safety performance.

8.5.11 The width of removable cover plate and removable bonnet gaskets shall be at least 10 mm (3/8 in.).

8.5.12 Gaskets shall be of one piece. Where welds are used, they shall meet the following:

a) Welds in the perimeter portion of the gasket shall be continuous and full-penetration. The cross-section, finish and flatness of these welded areas shall match the remainder of the perimeter gasket.

b) Welds shall not inhibit the sealing or compression of the perimeter gasket or pass ribs.

8.5.13 Double-jacketed gaskets shall not be used for the peripheral portion of the gasket in the following services:

a) Hydrogen service.

b) Operating temperature above 205 °C (400 °F).

c) Cyclic service.

d) Sour or wet hydrogen sulfide service.

e) Design pressure equal to or greater than 2100 kPa gauge (300 psig).

8.5.14 Tables in Annex A may be consulted for further guidance on gaskets. Action need specific reference

8.58.6 Other Components

8.5.1 Fin material shall be aluminum, unless otherwise specified or agreed by the Ppurchaser.

8.5.2X For offshore installations or when otherwise specified, aluminium the fin material shall be resistant to the environmental conditions. The grade of material shall be agreed between the purchaser and manufacturer.shall be marine grade (e.g. aluminium alloys 5005 and 1060).

8.5.32 Fan blades shall be of aluminum alloy or GRP, unless otherwise specified.

8.5.43 Plugs for threaded connections, such as vents, drains and instrument connections, shall be of the same material type as the connection.

8.5.4 Plenums, fan decks, partitions, platforms and fan rings shall be of carbon steel unless otherwise specified.

8.5.5 Metal gasket material shall be softer than the gasket contact surface.

8.5.6 Solid metal gaskets for shoulder plugs shall have a Rockwell hardness no greater than HRB 68 for carbon steel or HRB 82 for austenitic stainless steel.

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9 Fabrication of Tube Bundle

9.1 Welding

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9.1.1 General

9.1.1.1 Welding procedures and welders shall be qualified in accordance with the pressure design code. Welding shall be performed in accordance with the pressure design code.

9.1.1.2 All pressure-containing header welds and nozzle welds shall have full--penetration and full fusion.

9.1.1.3 The root pass of single-side welded joints without backing strips shall be made using gas metal arc welding (GMAW), gas tungsten arc welding (GTAW) or low-hydrogen shielded metal arc welding (SMAW).

9.1.1.4 Enclosed spaces between any welded attachment and the headers shall be vented by a 3 mm ($^{1}/_{8}$ in.) diameter drilled hole.

● **9.1.1.5** The Ppurchaser shall specify whether weld procedure qualifications for carbon steel in sour or wet hydrogen sulfide service, including tube to tubesheet welds, shall include a micro-hardness survey performed on a weld cross-section and transverse to the weld centerline. The micro-hardness testing and acceptance criteria shall be in accordance with NACE SP0472 or ISO 15156 (all parts), as applicable. Any additional restrictions on class, grade, residual elements or micro-alloying elements for the qualification test material shall be specified by the Ppurchaser.

9.1.2 Plug Headers

9.1.2.1 Partition plates shall be seal-welded to abutting tubesheet and plug-sheet plates and shall be welded from both sides, of the plate. The ; a full-penetration weld joint preparation shall be a full-penetration weld jointused. One sided Sseal welds on the ends of internal pass partitions plates are acceptableexcluded from this requirement.

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9.1.2.2 Stiffeners, including If pass partition plates are also used as stiffeners, shall be attached to the plug--sheet and tubesheet with a full-penetration welds. configuration shall be used and weld joint efficiencies shall be in accordance with the pressure design code. Where end plates are stiffened, full-penetration configurations shall be used. Weld efficiencies shall not exceed 0.6 without approval of the purchaser.

9.1.3 Removable Cover Plate and Removable Bonnet Headers

9.1.3.1 Removable cover plate flanges and removable bonnet header flanges shall be installed with full--penetration welding.

9.1.3.2 Partition plates and stiffeners shall be welded from both sides, along the full length of the three edges.

9.2 Postweld Heat Treatment

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9.2.1 All carbon steel and low-alloy chromium steel headers shall be subjected to postweld heat treatment. Welded tube-to-tubesheet joints shall be excluded unless required by the pressure design code or specified by the Ppurchaser.

9.2.2 Gaskets made of ferritic materials and fabricated by welding shall be fully annealed after welding.

9.2.3 For sour or wet hydrogen sulfide service, the minimum PWHT requirements for header boxes with carbon steel construction shall be in accordance with NACE SP0472, NACE MR0175, or ISO 15156 (all parts).

9.3 Tube-to-Tubesheet Joints

9.3.1 Tube Hole Diameters and Tolerances

9.3.1.1 Tube holes in tubesheets shall be finished to the sizes and under-tolerances shown under "Standard fit" in Table 11.

9.3.1.2 If work hardening materials such as austenitic stainless steel, duplex stainless steel, titanium, copper-nickel or high-nickel alloy (Ni >30 wt %) tubes are specified, the tube holes shall be machined in accordance with Table 11, "Special close fit".

9.3.1.3 No more than 4 % of the total number of tube holes in a tubesheet may exceed the over-tolerances shown under "Over-tolerance" in Table 11. No tube holes shall exceed the nominal tube-hole diameter given in Table 11 by more than 0.25 mm (0.01 in.).

Table 11 — Nominal Tube Hole Diameters and Tolerances

Dimensions in millimeters (in.)

Nominal tube OD	Standard fit		Special close fit		Over-Tolerance
	Nominal Tube Hole Diameter	Under-Tolerance	Nominal Tube Hole Diameter	Under-Tolerance	
19.05 ($^{3}/_{4}$)	19.30 (0.760)	0.10 (0.004)	19.25 (0.758)	0.05 (0.002)	0.05 (0.002)
25.40 (1)	25.70 (1.012)	0.10 (0.004)	25.65 (1.010)	0.05 (0.002)	0.05 (0.002)
31.75 (1$^{1}/_{4}$)	32.11 (1.264)	0.15 (0.006)	32.03 (1.261)	0.08 (0.003)	0.08 (0.003)
38.10 (1$^{1}/_{2}$)	38.56 (1.518)	0.18 (0.007)	38.46 (1.514)	0.08 (0.003)	0.08 (0.003)
50.80 (2)	51.36 (2.022)	0.18 (0.007)	51.26 (2.018)	0.08 (0.003)	0.08 (0.003)

9.3.2 Tube-hole Grooving

9.3.2.1 ~~All tubesheet holes f~~For expanded tube-to-tubesheet joints, ~~in tubesheets less than 25 mm (1 in.) thick~~ each groove shall be machined to ~~with one groove~~ approximately 3 mm ($^{1}/_{8}$ in.) wide and 0.4 mm ($^{1}/_{64}$ in.) deep. ~~A second~~ When two grooves are ~~shall be~~ provided ~~for~~ in the tubesheet, ~~s~~ the minimum distance between the two grooves shall be 6 mm (1/4 in.)~~25 mm (1 in.) or greater in thickness~~.

9.3.2.2 Tube-hole grooves shall be square-edged, concentric, and free of burrs.

9.3.2.3 The edge of the ~~G~~grooves shall be located at ~~least~~ a minimum of 3 mm ($^{1}/_{8}$ in.) plus the corrosion allowance from the ~~process face~~airside of the tubesheet or any recess. ~~and at least 6 mm ($^{1}/_{4}$ in.) from the air-side face of the tubesheet.~~

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9.3.3 Expanded Tube-to-Tubesheet Joints

9.3.3.1 Tubes shall be expanded into the tubesheet for a length equal to the tubesheet thickness ~~at least~~minus the smaller of the following:

a) starting 6 mm (1/4 in.) from the weld edge;

b) 3 mm (1/8 in.) from the tube-side face of the tubesheet and proceeding up to 3 mm; (1/8 in.) from the air-side face of the tubesheet;

c) edge of the recess (see 7.1.6.1.6) from the air-side face of the tubesheet.

~~d) 50 mm (2 in.);~~

~~e) tubesheet thickness less 3 mm (1/8 in.).~~

In no case shall the expanded portion extend beyond the air-side face of the tubesheet.

9.3.3.2 The expanding procedure shall provide essentially uniform expansion throughout the expanded portion of the tube without a sharp transition to the unexpanded portion.

9.3.3.3 The ends of tubes shall extend at least 1.5 mm (1/16 in.) and not more than 10 mm (3/8 in.) beyond the tubesheet.

● **9.3.3.4** When specified by the purchaser, tube-to-tubesheet expanded joint procedures shall be qualified in accordance with ASME *BPVC, Section VIII, Division 1* Appendix HH, or equivalent requirements.

~~Follow-up: Vendors to confirm 9.3.3.4 if any concern as stated.~~

~~9.3.3.7 If welded-and-expanded joints are specified, tube wall thickness reduction should begin at least 6 mm (1/4 in.) away from welds.~~

9.3.3.45 If roller-expanded joints are ~~utilized~~used, the tube wall thickness reduction shall be in accordance with Table 12 ~~X~~. editor note Also note on reason/limit of roller expansion

Table 12~~X~~ – ~~Maximum~~ Allowable Range for Tube Wall Thickness Reduction for Roller-expanded Tube-to-Tubesheet Joints editors note change table figures and materials to those in RCB-7.3.1, but add super duplex – keep 2% note

Material	~~Maximum~~Allowable Range for Tube Wall Thickness Reduction %
Carbon steel and low-allow (max. 9 % chromium) steel	108[a]
Stainless and high alloy steel	86[a]
Duplex and super duplex stainless steels	8B [a]
Titanium and work hardening nonferrous	75[a]
Nonferrous non-work hardening (e.g. admiralty brass)	108[a]

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[a] These can be increased by a further 2 %, if approved by the purchasers.
[b] To be agreed between purchaser and vendor. Tube expansion may increase hardness significantly. For more information, see API TR 938-C.

Follow-up: S. Radovcich, P. Harte, D. Slingerland, R. Hill to confirm values in table 12X above are correct (with mixed selection possible) (ex. Alloy 625, 800, High alloy steels)

End for 2/2/2022

Start for 2/16/2022

9.3.4 Welded Tube-to-Tubesheet Joints

9.3.4.1 The urchaser shall specify whether it is necessary that the tube-to-tubesheet joints be strength- or seal-welded.

Action: S. Shah. Propose paragraphs move to design section (section 7 – ex. New section 7.1.12) vs. in fabrication section (section 9)

9.3.4.12 If welding is used for sealing the tube-to-tubesheet joint and customary tube loads are carried by the expanded joint (seal-welded joint), the joints shall comply with 9.3.1, 9.3.2, and 9.3.3.For seal welded joints, the tubes shall be expanded per 9.3.2 and 9.3.3.

9.3.4.3 If welded-only tube joints are used as a complete substitute for expanded and strength-welded joints, the requirements of 9.3.1, 9.3.2, and 9.3.3 may be modified if agreed between the Vendor and the Purchaser.When strength welds are applied, the degree of expansion and the use of grooves shall be specified or agreed to by the purchaser. See A.4.2 for additional guidance on the selection of tube-to-tubesheet joints.

Action item – Slingerland - Copy API 660 A.4.4 to API 661 A.4.2 and merge in 9.3.4.X
Action Item – Task Group - Review Updated A.4.2

9.3.4.4X If a strength welded tube-to-tubesheet joint is specified the following shall apply:.

a) 1. If a strength welded tube-to-tubesheet joint is specified, tThe qualification of the weld shall be in accordance with the requirements of ASME Section IX, paragraph QW-193 and QW-193, or ISO 15614-8.

b) Unless otherwise agreed by the purchaser, when production welding is to be performed through the plug-sheet, this should be simulated in the procedure qualification assembly, with the access hole diameter and distance from the hole to tubesheet equal to the maximum production distances.

2. Unless otherwise approved, when production welding is to be performed through the plug sheet, this should be simulated in the procedure qualification assembly, with the access hole diameter and distance from the hole to tubesheet equal to the production distances ±10%.

Editor note Define the size of the mock-up required (number of tubes, size of box)

9.3.4.54 Recessed-type tube-to-tubesheet welds (in the tube holes) shall not be used.

9.3.4.6Z If welded-and-expanded joints are specified, tube wall thickness reduction should begin at least 6 mm (1/4 in.) away from welds.

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~~9.3.5 Welded and Expanded Tube-to-Tubesheet Joints~~

~~Action item: S. Shah. Initial draft of 9.3.5 requirements vs. 9.3.3 and 9.3.4. Possible inclusion of 7.5.7.3 from API 660 in update.~~

~~When a strength welded joint is used without a grooved joint, a light expansion may be used (with a 1-3% wall reduction).~~

9.4 Gasket Contact Surfaces

9.4.1 Final machining of gasket contact surfaces for removable cover plates shall be done after any postweld heat treatment.

9.4.2 Gasket contact surfaces of removable bonnet headers and removable cover plate headers shall be flat, with a maximum deviation over the entire length of 0.8 mm ($^{1}/_{32}$ in,). The flatness of tubesheet gasket contact surfaces shall be measured after expanding or welding of the tubesheet joints.

9.4.3 Plug gasket contact surfaces of the plug~~-~~sheet shall be machined to a finish of average roughness between 1.6 μm and 3.2 μm (63 μin. and 125 μin.).
~~Action Item – Allison/Edwards – Determine plug contact surface average roughness~~
~~Post Action item – potential addition into 7.1.7 for plug requirements~~

9.5 Thread Lubrication

9.5.1 Plug threads shall be coated with a suitable thread lubricant.

9.5.2 Header flange bolting shall be assembled using a thread lubricant suitable for the operating temperature.

9.6 Alignment and Tolerances

9.6.1 ~~Standard tolerances~~ Tolerances for the dimensions of air-cooled heat exchangers and for nozzle locations are shown in Figure 10. Tolerances apply to both forced-~~draft~~draught and induced-~~draft~~draught exchangers.

~~Action item – Editorial – fix draught throughout document~~

9.6.2 Header warpage, in the final as fabricated condition, shall ~~be~~ not ~~more~~ exceed~~than~~ the lesser of 12 mm ($^{1}/_{2}$ in.) or 5 mm/m ($^{1}/_{16}$ in./ft)~~,~~ based on the full length of the header~~, whichever is the lesser~~. ~~This applies to the final header, not in-process steps.~~

9.6.3 Bundles that will be stacked in service shall be trial assembled in the fabricating shop to confirm tolerance.

9.6.4 Manufacturing tolerances shall be such that nominally identical parts ~~shall be~~are interchangeable.

9.7 Assembly

9.7.1 Air-cooled heat exchangers shall be shop-assembled into the largest practical size to minimize field assembly work~~completely assembled for shipment except that, if complete assembly is impractical, they shall be partially shop-assembled into the largest practical sub-items to minimize field assembly work~~. The completeness of assembly for shipment shall be agreed between the ~~P~~purchaser and the ~~V~~vendor (see 5.4).

Feedback

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9.7.2 For austenitic stainless steel plug, and plug--sheets, the plugs shall be tightened by use of a manually controlled torque wrench. –Impact wrenches areshall not to be used for plug installation or removal.

Note: Austenitic and high-nickel alloy materials are subject to galling.

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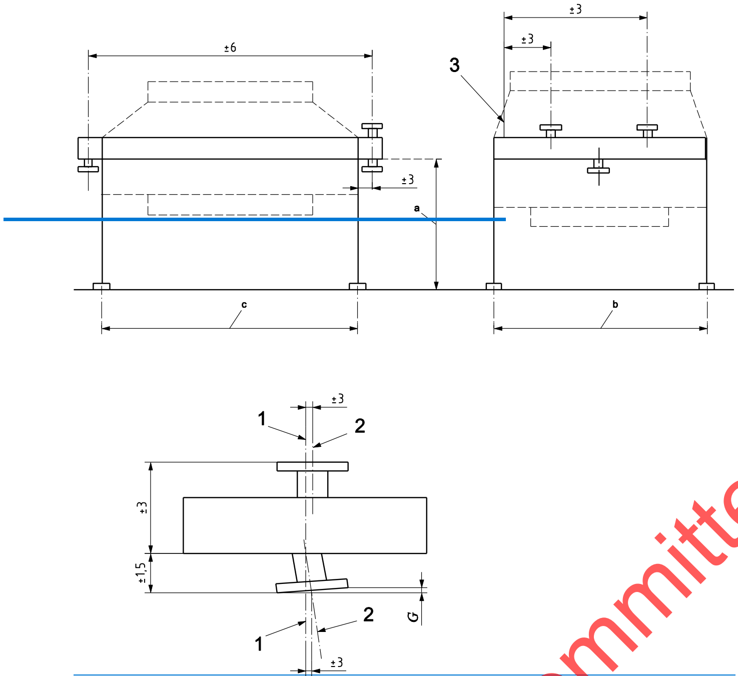
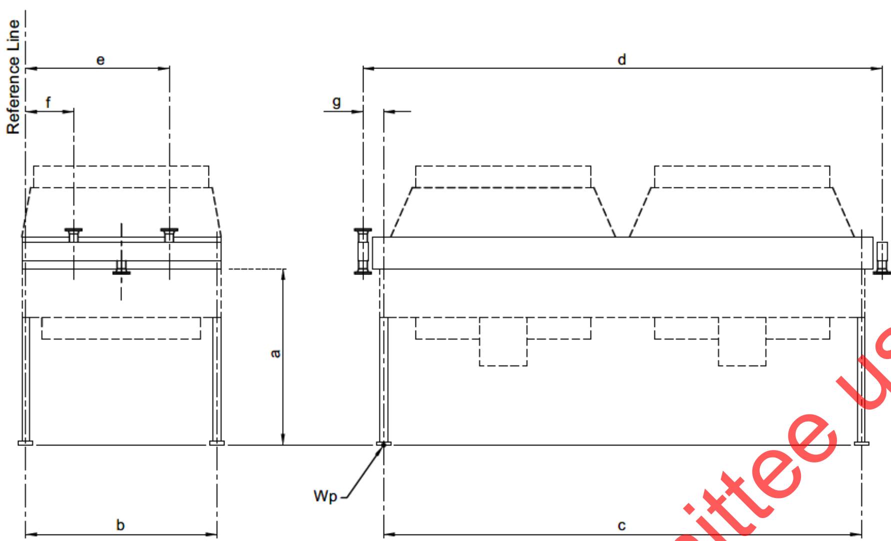
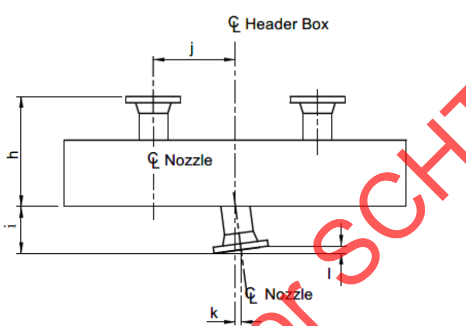
~~Tolerances in millimeters (in.)~~







Tolerances in millimeters (in)

Dimension	Tolerance	
a	+ 1 / -2 per meter	
b	± 1 per meter	
c	± 3 (Wp to 3m; + 1 / -2 for each additional meter)	
d	± 6 (1/4)	
e	± 3 (1/8)	
f	± 3 (1/8)	
g	± 3 (1/8)	
h	± 3 (1/8)	
i	± 1,5 (1/16)	
j	± 3 (1/8)	
k	± 3 (1/8)	
l	Nominal Nozzle Size DN (NPS)	Maximum Out-of-Plane Tolerance
	50 to 100 (2 to 4)	1,6 (1/16)
	150 to 300 (6 to 12)	2,4 (3/32)
	> 300 (> 12)	4,8 (3/16)
	stacked, all	0,8 (1/32)

Figure 10 - Standard Tolerances

Editor's note – the figure will be modified to include the tolerance table in dual units.

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Key

1 centerline header
2 centerline nozzle
3 reference line
G out-of-plane tolerance, as given belowin table x+1:

Nominal nozzle size DN (NPS)	**Maximum out-of-plane tolerance** *G* mm (in.)
50 to 100 (2 to 4)	1.6 ($^{1}/_{16}$)
150 to 300 (6 to 12)	2.4 ($^{3}/_{32}$)
> 300 (> 12)	4.8 ($^{3}/_{16}$)
stacked, all	0.8 ($^{1}/_{32}$)

a $^{+1}_{-2}$ per meter.

b ±1 per meter.

c ±3 (W_p to 3 m; $^{+1}_{-2}$ for each additional meter).

Action item – Allison – Update drawing to have letters in place of numbers and update key with values

Figure 1313 — Figure 10 — Standard Tolerances

9.8 Tubes

All tubes, including U-tubes, shall be formed from a single length and shall have no circumferential welds, unless approved by the purchaser.

10 Inspection, Examination, and Testing

10.1 Quality Control

10.1.1 ~~On components subject to full radiography, nozzle attachment welds that cannot be readily examined by radiography in accordance with the pressure design code shall have their root pass and final pass fully examined by the magnetic-particle or liquid-penetrant method after back-chipping or gouging (where applicable).~~Process nozzle attachment welds shall be examined by the magnetic-particle or liquid-penetrant method; this examination shall apply to the root pass after back-chipping or flame-gouging (where applicable) and to the completed weld, after any PWHT.

If 100 % volumetric examination is specified, the complete length of all pressure retaining welds including end-closure weld and nozzle to header welds shall be radiographically or ultrasonically examined.

10.1.2 If full radiographic or ultrasonic examination is not specified, ~~at~~ 10% or at least one spot radiographic or ultrasonic examination shall be made of ~~a~~ each longitudinal outside pressure weld and ~~an~~ each end-closure weld for each header. ~~Process nozzle attachment welds shall be examined by the magnetic-particle or liquid-penetrant method; this examination shall apply to the root pass after back-chipping or flame-gouging (where applicable) and to the completed weld, after any PWHT.~~

10.1.3 Spot radiographic or ultrasonic examinations shall include each start and stop of welds made by the automatic submerged arc-welding process and repaired areas of burn-through.

10.1.4 Spot radiographic or ultrasonic examinations shall cover either a length of at least 250 mm (10 in.) or the full length if the weld is less than 250 mm (10 in.) long.

10.1.5 For stainless steel and for ferritic alloy steel with a chromium content greater than 0.5 %, the root pass and final passes of welds not subject to full radiography shall be examined by the magnetic-particle or liquid-penetrant method.

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10.1.6 If the plates are not fully examined for laminations by ultrasonic examination and if set-on connections are used, the edge of the hole in the plate to which the connections are attached shall be examined for laminations by the magnetic-particle or liquid-penetrant method prior to welding. Subject to agreement with the Indicationspurchaser, indications found shall be cleared to sound metal and then back-welded.

10.1.6 If set-on connections are used they shall conform to the following:

a) If the header plates are not fully examined for laminations by ultrasonic examination, a 100 % ultrasonic examination shall be carried out on the header plate for a minimum of 50 mm (2 in.) around the nozzle, or to the edge of the header box, prior to cutting the hole in the header. Action re word with at the end of first sentence "if the UT not done then is required.

b) After cutting the hole in the header, dye-penetrant examination or magnetic particle inspection of the edge of the hole shall be performed prior to welding.

c) The nozzle internal weld shall be ground smooth without sharp / irregular shape, or excess of weld penetration. Visual inspection using an endoscope or similar devices shall be carried out if necessary to visually access small nozzle diameters.

d) If the pressure envelope is plate, after welding of the connections, 100% ultrasonic examination on the attachment welds and the plate shall be completed for at least 50 mm (2 in.) from the connection, or to the edge of the header box. Magnetic particle or dye-penetrant examination (including the cut edge hole surface) shall be also performed.

When full radiography is used or when specified by the purchaser, 100% ultrasonic examination of completed attachment welds shall …….

Action Item – Edwards/Miller – Proposed updated wording for 10.1.6 (merging org 10.1.6 with above proposed 10.1.6)

10.1.7 Production hardness testing shall be as follows.

a) Pressure-retaining welds in components made of carbon, Cr-Mo, 11/13/17 % chromium, and duplex stainless steels, shall be hardness tested. Hardness testing of the heat-affected zone shall be conducted if required by the pressure design code, or when specified by the Ppurchaser.

b) Hardness readings shall be taken with a portable Brinell hardness tester. Other hardness testing techniques may be employed if approved by the Ppurchaser. When access is available, tests shall be performed on the side of the weld in contact with the process fluid.

c) Examination shall be made after any required postweld heat treatment.

d) Unless otherwise agreed between the Vvendor and Ppurchaser, the weld hardness shall not exceed the values listed in Table 132.

e) Representative welds, including connection-to-header welds, shall be examined. Examination shall be made of one longitudinal weld, one weld at an end closure, and each connection-to-header weld if the connection is DN 50 (NPS 2) or larger. At least one header per item and every tenth header shall be examined.

f) Hardness test results and locations shall be recorded.

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Table 132 — Maximum Weld Hardness

Material	Maximum Weld Hardness
Carbon steel	225 HBW
Chromium steel (up to 3 % Cr)	225 HBW
Chromium steel (5 % Cr to 17 % Cr)	241 HBW
Duplex stainless steel (22 % Cr)	by agreement with Ppurchaser
Super duplex stainless steel (25 % Cr)	by agreement with Purchaser

NOTE ~~These hardness values are for general services.~~ More stringent hardness testing and acceptance criteria can be required for special services (e.g. sulfide stress cracking or other types of environmental cracking services as specified in NACE standards).

10.1.8 For tubes with circumferential welds, the Vvendor shall demonstrate by means of a qualification procedure that weld-root penetration on the tube inside diameter does not exceed 1.5 mm ($^1/_{16}$ in.). Permanent backing rings shall not be used.

10.1.9 Inspection of tubes with circumferential welds shall be as follows.

a) At least 10 % of the welded joints selected at random shall be examined using radiography. One double-wall elliptical exposure for double-wall viewing shall be taken for each joint.

b) Sampling shall be done progressively throughout the period of fabrication.

10.1.10 Bar stock material for tube access plugs shall be radially examined by an ultrasonic or radiographic method. There shall be no linear indications exceeding 10 mm ($^3/_8$ in.).

10.1.11 It is not necessary that individually forged tube access plugs, either hot- or cold-forged, be examined in accordance with 10.1.10.

● **10.1.12** If specified by the Ppurchaser, all carbon steel plate in sour or wet hydrogen sulfide service shall be subjected to an ultrasonic lamination check (e.g. to EN 10160 ~~grade S2E2~~ or ASTM A578~~, acceptance level A supplementary requirement S1~~). The acceptance level shall also be specified by the Ppurchaser. Action item – Editor – Check if dates are required for references/Jey spreadsheet

10.1.13 For austenitic and duplex stainless steels, the ferrite content of all accessible completed production welds shall be checked using a ferritescope. A minimum of three tests shall be made on each 1.5 m (5 ft) of weld, with at least three tests made on each header box longitudinal weld, three tests on each end plate weld, and three tests on each nozzle weld. The acceptance criteria for the minimum and maximum ferrite content shall be agreed between the Ppurchaser and Vvendor.

10.1.14 Where nozzle pipe and transitions are fabricated from plate, the welds shall be subject to 100 % radiography after final forming or after any required heat treatment.

10.1.15 All plate edges and plate openings for nozzle connections shall prior to welding, be examined by magnetic-particle or liquid-penetrant.

10.1.16 All welded tubes shall be provided by the mill including a nondestructive electric examination.

10.1.17 Plug gasket hardness shall be tested as required by 8.5.2, with nominal representative samples of 0.5 %, with a minimum of 2.

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10.1.15 If set-on connections are used and the pressure envelope is plate, after welding of the connections, 100% ultrasonic examination on the attachment welds and the plate shall be completed for at least 100 mm (4 in.) from the connection.

10.2 Pressure Test

10.2.1 Hydrostatic tests shall be in accordance with the pressure design code.

10.2.2 Hydrostatic test pressure shall be maintained for at least 1 h.

10.2.3 Water used for hydrostatic testing shall be potable. The chloride content of the test water used for equipment with austenitic stainless steel or Ni-Cu alloy materials that is exposed to the test fluid shall not exceed 50 mg/kg (50 parts per million by mass). Upon completion of the hydrostatic test, the equipment shall be promptly drained.

10.2.4 Unless otherwise specified by the Ppurchaser, paint or other coatings may be applied over welds prior to the final pressure test.

10.2.5 Joints taken apart after the final pressure test shall be reassembled with new gaskets.

● **10.2.6** Other types of test, such as helium tests, or additional requirements for equipment drying or preservation shall be performed if specified by the Ppurchaser.

10.2.7 If not specified in the design code, the primary membrane stress in any pressure containing component shall not exceed 95 % of the material minimum yield strength during hydrostatic testing.

10.3 Shop Run-in

● The extent of shop run-in tests of the driver, the drive assembly, and the fan of shop-assembled units shall be a matter of agreement between the Purchaser and the Vendor. Action: Allen will expand on 10.3, including bearing testing. He will liaise with vendors in this action.

Email from Allen 9May2019:

I suggest the following to replace current clause 10.3

10.3.1 A sShop run-in test of the driver, drive assembly, and fan shall be provided for shop assembled units.

10.3.2 Unless otherwise specified, one bay for each ten bays or portion thereof per service shall be tested.

10.3.3 The run-in test shall be performed on assembled bays including the completed tube bundle/header box assembly, louvers (if applicable), plenums, fan rings, fans, drivers, drive assemblies, motor mounts and support columns.

10.3.4 The run-in test shall consist of the following:

a) Check and record the fan tip clearances;

b) Set and record the fan blade pitches as per design blade angle (± 0.5° blade angle);

c) Check and record the radial run-out tolerance for the fan shafts;

d) Check and record the radial and axial run-out tolerances for the sprockets attached to the fan shafts;

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e) Run the motors and fans at design speed for a minimum of 15 minutes, recording the motor voltages, motor amperages, motor speeds, fan speeds, and vibration levels (see clause 7.3.2.1);.

f) Stroke testing of louver assemblies (if applicable).

10.3.5 When specified by the purchaser, air flow measurements shall be taken for each fan; test procedure and acceptance criteria to be agreed between purchaser and vendor (see Annex D).

10.3.6 A run-in test report, including all recorded values, shall be provided as part of the manufacturer's data book.

{Action Item - Editor Note: should include run-in test report in Clause 6.2.2

10.4 Equipment Air-c Cooler Performance Testing

If a post-installation performance test is specified by the Ppurchaser, e.g. to check the guaranteed performance of the exchanger unit, it shall be in accordance with ASME PTC 30, or other standard if agreed by the Ppurchaser.

10.5 Nameplates and Stampings

10.5.1 An austenitic stainless steel nameplate shall be permanently mounted on a bracket welded to affixed to the top of the inlet header of each tube bundle indicating the item number, marks required by the pressure design code and any other information specified by the Purchaser.

10.5.2 The nameplate shall be permanently mounted on a bracket welded to the top of the header.

10.5.23 The following parts shall be stamped with the vendor's serial number:

a) header;

b) cover plate flange of cover plate headers;

c) tubesheet flange of bonnet header flanges.

11 Preparation for Shipment

11.1 GeneralProtection

11.1.1 All liquids used for cleaning or testing shall be drained from units before shipment.

11.1.2 Tube bundles shall be free of foreign matter prior to shipment.

11.1.3 Exposed flanged connections shall be protected by either of the following:

a) gasketed steel covers fastened by the greater of the following:

1) 50 % of the required flange bolting,

2) four bolts;

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commercially available plastic covers specifically designed for flange protection.

11.1.3 All openings in tube bundles shall be suitably protected to prevent damage and possible entry of water or other foreign material.

11.1.4A All flange-gasket surfaces shall be coated with an easily removable rust preventative and shall be protected by suitably attached durable covers of such material as wood, plastic, or gasketed steel.

11.1.5B All threaded connections shall be protected by metal plugs or caps of compatible material.

● **11.1.6 C** The purchaser shall specify if there are requirements for surface preparation and protection (e.g. painting). EDITOR NOTE: Bullet paragraph.

11.1.7D Exposed threads of bolts shall be protected with an easily removable rust preventative to prevent corrosion during testing, shipping, and storage. Tapped holes shall be plugged with grease.

● **11.1.8E** The purchaser shall specify if an inert gas (e.g. nitrogen, argon) purge and fill is required. Positive pressure shall be indicated by a pressure gauge. Gauges shall be suitably protected from damage during transportation. The purchaser shall maintain the positive pressure of the inert gas during storage. See A.5 for additional information on draining and drying. Action Item – Editor - Verify against API 663

11.1.9F When an inert gas fill is used, the vendor shall apply a label or wired metal tag on all openings that states, "Contents are under <Inert gas> pressure and must be depressurized before opening." All transport regulations must also be complied with. EDITOR NOTE: Bullet paragraph

● **11.1.104** The extent of skidding, boxing, crating, protection or coating for shipment shall be specified or agreed by the Ppurchaser.

11.1.115 Each loose piece or assembly shall be properly protected to prevent damage during normal shipping and handling.

11.1.12G Unless otherwise specified, finned tube surfaces shall be protected with exterior grade plywood covers unless protected by hail screens, or louvers, or exhaust plenum, in the shipping conditionare provided.

11.1.H Shipping restraints (e.g. bolts and spacers) to be removed shall be clearly marked with bright, contrasting paint.

11.1.13I Shipping restraints that are to be removed before commissioning of the exchanger are to be clearly identified with bright, contrasting paint and noted on the field assembly drawings.

11.1.J The Vendor shall advise the Purchaser if bundles are temporarily fixed to bundle frames for shipping purposes. Transit and erection clips or fasteners shall be clearly identified on the equipment and the field assembly drawings to ensure removal before commissioning of the exchanger.

11.2 Surfaces and Finishes

11.2.1 Surfaces being painted shall be degreased and cleaned by wire brushing or a similar means to remove loose scale, dirt, and other foreign materials.

11.2.2 Machined surfaces that are exposed to the atmosphere in transit and subsequent storage shall be protected with an easily removable rust preventative.

11.2.3 Unless otherwise specified, carbon steel and low-alloy headers shall be blast-cleaned in accordance with ISO 8501-1, grade Sa 2$^1/_2$, and then coated with an inorganic zinc-rich primer to a dry-film thickness of at least 50 µm (0.002 in.).

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11.2.4 Other than surfaces of tubes, all exposed ferrous surfaces not otherwise coated shall be given one coat of the manufacturer's standard shop primer before shipment.

11.311.2 Identification and Notification

11.23.1 All separate parts shall be marked for identification.

11.23.2A The item number, shipping mass, and purchaser's order number shall be clearly marked on the heat exchanger.

11.2.3.B All boxes, crates, or packages shall be identified with the purchaser's order number and the item number.

11.32.4C When postweld heat treat is required by the design code or for process service, the words "DO NOT WELD" shall be stenciled on both bundle side frame adjacent to each header box that has been postweld heat treated (four total stencils).

11.23.5D All components that have been disassembled for shipping for field reassembly shall be suitably identified.

11.3.2 The Vendor shall advise the Purchaser if bundles are temporarily fixed to bundle frames for shipping purposes. Transit and erection clips or fasteners shall be clearly identified on the equipment and the field assembly drawings to ensure removal before commissioning of the exchanger.

Comment for addressing in Spring:

Since you are removing 11.2.2 is there a provision anywhere to cover machined surfaces like fan shafts, machined sheaves, etc.?

Action Item – Slingerland – Place IOGP on sharepoint site

End on 2/16/2022

12 Supplemental Requirements

12.1 General

Clause 12 provides additional design, fabrication and examination requirements that shall apply if specified by the Ppurchaser. In general, these supplemental requirements should be considered if the design pressure exceeds 14,000 kPa gauge (2000 psig).

12.2 Design

12.2.1 Header corner-joint design shall provide for clear interpretation of weld quality in accordance with the pressure design code. The Vvendor shall include in the proposal a drawing showing full details of the proposed welded joint design.

12.2.2 All tubes shall be either seal-welded or strength-welded to the tubesheet. Low-alloy chromium steel tubes shall not be used in this application. See A.4.1 for additional information on the use of low-alloy chromium steels.

12.3 Examination

12.3.1 Ultrasonic examination shall be performed on plates and forgings welded to other components if the thickness exceeds 50 mm (2 in.).

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12.3.2 Ultrasonic examination shall be performed on all forgings exceeding 100 mm (4 in.) thickness, except for bolted flat covers and standard flanges.

12.3.3 All external pressure boundary welds, with the exception of tube-to-tubesheet welds, shall be either ultrasonically or radiographically examined.

12.3.4 After ultrasonic examination of plates, forgings and welds has been performed, the ~~Purchaser~~ fabricator shall ~~be supplied with~~supply a report that includes:

a) diagrams of the surfaces scanned, the indications obtained, the areas repaired, the nature of defects repaired and the repair procedures used; ~~. The following information shall be provided:~~

~~a)~~b) pulse-echo unit manufacturer, model, and damping control setting;

~~b)~~c) search unit manufacturer, model, dimensions, and the substance (such as oil or water) that is used to couple the transducer with the material being inspected;

~~c)~~d) frequency used and the test angle on the component's surface;

~~d)~~e) wedge medium for angle-beam examination.

12.3.5 The external pressure boundary root and final weld passes shall be examined by the magnetic-particle or liquid-penetrant method. This requirement excludes tube-to-tubesheet welds.

12.3.6 Ultrasonic or radiographic examination shall be performed on all weld repairs after postweld heat treatment.

12.3.7 Prior to welding, a magnetic-particle or liquid-penetrant examination shall be performed on all edges and plate openings prepared for welding. Defects found shall be cleared to sound metal.

12.3.8 A magnetic-particle or liquid-penetrant examination shall be performed on all attachment welds, ~~(~~e.g. supports~~)~~.

12.3.9 A magnetic-particle or liquid-penetrant examination shall be made of areas where temporary lugs have been removed; these areas shall be prepared for examination by grinding.

~~**12.3.10** After hydrostatic testing, all exterior pressure-retaining welds and all interior nozzle welds that are accessible without disassembly shall be examined by the magnetic-particle or liquid-penetrant method.~~

12.3.10~~1~~ For pipe-manifold-type header construction, all boss-to-tube and tube-to-U-bend welds shall be 100 % examined by radiography or ultrasonic testing. Boss-to-header welds shall be examined externally by the magnetic-particle or liquid-penetrant method.

~~**12.3.12** Non-destructive examinations and acceptance criteria shall comply with the pressure design code.~~

12.3.11~~3~~ If postweld heat treatment is required, the tests within 12.3 shall be performed after completion of the postweld heat treatment.

12.3.12~~4~~ Prior to use in the fabrication of the bundle, all welded tubes shall be provided by the mill including a nondestructive electric examination~~be eddy-current tested~~ and pressure tested.

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12.4 Testing

12.4.1 A shop-air test at 100 kPa gauge to 170 kPa gauge (15 psig to 25 psig) shall be applied after tube-to-tubesheet welding, prior to tube expansion. Tube-to-tubesheet joints shall be examined for leaks by applying a soap solution.

~~12.4.2 After the final pressure test, plug joints and all gasketed joints shall be air-tested at 100 kPa gauge to 170 kPa gauge (15 psig to 25 psig), testing for leaks either by applying a soap solution or by total immersion in a water tank.~~

ACTION item testing requirements for non-hp units. Probably move 12.4 to main body and expand a little. Perhaps becomes a bullete item in main text. By Allen.

13 Supplemental Requirements for Services Subject to High Temperature Hydrogen Service (HTHS)

Editor note: Action: Place holder for section 13 from API 660 once approved

13.1 General

13.1.1 The purchaser shall specify if the additional HTHS requirements in Section 13 shall be applied to the tube side of the heat exchanger. See A.9 for additional guidance.

13.1.2 The requirements in previous sections of this document that address hydrogen service shall be applied.

13.2 Design Temperature

Material selection temperatures for each side subjected to HTHS shall be specified by the purchaser. See A.9.2.1.

13.3 Materials

13.3.1 Materials, including pressure-retaining internal components such as tubes, tubesheets, floating heads, and internal bellows, shall be specified by the purchaser in accordance with API RP 941, including any design margins to be applied based on integrity operating window (IOW) limits. See A.9.3 and A.9.4.

13.3.2 For heat exchangers arranged in series, nominal material composition shall not vary between the different tube bundles~~shells~~, unless specified by the purchaser.

13.4 Fabrication

13.4.1 Weld details used on components in HTHS, including tubesheet to cylinder welds and nozzle assembly butt welds, shall be full-penetration, full-fusion butt welds that can be 100 % volumetrically examined for the entire length.

13.4.2 Nozzle connections for components in HTHS shall be full-penetration, full-fusion welds.

13.4.3 All components constructed of carbon steel shall be postweld heat treated after completion of fabrication. ACTION NB consider tube to tubesheet welds

13.4.4 Dissimilar metal welds shall not be allowed in a single bundle~~shell~~ in HTHS, except as allowed in 13.3.2. When dissimilar materials are used, the welding and PWHT procedure shall be agreed between the vendor and purchaser, taking account of the varying microstructure of the weld.

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13.5 Inspection and Testing

13.5.1 All materials other than carbon steel used for construction of the pressure retaining envelope and heat transfer tubes shall be verified by positive material identification. The extent and method shall be agreed between purchaser and vendor.

13.5.2 All butt welds shall be 100 % volumetrically examined after any required postweld heat treatment.

13.5.3 Wet fluorescent magnetic particle examination shall be performed on accessible wetted surfaces, for all carbon or low-alloy steel pressure-retaining welds, after any required postweld heat treatment. When the component is clad, the base material weld shall be wet fluorescent magnetic particle examined prior to restoration of the cladding. When the minimum required preheat temperature is above the limits of wet fluorescent magnetic particle solution, a dry magnetic particle method may be used prior to the restoration of the cladding.

13.5.4 Production hardness testing for all pressure-retaining welds and heat-affected zones exposed to HTHS shall be performed in accordance with 10.1.6.

13.5.5 When specified by the purchaser, welds subject to HTHS shall be provided with baseline UT examination reports. The extent, locations, and type of ultrasonic examination shall be as agreed with the purchaser. See API RP 941, Annex E for ultrasonic examination inspection methods.

13.5.6 When specified by the purchaser, clad and weld overlay construction shall be tested for susceptibility to hydrogen disbonding. The testing requirements and acceptance criteria shall be agreed between the purchaser and vendor.

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Annex A
(informative/normative)

Recommended Practices

A.1 Introduction

This annex has been prepared to give advice in areas outside the scope of this standard. The advice is not mandatory and is offered for guidance only.

A.2 General — Selection of Induced- draftDraught or Forced- draftDraught — Guidance to 4.2

Forced-draftdraught fans should be used, except that induced-draftdraught fans should be considered for the following situations:

q)a) if temperature control of the process is critical and sudden downpour of rain (i.e. excessive cooling) can cause operating problems;

r)b) to minimize the risk of hot-air recirculation;

s)c) on sites where air-side fouling is a significant problem, however forced draft can be used if screens are specified;

t)d) to improve thermal performance in the event of a fan failure (due to the stack effect);

u)e) in hot climates, where the fan plenum chamber shields the bundle from the sun;

v)f) for services that have a temperature approach of 11 °C (20 °F) or less.

NOTE Temperature approach is the difference between process outlet temperature and air entering temperature.

A.3 Design

A.3.1 High Piping Movements — Guidance to 7.1.1.3

Thrust blocks, which are structural members provided by the air cooler supplier upon request and used to physically tie together adjacent air cooler bays and header boxes. They can be used by the piping designer as a method to transmit the lateral movement and resulting load of individual header boxes, compensating for the individual header box movements and reducing the individual nozzle loads applied to each header box. These may be utilized for installations having a relatively high number of bays/header boxes or those that may operate at higher relative temperatures.

A.3.1A.3.2 Multi-pass Condensers — Guidance to 7.1.1.7

Multi-pass condensers which

— operate in vacuum service,

— have a separate aqueous phase and a minimum ambient temperature less than 0 °C (32 °F), or

— are expected to operate partially flooded, as specified by the Ppurchaser on the equipment data sheets,

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should have the tubes in each pass, including any sub-cooling pass, sloped 10 mm/m (1/8 in./ft) in the direction of flow.

A.3.2A.3.3 Cyclic Design — Guidance to 7.1.1.12

Editor Note: Bring API 661 in alignment with API 810

A.3.2.1 The following is guidance to assist in identifying a potential cyclic service application:

— 20 15 % variance in normal operating pressure, and/or;

— 20 % variance in process flow ratevariations in normal operating temperature that exceeds 28 °C (50 °F).;

— variations in normal operating temperature that exceed 110 °C (200 °F);

where for oOne cycle is where the variance occurs in a time frame of less than 24 h and number of cycles exceeds 12 per year.

NOTE 1 The variation in the normal operating temperature is suggested by API RP 571-11, Section 4.2.9.3.c), Thermal Fatigue.

NOTE 2 Change in operating modes including flowrate, composition, or other conditions, can result in variations of pressure and temperature.

A.3.2.2 For assistance in specifying cyclic conditions, it is suggested that the purchaser follow the guidance of ASME BPVC, Section VIII, Division 2, and complete a User Design Specification. Methodologies are also available in other pressure design codes, including EN 13445 (all parts).

A.3.2.3 The manufacturer can use the screening method provided in ASME BPVC, Section VIII, Division 2, to determine whether a fatigue analysis is required for the given cyclic loading. Methodologies are also available in other pressure design codes including EN 13445 (all parts).

A.3.3A.3.4 Tubes and Finning — Guidance to 7.1.11

A.3.3.1 The maximum process temperature for various types of fin bonding should be as given in Table A.1. The fin selection temperature is the temperature at the interface between the liner tube and the fin at maximum normal operating conditions. The maximum process temperature is a good approximation of the fin selection temperature.

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Table A.1 — Maximum Fin Selection Temperature for Fin Bonding Types

Fin Bonding Type	Maximum Process Temperature °C (°F)
Embedded fins	400 (750)
Externally bonded (hot-dip galvanized steel fins)	360 (680)
Extruded fins	300 (570)
Footed fins (single L) and overlap footed fins (double L)	130 (270)
Knurled footed fin, either single L or double L	200 (390)
Externally Bonded (-welded or brazed fins)	> 400 (750) (maximum should be agreed by Purchaser)
Except where stated otherwise, the above limits are based on a carbon steel core tube and aluminum fins; different materials for the core tube and/or the fins may result in a different temperature limit and the manufacturer shall be consulted.	

A.3.3.12 Serrated, segmented and louvered fins, and fins with spacing tabs, have a slightly higher air-side film coefficient. The disadvantage, however, is that they are more susceptible to air-side fouling and are more difficult to clean due to the sharp edges at the discontinuities, so they should be considered only for low-fouling duties.

A.3.3.23 In areas prone to air-side fouling due to airborne particulates, the maximum fin density should not exceed 394 fins per meter (10 fins per in.) and the minimum gap between the fins on adjacent tubes should be 6.4 mm ($^{1}/_{4}$ in.) to allow effective cleaning of the fins.

A.3.3.34 Tube supports should be designed such that mechanical loads are transferred to the core of the tube.

A.3.3.45 For elliptical tubes, the minimum tube wall thickness shall be as specified in 7.1.11.3.

A.3.3.56 The minimum dimensions of elliptical tubes shall be: short axis 14 mm ($^{9}/_{16}$ in.), long axis 36 mm (1$^{7}/_{16}$ in.).

A.3.3.67 For elliptical tubes the maximum process temperatures for selecting the type of fin bonding shall be in accordance with A.3.3.17.1.11.X.

A.3.4A.3.5 Tube-to-Tubesheet Joint Calculations — Guidance to 7.1.6.1.3

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During the inquiry phase, the Ppurchaser should specify the operating cases requiring the tube-to-tubesheet calculations; special consideration should be given to cases with the largest tube metal temperature differences between tube rows or passes.

A.3.5A.3.6 Fans — Guidance to 7.2.3

A.3.5.1 Variable-speed (speed frequency controlled, SFC) fans or automatic variable-pitch (AVP) fans may be used for process control.

A.3.5.2 If there are stringent noise limitations during night-time and if, due to a lower air-inlet temperature at night-time, the air flow rate can be reduced, variable-speed fans should be used.

~~A.3.6~~A.3.7 Maximum Allowable Nozzle Loads — Guidance to 7.1.10

Where the ~~P~~purchaser specifies piping loads in excess of the nozzle loads shown in 7.1.10.2, these higher nozzle loads can require stiffening of the heat exchanger components and structural supports, and will increase the loads on the supporting pipe-racks or foundations. This can result in higher fabrication and erection cost of the exchanger and supporting structure.

~~A.3.7~~A.3.8 Walkways and Platforms — Guidance to 7.3.5

Open grating should be used for the maintenance floor underneath the fan inlets to reduce air-side pressure drop. If solid plate is used, the effect on air-side pressure drop should be taken into account. To minimize this effect, a larger distance from maintenance floor to fan inlet can be required.

~~A.3.8~~A.3.9 Selection of Header Type — Guidance to 7.1.6

A.3.8.1 The header types should be selected in accordance with Table A.2.

Table A.2 — Header Selection

Header Type	Design Pressure kPa gauge (psig)
Plug type headers, removable cover plate headers or bonnet type headers	< 3000 (435)
Plug type headers	≥ 3000 (435) and/or for hydrogen service

A.3.8.2 For fluid streams with a fouling resistance greater than 0.000 34 $m^2 \cdot K/W$ (0.001 93 $°F \cdot ft^2 \cdot h/Btu$), or if fouling layers are expected that cannot be removed by chemical means, the bundle construction shall be suitable for mechanical cleaning.

A.3.8.3 In heat exchangers having a condensing duty, the passes for the condensing phase should extend over the full width of the bundle. In case of total condensation, the size of the outlet nozzles should be such that flooding of the bottom rows of tubes cannot occur.

A.3.8.4 When considering maximum cooling conditions under minimum ambient temperature, the purchaser may wish to consider the active process outlet temperature control that is being applied (e.g. by-pass control of the process fluid, air-flow control by on/off fans or fan speed control) and whether these normal control functions are to be considered as remaining active during low-ambient operation or if it is necessary to consider a failure of these systems. When such control systems fail the mode of failure may also be considered (e.g. by-pass valves failing either open or closed, speed failure to either minimum, maximum, or last speed) along with any alarms and functions that may be taken in the event of such failures which may protect the equipment. For winterized air coolers, the failure of the winterization system to control the air inlet temperature may have to be considered separately from process control failures when considering low ambient temperature operation.

A.3.8.5 Redundant or safe failing control systems may be considered to mitigate against requirement to use split headers.

~~A.3.9~~A.3.10 Air Design Temperature — Guidance to 7.2

A.3.9.1 To determine the air design temperature, the higher of the following temperatures may be used for non-critical processes:

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— the highest air temperature that is exceeded for 400 h/y;

— the highest air temperature that is exceeded for 40 h/y, less 4 °C (7 °F).

A.3.9.2 For critical processes, the air design temperature shall be the highest air temperature that is exceeded for 40 h/y.

A.3.9.3 For an optimum design, the following temperatures should be specified, together with alternative process conditions specified in 7.1.6.1.1:

— minimum design metal temperature;

— design metal temperature;

— minimum ambient temperature;

— design ambient temperature;

— fin selection temperature.

~~A.3.10~~A.3.11 Air Side Design — Guidance to 7.2.1

A.3.10.1 Pipe rack mounted bays require special consideration when looking at the adequacy of air entering the air-cooled heat exchangers. Normally if the height of the pipe rack above grade is equal to or greater that one half of the length of the tubes of the air-cooled heat exchanger and the air-cooled heat exchangers have mechanical equipment walkways located beneath the bays and the area directly below the mechanical equipment walkways provides a 50 % or greater net free area, then adequate air flow can be expected.

A.3.10.2 Several banks of air-cooled heat exchangers located in one plant or one process area can affect the operation of other bays by the recirculation of hot exiting air from one bay entering the air flowing into another or the same bay. This is termed "hot air recirculation" and can be controlled by the judicial placement of the units with respect to one another as well as taking prevailing winds of the plant location into consideration. Computational fluid dynamics (CFD) computer programs are available for modeling plant sites to determine the amount of hot air recirculation that can occur under differing conditions. These CFD programs can help in sighting equipment and can provide an estimate of how much to increase the design air temperatures entering the air-cooled heat exchangers. Design air entering temperature is especially important to predict accurately in some critical close process temperature to design air temperature entering approach air-cooled heat exchangers.

A.3.10.3 Forced draft and induced draft air-cooled heat exchangers should not be located adjacent to each other due to the potential for unwanted hot air recirculation.

~~A.3.11~~A.3.12 Bearing Lubrication — Guidance to 7.2.5

To allow proper lubrication, it should be ensured that the new grease displaces the maximum amount of old grease and automatically ejects any surplus to the outside; this should be achieved either by the bearing design or by fitting an external relief device.

~~A.3.12~~A.3.13 Gaskets for Bonnet or Cover-plate Type Headers — Guidance to 7.1.6.2 and 7.1.8

A.3.12.1 Gasket types are given in Table A.3 and the required gasket contact face surface finish is given in Table A.4.

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A.3.12.2 Gaskets shall not contain asbestos.

A.3.12.32 Service conditions are listed in Table A.5 and the gaskets should be selected using Table A.6.

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Table A.3 — Gasket types

	Description	Minimum Width mm (in.)	Minimum Thickness mm (in.)
1	Aramid-fiber-filled NBR, oil and acid resistant	9.5 (3/8)	2 (5/64)
2	Compressed sheet composition, oil or acid resistant	9.5 (3/8)	1.6 (1/16)
3	Flat metal-jacketed, soft iron, filled	12.5 (1/2)	3.2 (1/8)
4	Flat metal-jacketed, stainless, filled	12.5 (1/2)	3.2 (1/8)
5	Metal-reinforced PTFE layers	9.5 (3/8)	1.6 (1/16)
6	Metal-reinforced expanded graphite	9.5 (3/8)	1.6 (1/16)
7	Grooved gaskets with graphite layers[a]	12 (1/2)	6.4 (1/4) or 3.2 (1/8)

[a] The minimum thickness of grooved gaskets with graphite layers should be 3.2 mm (1/8 in.) to provide a width-to-thickness ratio of 4 to 1.

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Table A.4 — Gasket Contact-surface Finish

Gasket Type	R_a Value μm	(μin.)
1, 2, 5, 6, 7	3.2 to 6.3	(125 to 250)
3, 4	0.8 to 1.6	(32 to 64)

Table A.5 — Service Conditions

Service Condition	Description
I	Non-corrosive and mildly corrosive
II	Hydrocarbon streams containing sulfur compounds and naphthenic acids with an acid value exceeding 300 mg/kg KOH (300 × 10–6 mass fraction KOH), and for maximum operating temperatures above 230 °C (446 °F)
III	Hydrocarbon streams containing sulfur compounds and naphthenic acids with an acid value not exceeding 300 mg/kg KOH (300 × 10–6 mass fraction KOH) and for maximum operating temperatures above 330 °C (626 °F)
IV	Hydrocarbons containing hydrogen
V	Non-corrosive cooling water below 50 °C (122 °F)
VI	Mildly corrosive cooling water below 50 °C (122 °F)
VII	Corrosive cooling water below 50 °C (122 °F)
VIII	Frequent changes in temperature and pressure, (e.g. hot washing, dewaxing, chilling) and frequent cleaning (i.e. more than twice a year under all conditions I to VII)

Table A.6 — Gasket Selection

Service Condition	Design Temperature		Maximum Design Pressure		Recommended Type	Alternative Type
	°C	(°F)	kPa (ga)	(psig)		
I	–200 to 0	(–300 to 32)	3000	(435)	6	4
	0 to 150	(32 to 300)	2000	(290)	1	2, 5, 6
	0 to 240	(32 to 460)	3000	(435)	6	3
	240 to 450	(460 to 840)	3000	(435)	6	3
II	0 to 150	(32 to 300)	2000	(290)	1	2, 5, 6
	0 to 240	(32 to 460)	3000	(435)	6	3
	240 to 450	(460 to 840)	3000	(435)	6	4
III	330 to 450	(630 to 840)	3000	(435)	6	
IV	0 to 450	(32 to 840)	3000	(435)	6	
V, VI, VII	0 to 50	(32 to 120)			1 [3.2 mm (1/8 in.) thick]	2, 5, 6
VIII	0 to 450	(32 to 840)	6000	(870)	4	

A.4 Materials

A.4.1 Welded Tube Ends — Guidance to 9.2.1 and 12.2.2

Mock-up bullet item, review the requirements and locate into the normative section (modification of 9.1.1.5 & possible new 9.1.1.6 paragraphs). Action: A. Miller.

Vendors to provide HBW values current procedures are able to meet. Action: T. Ferguson, S. Edwards, J. Allison.

A.4.1.1 Seal welded or strength welded tube-to-tubesheet joint should be specified by the purchaser. When welded tube ends are specified or required, following points should be considered. Tube fins shall be protected during welding of tube ends and also during PWHT. Partial strength welds should not be used.

a) Provide adequate unfinned tube length behind the tubesheet to protect tube fins during welding and PWHT if required.

b) Tubes and tubesheet material shall be of similar composition. Filler materials used for welding shall be of the same or higher composition of base metals or tubes & tubesheet materials. Eliminate bimetallic welds

c) PWHT of tube-to-tubesheet joint shall be performed when specified or required for service or other requirements.

d) Local PWHT should be performed per design code.

e) Mock-up test for strength welded tube-to-tubesheet joint should be performed. Mock-up test should duplicate actual production tubes & tube layout configuration. Mock-up tubesheet thickness should be minimum 25 mm (1 inch) thick. Mock-up test should be performed on minimum 5 tube welds. Mock-up shall be sectioned longitudinally through the centerline of each tube. Micro harness should be measured for welds, and Heat Affected Zone. Weld and Heat Affected Zone hardness should not exceed as shown in Table #.

TABLE #

Material	Weld and Heat Affected Zone Hardness
Carbon Steel	225 HBW
Chromium Steel (up to 3% Cr)	225 HBW
Chromium Steel (5 % Cr to 17% Cr)	235 HBW
Duplex Steel (22% Cr)	280 HBW
Super Duplex (25% Cr)	To be agreed between purchase & vendor
Note: NOTE These hardness values are for general services. More stringent hardness testing and acceptance criteria can be required for special services (e.g. sulfide stress cracking or other types of environmental cracking services as specified in NACE Standards).	

~~Where welded tube ends are specified or required, tube and tubesheet materials should be selected such that a PWHT of the tube ends welds can be avoided. Low-alloy chromium steel (i.e. 1 % Cr to 9 % Cr) material is not recommended when tube end welding is specified, due to exposure of the aluminum fins to high temperatures during the PWHT process.~~

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[TASK GROUP REVIEW]

A.4.2 Tube-to-Tubesheet Joint — Guidance to 9.3.4

A.4.2.1 For heat exchangers in hydrogen service, tube-to-tubesheet joints should be welded and expanded.

A.4.2.2 If weld overlay or cladding of the tubesheet is specified to eliminate the effects of welding dissimilar materials, a 4.8 mm ($^3/_{16}$ in.) minimum overlay or clad should be provided. The overlay or cladding should have the same metallurgy as the tubes. [TASK GROUP REVIEW]

A.4.2.1 Where work hardening of the tube material during rolling could result in the potential for environmental cracking, a strength-welded tube-to-tubesheet joint should be applied.

A.4.2.1A When specifying a strength welded joint would require PWHT, caution should be considered if a strength welded joint should be used vs. rolled only joint.
Action: A. Miller to update/propose new wording for A.4.2.A

A.4.2.2 Strength-welded tube-to-tubesheet joints should be considered by the purchaser for the following conditions.

a) If the design pressure exceeds 7000 kPa (ga) (1000 psig).

b) If duplex stainless steel tubes are used in wet hydrogen sulfide service.

c) If titanium tubes are used (provided the wall thickness is adequate for strength welding).

d) Where austenitic stainless steel tubes and a ferritic steel tubesheet are used and the metal temperature is above 205 °C (400 °F).

e) For fixed tubesheet exchangers used in sulfur plant applications (e.g. waste heat exchangers, sulfur condensers, reheaters, acid gas preheaters, etc.).

f) In heat transfer fluid services with operating temperatures exceeding 205 °C (400 °F).

g) In cyclic service.

h) In a service where sudden temperature excursions can occur.

i) When the fy ratio of tubesheet SMYS to tube SMYS, as defined in ASME BPVC, Section VIII Division 1, Nonmandatory Appendix A, “Basis for Establishing Allowable Loads for Tube-to-Tubesheet Joints” is less than 0.6.

j) For high temperature hydrogen service, and included expansion of tube

Note: PWHT may be required for carbon steel tubes and header box with strength welded joint per API 941 for HTHS.

A.4.2.3 For clad tubesheets, the tubesheet yield stress used in the calculation of fy should be that of the base material.

A.4.2.3 Seal-welded or strength-welded tube-to-tubesheet joints should be considered by the purchaser for the following conditions.

a) For exchangers handling steam or boiler feed-water at design conditions exceeding class 150 flange rating.

A.4.2.4 For heat exchangers in hydrogen service the tube-to-tubesheet joints should be strength-welded and expanded when either of the following cases apply:operating in high temperature hydrogen service.

a) When the designoperating pressure of the exchanger is 7000 kPa (ga) (1000 psig) or higher.

b) When the designoperating temperature is in excess of 230200 °C (450400 °F).

Note: PWHT may be required with strength welded joint per API 941 for HTHS.

A.4.2.4 Tube-to-tubesheet joints for tubesheets with clad or weld overlay on the tubesheet should be strength-welded to the tube side cladding or weld overlay.

A.4.2.5 If welded tube-to-tubesheet joints are specified for dissimilar tubes and tubesheet material, weld overlay or cladding should be considered on the tubesheet to eliminate bimetallic welds. The overlay or cladding should have the same metallurgy as the tubes.

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A.5 Preparation for Shipment Protection — Guidance to Clause 11

A.5.1 If water residues cannot be tolerated, equipment should be dried by one of the following methods:

a) blowing dry air or nitrogen, of relative humidity less than 15 % (usually dehumidified), through the heat exchanger and monitoring the outlet air until the relative humidity falls below 30 %;

b) evacuating the heat exchanger with a vacuum pump to an absolute pressure of between 0.4 kPa (0.06 psi) and 0.5 kPa (0.075 psi).

A.5.2 After draining and drying, internal surfaces may be protected against corrosion by the addition of a desiccant (e.g. silica gel), by the addition of a volatile corrosion inhibitor, or by blanketing with an inert gas such as nitrogen [typically at gauge pressures from 35 kPa (5 psi) of up to 100 kPa (15 psi)].

Annex B
(informative)

Air-cooled Heat Exchanger Checklist and Data Sheets

Contents and Usage

Completion of the checklist (Table B1) is the responsibility of the purchaser.The checklist and data sheets in this annex provide the data necessary for the description and design of air-cooled heat exchangers for petroleum and natural gas services.

The checklist is used to note for listing the purchaser's specific requirements for which the paragraphs or subsections within this standard include a choice or which designate, by use of a bullet [●] in the margin, that a decision is required. the Purchaser shall make in response to the clauses and subclauses in this standard alongside which bullets (●) are used to indicate that more information is required or that it is necessary to make a decision.

Completion of the checklist is the responsibility of the Purchaser. Completion of the data sheets is the joint responsibility of the Purchaser and the Vendor. The Purchaser is responsible for the process data on the data sheets.

The transport properties shall be based on the total composition of each of the phases (water, steam, air, and hydrogen or another permanent gas) if these components are parts of a homogeneous phase. If the liquid has immiscible phases, the liquid properties shall be separately and completely specified for each phase. If the mentioned components are not included in the transport properties and they are present, their concentrations in the process stream shall be stated. In the simple case of a well defined, no-change-of-phase service, the Ppurchaser may use the data-sheets as the only document for data transmittal.

The Purchaser may submit the checklist and data sheets to the Vendor in a form other than that indicated herein.

Table B.1—Checklist

Section	Requirement	Item	
4.1	Pressure design code:		
4.4	Applicable local regulations:		
4.6	Is service designated as sour or wet hydrogen sulfide service?	Yes	No
4.7	Winterization requirement and type?		
5.7	Is noise data-sheet required?	Yes	No
6.1.1	Which documents are to be submitted? Which documents are subject to Ppurchaser's approval?		

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Section	Requirement	Item	
6.1.3	Are calculations to be submitted for approval?	Yes	No
6.1.4	Are welding data to be submitted for approval?	Yes	No
6.1.6	Additional engineering information required:		
6.2.2	Final records to be furnished and whether they shall be in electronic form:		
7.1.1.11	Is internal steam-out design required? Temperature, pressure and operating conditions:	Yes	No
7.1.1.12	Is cyclic service design required? Type and magnitude of variation in pressure, temperature, flowrate, time for the variation and number of cycles or frequency:		
7.1.3.1	Maximum design temperature: Minimum design temperature: Minimum design metal temperatures:		
7.1.3.2	Maximum operating temperature for fin selection:		
7.1.4	Design pressure of tube bundle:		
7.1.5.1	Corrosion allowance:		
7.1.6.1.1	Is an analysis required of alternative operating conditions in design of headers?	Yes	No
7.1.9.7	Plane of process flanges if not horizontal:		
7.1.9.15	Chemical cleaning connection size, type, and location:		
7.1.11.2	Maximum tube length:		
7.1.11.7	Type of finned tube construction:		
7.1.11.12	Is heat treatment required after bending of U-tubes?	Yes	No
7.2.1.1	Special environmental factors affecting air-side design:		
7.2.1.8	Is an estimate of design exposure temperatures for mechanical components required?	Yes	No
7.2.2.1	Location of noise level values:		
7.2.3.10	Use of automatic control for varying the blade pitch?	Yes	No

Section	**Requirement**	**Item**	
7.2.3.11 e	Any special blade pitch limit stop setting:		
7.2.7.1.1	Type of drive system: Drive equipment supplier:	Purchaser	Vendor
7.2.7.2.1	Electric motor construction; supply and classification:		
7.2.7.2.9	Is a self-actuating braking device required?	Yes	No
7.2.7.3	Requirements for variable-speed drive systems:		
7.2.9.1	Specify the type of vibration monitoring device.		
7.2.9.2~~1~~	Are vibration cut-out switches required? If required what type.	Yes	No
7.2.10.19	Louver position upon loss of control-air pressure:		
7.2.11.1	Are screens required? If required what type. ~~Type:~~	Yes	No
7.3.1.1	Structural code:		
7.3.2.2	Is shop test for vibration check required?	Yes	No
7.3.3.2	Extent and mass of fireproofing:		
7.3.3.11	Snow load:		
7.3.3.12	Exact type, location, magnitude, and direction of other design loads:		
7.3.4.5	Plenum partition requirements for recirculation systems:		
7.3.5.1	Number and location of header access platforms, interconnecting walkways and ladders:		
7.3.5.8	Are there any special requirements for personnel protection against high air-outlet temperature? If yes, state:	Yes	No
8.2.3	Maximum allowable Carbon Equivalent: Restrictions on other residual elements and micro-alloying elements:		

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Section	Requirement	Item	
9.1.1.5	Weld procedure qualifications for carbon steel in sour or wet hydrogen sulfide service to include cross-sectional micro-hardness testing? Additional restrictions for the qualification test material:	Yes	No
9.3.4.1	Are tube-to-tubesheet joints to be seal-welded? Are tube–to-tubesheet joints to be strength-welded?	Yes Yes	No No
10.1.12	Is carbon steel plate in sour or wet hydrogen sulfide service subject to ultrasonic lamination checks?	Yes	No
10.2.6	Are special tests or additional requirements for drying or preservation required? Details:	Yes	No
10.3	Are shop run-in tests required? Details:	Yes	No
10.4	Is a performance test required?	Yes	No
11.1.4	Extent of skidding, boxing, crating, protection or coating for shipment:		
12.1	Supplemental requirements of Clause 12 that apply:		

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Annex C
(informative)

Winterization of Air-cooled Heat Exchangers

C.1 Scope

This annex presents design features and other considerations that contribute to satisfactory functioning of air-cooled heat exchangers operating with low-temperature inlet air. Data related to structural materials for low-temperature service and safety precautions related to the accumulation of snow and ice are not included.

C.2 Winterization Problem Areas

C.2.1 General

The purposes of C.2 are as follows:

a) to identify reasons for winterization of air-cooled heat exchangers;

b) to outline general design data requirements for winterization and guidelines for supplying such data;

c) to review heat losses and general problem areas;

d) to establish process categories that can require winterization and safety margins for each category.

~~C.1.1~~ C.2.2 Reasons for Winterization

Winterization is generally applied to maintain the tube-wall temperature at or above a specified minimum tube-wall temperature to prevent operating problems. The specified minimum tube-wall temperature is the point at which the tube-wall temperature approaches the fluid's critical process temperature. Critical process temperatures include the freezing point, pour point, wax point, dew point (if condensation causes corrosion), hydrate formation point and any other temperature at which operating difficulties can occur.

In cold climates, where the ambient temperature can vary from –29 °C (–20 °F) or lower during winter months to 30 °C (86 °F) or higher during summer months, airflow control alone can be inadequate to provide control of the process outlet temperature and the tube wall temperature. In such cases, winterization can also be required as a means of providing process control.

~~C.1.2~~ C.2.3 General Design Data Requirements

The ~~P~~purchaser should specify the following:

a) minimum tube-wall temperature, which should include a safety margin as discussed in C.2.7;

b) minimum design air temperature;

c) all alternative process conditions, including reduced flow (turndown) operations;

d) design wind velocity and the prevailing wind direction;

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e) availability of steam or another source of heat for start-up in cold weather. (If steam is available, the steam pressure should be specified.)

~~C.1.3~~ C.2.4 Heat Losses

The effect of heat losses (by conduction and convection, louver leakage and natural draft~~draught~~) on the tube-wall temperature during start-up, shutdown and standby operating conditions should be considered when the requirements for a heating coil are determined.

~~C.1.4~~ C.2.5 General Problem Areas

The exit fluid temperature for any single row of any given pass might not be the same as the average exit fluid temperature for that pass. To avoid potential problems in the field, the exit fluid temperature for each row should be calculated separately to determine the lowest tube-wall temperature.

For critical services, it can be desirable to monitor the tube-wall temperature in the coldest zone. This may be done by installing thermocouples at critical points.

Mal-distribution of the process fluid or airstream can also cause problems that should be considered in the design of the equipment.

~~C.1.5~~ C.2.6 Process Categories

~~C.1.5.1~~ C.2.6.1 General

Most winterization problems fall into one of the following six categories:

a) problems with water and dilute aqueous solutions;

b) problems with total steam condensers;

c) problems with partial steam condensers;

d) problems with condensing process fluids containing steam with or without noncondensables;

e) problems with viscous fluids and fluids with high pour points;

f) problems resulting from freezing, hydrate formation, and corrosion caused by condensate.

These categories and the ways in which they apply to typical operating cases are described in C.2.6.2 through C.2.6.7.

~~C.1.5.2~~ C.2.6.2 Category 1 — Water and Dilute Aqueous Solutions

Water and dilute aqueous solutions have high tube-side heat transfer coefficients, resulting in relatively high tube-metal temperatures. When these fluids are present, simple winterization systems, such as airflow control systems, are indicated. In cold climates, where the ambient temperature can be –29 °C (–20 °F) or lower during winter months, airflow control alone can be inadequate as a means of providing protection against freezing. In such case, more elaborate winterization schemes should be considered. Start-up and shutdown at extremely low temperatures can require additional measures.

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~~C.1.5.3~~ C.2.6.3 Category 2 — Total Steam Condensers

Total steam condensers that are single pass can be subject to a backflow of steam from the outlet end of the upper (hotter) tube rows into the outlet end of the lower (colder) tube rows. This usually leads to non-condensable contaminants collecting near the outlet end of the colder tubes. The presence of noncondensables results in diminished performance and in subcooling and possible freezing of condensate in the colder tubes. Corrosion can also occur.

In quite a few installations, a particular set of conditions has caused rapid perforation of tube walls. The perforations occur near the exit end of the lower (colder) tube rows. When this happens, a repetitive knocking or clicking noise, called water hammer, is always present. These failures, which have occurred in numerous locations, have the following common characteristics:

a) one pass with four or more rows of tubes whose outside diameter is 25.4 mm (1 in.) and whose length is 11 m to 16 m (36 ft to 52 ft);

b) inlet steam pressure between 0 kPa and 170 kPa gauge (0 psig and 25 psig).

The perforations have occurred as quickly as within one day of service on tubes with a wall thickness of 0.89 mm (0.035 in.) and as slowly as three months on tubes with a wall thickness of 2.11 mm (0.083 in.). It appears that the rapidity of failure appears is related to the severity of the water hammer.

Measures to prevent this type of failure are all aimed at reducing or eliminating the quantity of steam back-flowing into the colder tubes. For instance, in a four-row, one-pass condenser, limiting the tube length to 360 times the tube outside diameter seems to suffice [for example, a length of 9 m (30 ft) for tubes with an outside diameter of 25.4 mm (1 in.)]. Alternatively, the rear header can be separated into four non-communicating compartments with drains provided for each compartment. Another method is to use restriction orifices in the tube inlets; however, this measure might not be completely effective at all flow-rates.

~~C.1.5.4~~ C.2.6.4 Category 3 — Partial Steam Condensers

In category 3 process streams, the quantity of outlet vapor is large enough that backflow cannot occur and steam exits continuously from the outlet ends of all tube rows. The quantity of outlet vapor is typically 10 % to 30 % by mass of the total inlet flow. Outlet quantities below 10 % by mass are characteristic of category 2 condensers. The exact quantity of outlet vapor should be established by calculation, with consideration given to the mode of operation at the minimum ambient temperature. If calculations show that backflow does not occur, simple winterization systems, such as airflow control, are indicated. If calculations indicate that backflow does occur, moderate to extensive protection systems can be indicated.

~~C.1.5.5~~ C.2.6.5 Category 4 — Condensing Process Fluids Containing Steam with or without Noncondensables

Category 4 is an extension of category 3. Category 4 highlights the effects of other condensables on the tube-wall temperature. Prediction of the tube-side flow regime is essential for an accurate evaluation of tube-wall and fluid temperatures. Consider, for example, a stream containing steam, condensable hydrocarbons and non-condensables. Annular flow can exist at the condenser inlet, with a liquid hydrocarbon annulus being formed on the cold tube wall and surrounding a gas core. Stratified flow can exist at the condenser outlet, with water and liquid hydrocarbons draining from the bottom of the tube while steam condenses on the upper portion. Simple winterization systems are usually indicated when these conditions are present. In cold climates, where the ambient temperature can be −29 °C (−20 °F) or lower during winter months, airflow control alone has proven to be unreliable as a means of providing protection against freezing. In such case, more elaborate winterization schemes should be considered.

~~C.1.5.6~~ C.3.6.6 Category 5 — Viscous Fluids and Fluids with High Pour Points

See Annex F for more information.

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When a viscous fluid is flowing through a number of parallel paths, local variations in cooling can cause a drastic reduction in velocity in some of the flow paths. This phenomenon is called “unstable flow”. Unstable flow is caused when, under certain conditions of bulk viscosity, wall viscosity and pressure drop, the increase in pressure drop resulting from a higher viscosity (caused by the additional cooling allowed by a lower velocity) offsets the decrease in pressure drop resulting from the lower velocity. This can occur only when the fluid is in laminar flow.

When unstable flow occurs, the velocities in parallel tubes within a pass can differ by as much as 5:1. As a result, the exchanger's overall tube-side pressure drop can increase by up to 100 % and the heat removal can decrease to less than 50 % of that possible if the fluid were equally distributed among the tube paths. This flow mal-distribution is a major factor in many cases of diminished performance of viscous and high-pour-point fluid coolers.

Liquids of high viscosity have been one of the more difficult fluids to adequately design for, and this difficulty increases as the ambient temperature decreases.

At present, only general guidelines exist for avoiding such mal-distribution. These guidelines are as follows.

a) The bulk viscosity of the process fluid at the outlet temperature should not exceed 50 mPa·s (50 cP).

b) The ratio of wall viscosity to bulk viscosity should not exceed 3:1.

The following additional factors should be given extra emphasis in both design and fabrication for this type of service.

— Air-side flow distribution and temperature distribution should be as uniform as possible. ~~External r~~Recirculation of air over only one side can cause non-uniform air flow and air temperature to the bundle. Over the end recirculation or recirculation over both sides should, therefore, be considered.

— Air bypassing the bundle between the side frames and tubes should be minimized by conforming to a maximum gap of 10 mm ($^3/_8$ in.) as specified in 7.1.1.8.

— Allowable process fluid pressure drop should be high. Pressure drops of 275 kPa (40 psi) or higher are common. The tube diameter and velocity should be established to avoid laminar flow where possible. Since such designs tend to be controlled by the low tube side heat transfer coefficient, utilizing higher pressure drop and higher velocity normally results in an appreciable reduction in required surface area, offsetting the cost of a larger pump.

— Tube-side flow should be uniformly distributed within the headers. This can require additional nozzles and/or external insulation of the headers.

— Where laminar flow cannot be avoided, tube inserts should be considered (with the ~~P~~purchaser's approval), to increase turbulence, at the expense of additional pressure drop.

There can be cases in which successful operation can be achieved while violating these guidelines. However, when successful experience is lacking, it is risky to ignore these recommendations. Alternative designs that should be considered include indirect systems and air-cooled heat exchangers with serpentine coils.

~~C.1.5.7~~ C.2.6.7 Category 6 — Freezing Point, Hydrate Formation Point, and Dew Point

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Category 6 process streams are characterized by a discrete critical process temperature. For such streams, the calculation of wall and fluid temperatures tends to be straightforward. Depending on design conditions, recommended winterization systems include the full range outlined in C.3.

C.1.6 C.2.7 Safety Margins

So many variables are involved in the process streams described in C.2.6.2 through C.2.6.7 that establishing a fixed safety margin (the tube-wall temperature minus the critical process temperature) is difficult. Each problem should be analyzed on an individual basis.

In the absence of more specific information, the safety margins given in Table C.1 should be added to the critical process temperature to determine the specified minimum tube-wall temperature.

Table C.1 — Safety Margins for Different Process Categories

Category	Safety Margin °C (°F)
1	8.5 (15)
2	8.5 (15)
3	8.5 (15)
4	8.5 (15)
5	14 (25)
6	11 (20)
NOTE See C.2.6 for description of categories.	

C.2 C.3 Methods of Winterization

C.2.1 C.3.1 Air fFlow and Air Temperature Control Systems

C.2.1.1 C.3.1.1 System A — Airflow Control

C.3.1.1.1 System A generally uses variable speed drives or automatically controlled variable-pitch fans, as shown in Figure C.1, and/or automatically or manually controlled louvers, as shown in Figure C.2, to control air flow.

C.3.1.1.2 Variable speed drives and automatically controlled variable-pitch fans offer the following advantages over louvers:

— better airflow control, providing more sensitive control of process temperatures at or near design conditions;

— lower power requirements at reduced ambient temperatures.

C.43.1.1.3 Automatically controlled variable-pitch fans have the following disadvantages:

— less precise airflow control when the required airflow is less than 30 % of the full airflow;

— more sensitivity to wind effects at lower air flows.

C.3.1.1.4 Louvers offer the following advantages over automatically controlled variable-pitch fans:

— more precise airflow control when the required airflow is less than 30 % of the full airflow;

— less sensitivity to wind effects;

— capability of full closure for warming the unit at start-up and shutdown.

C.3.1.1.5 Louvers have the following disadvantages:

— less precise control when the required airflow is more than 30 % of the full airflow, since louvers have non-linear control characteristics;

— potentially inoperable linkages as a result of ice, snow, corrosion or wear.

Airflow control is used primarily to control process temperatures and offers the least winterization protection.

Variable speed drives have become much more prevalent in recent years, especially in cold climates where there is a significant variation in ambient air temperature between summer and winter months. The incorporation of variable speed drives provides substantial improvements in the areas of process control, electric power reduction and noise reduction. The power and noise reductions with fan speed are substantial, since power is proportional to fan speed to the 3rd power, and noise is proportional to fan speed to the 5th power.

Fan efficiency varies with blade pitch angle and reaches a maximum at an optimum angle, decreasing beyond that. Increasing blade pitch angle beyond the stall point actually causes a decrease in airflow. Increased fan speed, on the other hand, results in an increase in airflow since airflow is directly proportional to the revolutions per minute, RPM, (speed) of the fan.

Louvers should always be used in combination with variable speed drives when the airflow requirement for any operating case is less than 20 % of the required design airflow.

~~C.2.1.2~~ C.3.1.2 System B — Airflow Control Plus Air Temperature Control Using a Noncontained Internal Recirculation System

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In system B, the automatically controlled variable-pitch fan near the process outlet reverses airflow when the inlet air temperature is low. The air heated from flow over the tubes enters a zone beneath the tube bundle that is protected to some degree from wind effects by downward-projecting hot air recirculation baffles~~wind skirts~~. Part of the heated air is then mixed with inlet air as shown in Figure C.3 and Figure C.4. This system can be subject to uneven air mixing below the tube bundle and does not provide a positive method of controlling the mixed air inlet temperature. In addition, wind can adversely affect the circulation of the hot air. Care should be taken in selecting mechanical equipment installed below the downflow fan because of the higher air temperature. This system is not generally recommended but has been used for heat exchangers requiring moderate winterization protection.

~~C.2.1.3~~ C.3.1.3 System C — Airflow Control Plus Air Temperature Control Using a Contained Internal Recirculation System

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In system C, the automatically controlled variable-pitch fan near the process outlet reverses when the inlet air temperature is low to direct airflow downward while the exhaust louvers partially close, as shown in Figure C.5. Simultaneously, the vertical bypass louvers above the tube bundle open to redirect part of the exhaust air along the length of the tube bundle. This air is mixed above the downdraft~~draught~~ side of the tube bundle with incoming ambient air. Only enough air is directed through the bypass louvers to ensure that the mixed air temperature above the down draft~~draught~~ fan is above a preset level. For certain design cases, hot air recirculation baffles~~wind skirts~~ can be required below the tube bundle. The disadvantage of this system is that areas of the bundle can be exposed to low air temperatures as a result of uneven air mixing. Care should be taken in selecting mechanical equipment installed on and below the downflow fan because of the higher air temperature. This system offers an additional degree of winterization protection, compared with the systems described in C.3.1.1 and C.3.1.2.

~~C.2.1.4~~ C.3.1.4 System D — Airflow Control Plus Air Temperature Control Using an External Recirculation System

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In system D, hot exhaust air is recirculated through an external recirculation duct ~~-~~being mixed with inlet air when the inlet air temperature is low. The amount of air recirculated and the temperature of the mixed stream are controlled by partially closing the exhaust louvers while modulating the inlet and bypass louvers. This system normally includes a floor so that the unit is completely enclosed, thus providing positive control of the entering airflow. Although the temperature of the process fluid can be controlled by louver action alone, this is not recommended. Variable speed drives or automatically controlled variable-pitch fans should be used to control the process temperature more precisely. Variable speed drives or automatically controlled variable-pitch fans can also enable the user to reduce the fan power required at lower ambient temperatures.

Figure C.6 illustrates recirculation over both sides of the unit. Some units may have a recirculation duct over one side only. Alternatively, a recirculation duct may be placed at one or both ends of the unit to minimize the width of the bay or to provide an enclosed heated area for headers and header walkways. In addition, various combinations and locations of inlet louvers can be used to maximize mixing of hot and cold airstreams.

This system provides maximum winterization protection, compared with the systems described in C.3.1.1 through C.3.1.3, and can operate in ambient temperatures lower than any previous design discussed. For this reason, it is generally the most suitable in cold climates where the ambient temperature is below −29 °C (−20 °F), providing the highest degree of plenum temperature control and process temperature control. Since it can be totally enclosed by closing the inlet and exit louvers, it provides more effective protection during start-up and shutdown situations during cold weather.

Recirculation over one side is generally suitable for most applications and bundle sizes. When applied, the recirculation duct should always be placed on the prevailing, windward side of the tube bundle for protection. It should be noted, however, that ideal mixing of the warm recirculation air and the colder inlet air is never fully achieved. Propeller type fans are not mixing devices. Unless provision is made in recirculation systems for mixing of cold inlet air and warm recirculation air, the temperature of the mixed air stream is not uniform and can vary significantly from one part of the plenum to another.

~~C.2.1.5~~ C.3.1.5 Recirculation Ducts — Arrangement and Location

~~C.2.1.5.1~~ C.3.1.5.1 Multi-bay Units

For units with non-symmetrical piping manifolds (typically single-phase gas or liquid cooling service), recirculation over one side should be considered adequate in the majority of cases.

For units with symmetrical piping manifolds (typically with two-phase flow conditions at the inlet and/or outlet, and an even number of bays), recirculation over one side may be used, however the ducts should be located on the outer sides of each pair of bays (i.e. a mirror arrangement), to provide uniform distribution of recirculation air to each bundle. A full partition wall and door should be provided between each pair of bays. Recirculation over both sides may also be provided.

~~C.2.1.5.2~~ C.3.1.5.2 Single Bay Units

Recirculation over one side only may be used when the unit is located adjacent to or within a bank of other units.

For units where both sides can be exposed to ambient wind conditions, recirculation over both sides should be considered.

~~C.2.1.5.3~~ C.3.1.5.3 Special Services (Single or Multi-bay Units)

For services with viscosity exceeding 10 cP at the process outlet temperature or for services with a high pour point, recirculation over both sides should be provided.

For vacuum system condensers located in freezing climates, recirculation over both sides should be provided. Alternately, recirculation over the end may be applied.

In arctic climates (ambient temperatures of −45 °C [−50 °F] and lower), recirculation over both sides is strongly advised. In addition, recirculation over the ends can be necessary to protect the header boxes.

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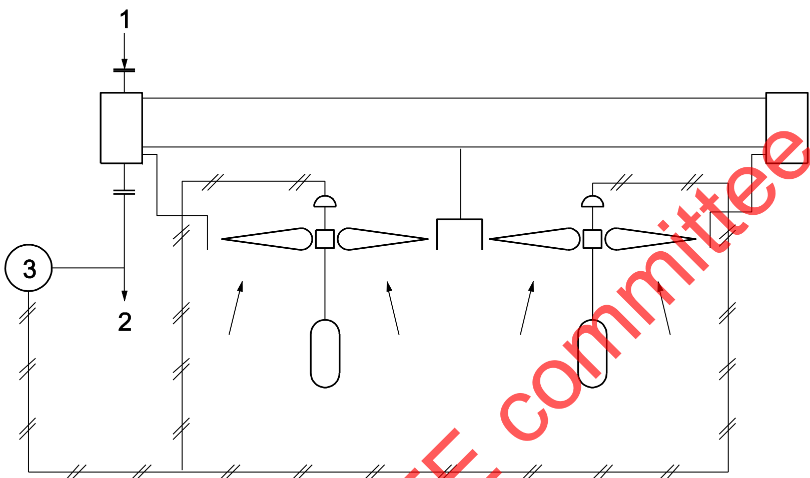
All fans should be equipped with variable speed drives or auto-variable pitch for external over the side recirculation to avoid mal-distribution of the recirculation air, especially for units with process turndown rates at 50 % of design or lower. For over-the-end recirculation, the fans at the outlet end of the bundle only may be equipped with variable speed drives or auto-variable pitch. The variable-pitch or variable speed fan should always be located on the outlet (coldest) end of the process bundle to maximize tube wall temperatures at the coldest section of the tube bundle. When a variable speed drive system is used, the minimum allowable fan speed should not be less than 30 % in order to ensure that there is adequate driving force for air recirculation.

If multiple units (services) are arranged adjacent to each other in banks, each unit (service) should be separated by a full partition wall, with a suitable access door. Full partition walls between bays in the same service should be considered for multi-bay units where uniform distribution of the re-circulation air is critical (e.g. condensers, viscous coolers). The number and location of partition walls should be agreed between the Ppurchaser and the Vvendor.



Key
1 process in
2 process out
3 temperature-indicating controller

NOTE The air-cooled heat exchanger can be of the forced- or induced-draftdraught type.

Figure C.11 — System A — Airflow Control with Variable Speed Drives or Automatically Controlled Variable-pitch Fans

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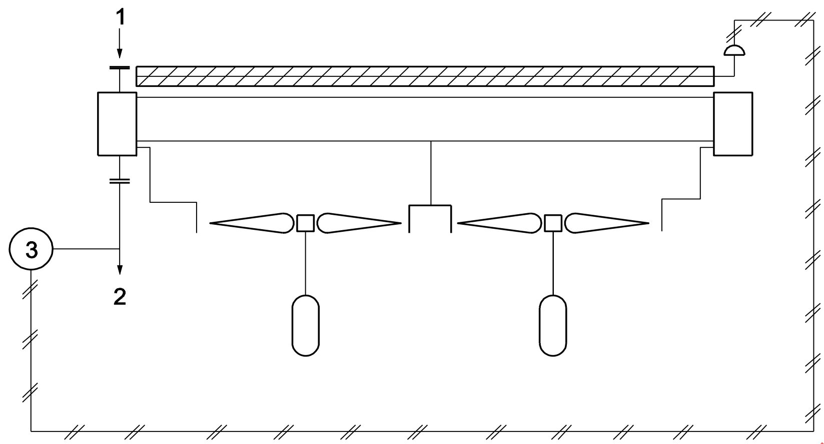

Key
1 process in
2 process out
3 temperature-indicating controller

NOTE The air-cooled heat exchanger can be of the forced- or induced-draft~~draught~~ type.

Figure C.2 — System A — Airflow Control with Automatically Controlled Outlet Louvers and Fixed-pitch Fans

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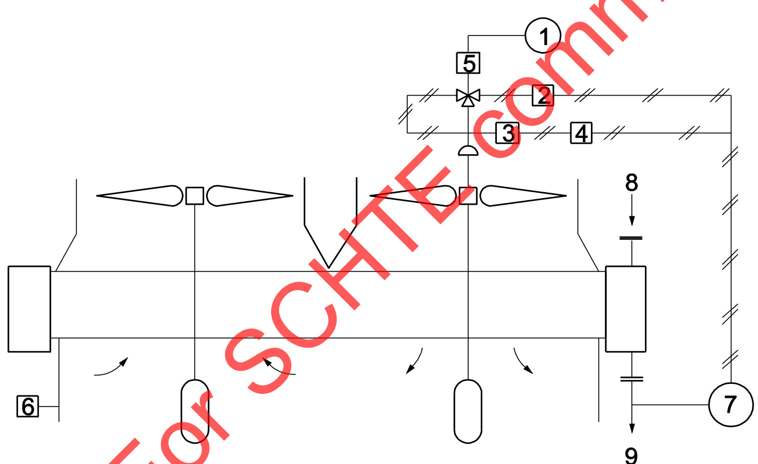

Key
1 ambient air temperature switch
2 high-limit relay
3 reversing relay
4 low-limit relay
5 three-way solenoid switch
6 hot air recirculation baffle~~wind skirt~~
7 temperature-indicating controller
8 process in
9 process out

NOTE All fans can be of the automatically controlled variable-pitch type.

Figure C.3 — System B — Induced draft~~Draught~~ with Non-contained Internal Air Recirculation

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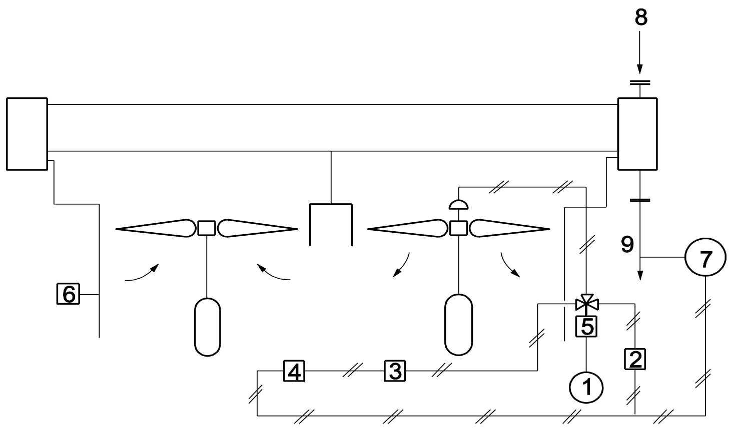

Key

1 ambient air temperature switch
2 high-limit relay
3 reversing relay
4 low-limit relay
5 three-way solenoid switch
6 hot air recirculation bafflewind skirt
7 temperature-indicating controller
8 process in
9 process out

NOTE All fans can be of the automatically controlled variable-pitch type.

Figure C.4 — System B — Forced -draftDraught with Non-contained Internal Air Recirculation

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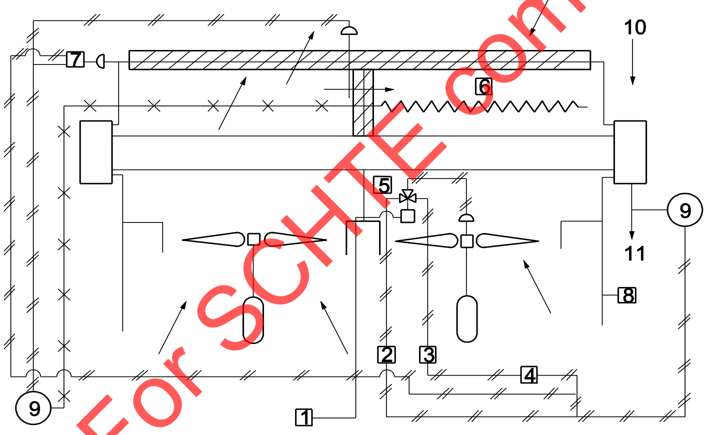

Key

1 ambient air temperature switch
2 high-limit relay
3 reversing relay
4 low-limit relay
5 three-way solenoid switch
6 temperature-sensing capillary tube
7 low- or high-pressure selector
8 hot air recirculation bafflewind skirt (optional)
9 temperature-indicating controller
10 process in
11 process out

Figure C.5 — System C — Typical Forced-draftdraught Air-cooled Heat Exchanger with Contained Internal Air Recirculation

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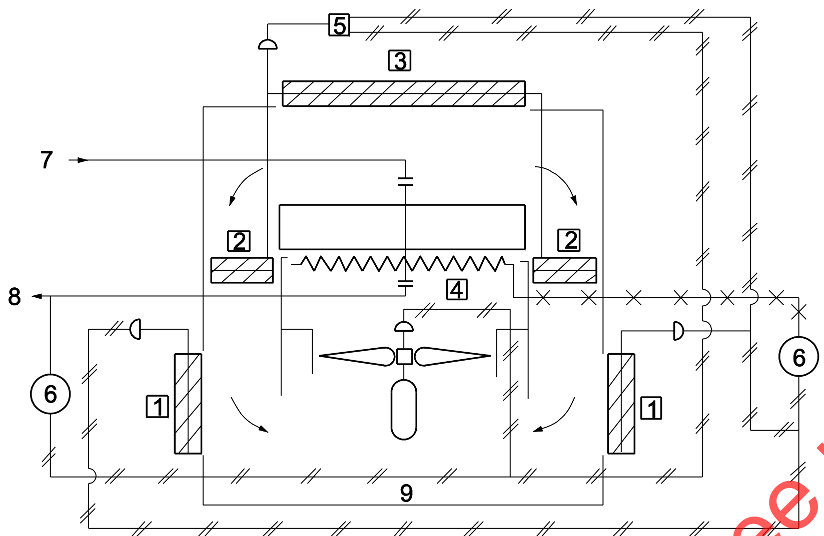

Key

1 intake louvers
2 bypass louver
3 exhaust louvers
4 temperature-sensing capillary tube
5 low- or high-pressure selector switch
6 temperature-indicating controller
7 process in
8 process out
9 floor plate or grade

50 % to 100 % of the fans should be of the variable speed type or automatically controlled variable-pitch type.

Figure C.6 — System D — Typical Forced-~~draught~~draft Air-cooled Heat Exchanger with External Air Recirculation

~~C.2.2~~ C.3.2 Concurrent Flow

In a concurrent flow system, the process fluid begins its flow path at the bottom row of tubes, which is incident to the inlet air, and exists at the top row, which is swept by warm air. Thus, the coldest fluid exchanges heat with the warmest air, resulting in wall temperatures higher than those in a countercurrent arrangement. The design of the air-cooled heat exchanger can thus be kept simple, with no recirculation system required if the tube-wall temperature is kept above the specified minimum.

The main disadvantage of a concurrent flow system is that additional surface area is required as a result of the reduced mean temperature difference between the process fluid and the cooling air.

~~C.2.3~~ C.3.3 Bare Tubes or Reduced Fin Density

For viscous fluids and other fluids that exhibit low tube-side heat transfer coefficients, the tube-wall temperature can be increased by reducing the fin density or by using bare tubes. If the tube-wall temperature is thus maintained at or above the specified minimum value, no additional winterization protection is required.

~~C.2.4~~ C.3.4 Varying the Active Heat Transfer Surface

Heat rejection from the process fluid can be controlled by removing bundles from service, usually by the use of valves, as the ambient temperature drops. This system minimizes heat losses and maintains a higher tube velocity in the active bundles. The higher tube velocity results in a higher tube-wall temperature.

The effectiveness of this system depends on whether the reduction in active surface area results in a tube-wall temperature above the specified minimum value. Pumping capacity should be checked to ensure that it is adequate for the additional pressure drop that results.

It can be necessary to purge or displace the contents of tubes in idle bundles. The stepwise nature of the operation can limit its applicability.

~~C.2.5~~ C.3.5 Serpentine Coils

A serpentine coil design uses a single or limited number of continuous flow paths from the inlet to the outlet. Because of the limited number of flow paths, tubes with a large diameter [generally 50 mm to 150 mm (2 in. to 6 in.)] are used. The tubes can be finned or bare, depending on economics and the specified minimum tube-wall temperature that it is necessary to maintain.

This system usually requires high pressure drops, but the design is frequently favored for viscous fluids because there is little or no possibility of mal-distribution.

~~C.2.6~~ C.3.6 Indirect Cooling

The normal design of an indirect (closed-loop tempered-water) cooling system uses recirculated water in a conventional shell-and-tube heat exchanger to cool the process fluid. The recirculated water is, in turn, cooled to a controlled temperature in an air-cooled heat exchanger that uses a fairly simple form of airflow control (variable speed drives, automatically controlled variable-pitch fans or louvers) but is not winterized. For ambient temperatures above 0 °C (32 °F), ordinary condensate or treated water may be used. For ambient temperatures less than or equal to 0 °C (32 °F), the water should be mixed with an amount of antifreeze, such as ethylene or propylene glycol, sufficient to lower the solution's freezing point to a value less than the lowest expected air temperature.

This system is usually applied to fluids with a high viscosity or a high pour point. The system offers several advantages for these fluids:

a) better process temperature control;

b) less chance of process fluid mal-distribution;

c) better general operability;

d) usually more economical operation.

However, an economic comparison should be made. ~~C.10 provides an example of such a comparison.~~

~~C.2.7~~ C.3.7 Duty Separation

The duty separation approach divides the process heat duty into two separate services. The intermediate temperature between the services is chosen to ensure that the tube-wall temperature in the upstream unit is above the specified minimum tube-wall temperature for the full range of ambient air temperatures. The upstream unit does not require winterization; only the downstream unit is winterized.

C.2.8 C.3.8 Combinations

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Depending on minimum air temperatures and specified minimum tube-wall temperatures, various combinations of the protection methods as described in C.3.1 through C.3.7 can prove economically attractive. The following are examples of combination protective methods:

a) combination of cocurrent and countercurrent bundles;

b) cocurrent bare-tube bundles;

c) duty separation, with varying fin densities, in subsequent bundles in series.

C.2.9 C.3.9 Instrumentation

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C.2.9.1 C.3.9.1 General

Figure C.1, Figure C.2, Figure C.3, Figure C.4, Figure C.5, and Figure C.6 illustrate typical instrumentation schemes for the systems described in C.3.1.1 through 3.1.4. The instrumentation methods shown are only suggestions.

C.2.9.2 C.3.9.2 System A

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Typical instrumentation for system A (see Figure C.1 and Figure C.2) consists of a temperature sensor in the exit fluid stream and a controller that receives a signal from the sensor and sends signals to one or more devices that control the airflow. These devices may be outlet louvers with a louver actuator, automatically controlled variable-pitch fan hubs or variable-speed fan drivers.

The most commonly used arrangements include one or more of the following components:

a) louvers with pneumatic operators, including valve positioners;

b) automatically controlled variable-pitch fans responding to a pneumatic signal;

c) pneumatic controllers having at least proportional-band and reset features; a manual/automatic setting is very desirable.

Electronic controllers and sensing elements may be used instead of pneumatic controllers. They usually require an electronic-to-pneumatic conversion at the fan hub or louver actuator.

C.2.9.3 C.3.9.3 Systems

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C.2.9.3.1 C.3.9.3.1 Induced -draftDraught

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An induced-draftdraught system typically employs several of the components discussed in C.3.9.2 [items b) and c)]. However, using the simple types of automatically controlled variable-pitch fans usually makes it necessary to use half the signal range from the controller for upflow and half for downflow. It is also necessary to cause a reversal of either the upflow or the downflow portion of the signal range. A simple way of reversing the signal is to use a reversing relay in conjunction with a low-limit relay, as shown in Figure C.3. Since it is necessary that the system operate in two modes (upflow and downflow), an ambient temperature sensor and a selector valve are commonly used for mode selection. The high-limit relay shown in Figure C.3 is required to cause the split-range operation to occur. The exit end of the last pass is normally the most vulnerable to winterization problems and should be located under the downflow fan in the warmest air.

C.2.9.3.2 C.3.9.3.2 Forced -draftDraught

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A forced-draftdraught system, illustrated in Figure C.4, employs the same components as discussed in C.3.9.3.1.

~~C.2.9.4~~ C.3.9.3.4 System C

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Typical instrumentation for system C (see Figure C.5) consists of a temperature sensor in the exit process fluid stream, a controller that receives a signal from the sensor and sends signals to the exhaust louvers, and one or more variable speed drives or automatically controlled variable-pitch fans. Another temperature sensor (usually a long averaging bulb) is placed in the airstream above the bundle segment most vulnerable to freezing or other problems. A second controller receives a signal from this sensor and sends a signal to the partition louvers and the exhaust louvers. The exhaust louvers thus receive two control signals and respond to the one requiring the more closed position. A high- or low-pressure selector relay is typically used to determine which signal reaches the exhaust louvers. It is not good practice to delete either the partition louver or a separate actuator for the partition louver. Deletion of the partition louver leads to maximum cross-flow at all conditions and sacrifices heat transfer capability in certain ranges of operation while reducing cost very little.

The control elements between the controller and the variable speed drive or automatically controlled variable-pitch fan are the same as those discussed in C.3.9.3.1 and function in the same manner.

~~C.2.9.5~~ C.3.9.5 System D

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The typical instrumentation for system D (see Figure C.6) consists of a temperature sensor in the exit process fluid stream and a controller that receives a signal from the sensor and sends signals to the variable speed drives or automatically controlled variable-pitch fans and, optionally, to the exhaust louvers. A second temperature sensor (usually a long averaging bulb) is placed in the airstream below the bundle segment most vulnerable to freezing or other problems. For operation in cold climates with ambient temperatures below −29 °C (−20 °F), a separate temperature sensor should be placed in the airstream above each fan, especially if only some of the fans are controlled by variable speed drives or variable-pitch fans. A second controller receives a signal from these sensors and sends a signal to the exhaust louvers, the bypass louvers (if separately actuated), and the inlet louvers. Where more than one sensor is used in a bay, the lowest temperature measured should be selected via control logic, to control the louver positions. Some of the inlet louvers may be manually operated, and the inlet louvers closest to the fans should be closed in the winter, effectively acting as a wind shield. Inlet louvers closer to grade are automatically controlled.

Where freezing of the fluid in the tubes can lead to a tube failure and loss of containment, the automatic inlet and exhaust louvers' actuators should be specified to fail closed, and the automatic recirculation louvers specified to fail open, on loss of instrument air or control signal, to provide maximum winterization protection. Other configurations, such as fail in last position, may be considered only with approval of the ~~P~~purchaser.

~~C.3~~C.4 Critical Process Temperatures

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~~C.3.1~~ C.4.1 Pour Points of Hydrocarbon Liquid Mixtures

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Air-cooled heat exchangers that handle gas oil and residuum cuts can require winterization. The pour points of these hydrocarbon liquid mixtures vary from −51 °C to 63 °C (−60 °F to 145 °F).

The pour point of a fraction of a hydrocarbon liquid cut with a known pour point cannot be predicted mathematically. The only realistic method of establishing the pour point of such a fraction is by measurement, using ASTM D97.

The pour point of a blend of two hydrocarbon liquid cuts with known pour points can be approximated by calculation. Because of the imprecision of such calculations, however, when the actual pour point of the blend cannot be measured, a safety margin that respects the consequences of an air-cooled heat exchanger freezing up should be added to any predicted value.

NOTE Numbers in square brackets in this annex refer to references in the bibliography.

~~C.3.2~~ C.4.2 Freezing points of Hydrocarbons and Other Organic Liquid Pure Compounds

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Table C.2 lists the freezing points of frequently encountered refinery hydrocarbon and organic liquid pure compounds. Air-cooled heat exchangers that process these liquids can require winterization.

~~C.3.3~~ C.4.3 Water Solutions of Organic Compounds

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Water solutions of some of the organic compounds in Table C.2 are also subject to freezing in air-cooled heat exchangers. Freezing-point-concentration relationships for these materials are valid only for very dilute solutions. ~~Figure C.7, Figure C.8, and Figure C.9 show measured values for freezing points over the entire concentration range.~~

Table C.2 — Freezing Points of Frequently Encountered Liquid Pure Components

Compound	Relative Molecular Mass	Freezing Point	
		°C	(°F)
Water	18.0	0.0	(32.0)
Benzene	78.1	5.6	(42.0)
o-Xylene	106.2	–25.2	(–13.3)
p-Xylene	106.2	13.3	(55.9)
Cyclohexane	84.1	6.6	(43.8)
Styrene	104.1	–30.6	(–23.1)
Phenol	93.1	40.9	(105.6)
Monoethanolamine	61.1	10.3	(50.5)
Diethanolamine	105.1	25.1	(77.2)
Glycerol	92.1	18.3	(65.0)
Ethylene glycol	62.1	–13.0	(8.6)
Naphthalene	128.2	80.3	(176.5)

~~C.3.4~~ C.4.4 Ammonium ~~Bisulfide~~Salts

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Solid ammonium bisulfide (NH_4HS) and ammonium chloride (NH4Cl) can be deposited by gas or vapor streams when the product of the partial pressures of ammonia (NH_3) and hydrogen sulfide (H_2S) or hydrogen chloride (HCl) exceeds the dissociation constant, K_d, at the temperature of interest and no liquid water is present. In particular, hydroprocessing unit reactor effluent and downstream fractionator overhead condensing systems are prone to fouling and corrosion by ammonium bisulfide (NH_4HS) and ammonium chloride (NH_4Cl) salts.~~Solid ammonium bisulfide (NH_4HS) can be deposited by gas or vapor streams when the product of the partial pressures of ammonia (NH_3) and hydrogen sulfide (H_2S) exceeds the dissociation constant, K_d, at the temperature of interest and no liquid water is present.~~

~~Figure C.10 is a plot of K_d versus temperature.~~ Deposition is not a problem in all-hydrocarbon streams, since the solubility of NH_4HS and NH4Cl are~~is~~ negligible in hydrocarbons.

An understanding of all variables impacting corrosion and fouling in these systems is necessary to improve the reliability, safety, and environmental impact associated with them. Past attempts to define generic optimum equipment design and acceptable operating variables to minimize fouling and corrosion have had limited success due to the interdependence of the variables. Corrosion can occur at high rates and be extremely localized, making it difficult to inspect for deterioration and to accurately predict remaining life of equipment and piping. Within the industry, continuing equipment replacements, unplanned outages, and catastrophic incidents illustrate the current need to better understand the corrosion characteristics and provide guidance on all factors that can impact fouling and corrosion.

Refer to API RP 932B for those process systems in which NH_4Cl and NH_4HS salts can form and deposit in equipment and piping, or dissolve in water to form aqueous solutions of these salts. Included in this practice is a discussion of the following:

a.) Deterioration mechanisms from ammonium salt deposition in air-cooler services;
b.) Methods to assess and monitor the corrosivity of systems;
c.) Details on materials selection, design, and fabrication of equipment for new and revamped processes;
d.) Use of Wash Water injection to prevent fouling and corrosion of heat exchanger and air cooler tubes;
e.) Considerations in equipment repairs; and
f.) Details of an inspection plan.

~~C.3.5~~ C.4.5 High-pressure Gases

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Certain gases at high pressure, including C_1 to C_4 paraffins and olefins, hydrogen sulfide and carbon dioxide, can form hydrates when saturated with water at temperatures above water's freezing point. These hydrates are solid crystals that can collect and plug the tubes of air-cooled heat exchangers. ~~Figure C.11 shows the hydrate-formation conditions for these pure gases.~~ Reference [12] gives semi-empirical methods for predicting hydrates in gas mixtures. ~~Recommended change: Purchaser shall provide process related conditions related to freezing points, hydrate-formation, pour points, etc. that would require winterization.~~ Review throughout document & update accordingly. Action: D. Slingerland
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~~C.4~~ C.5 Tube-wall Temperature Calculations

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~~C.4.1~~ C.5.1 General

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C.5.1.1 The need for winterization of air-cooled heat exchangers is a function of the tube-wall temperature resulting from the inlet air temperature and the critical process temperature of the fluid. Consideration should be given to the type of design, the operating modes and the fluid flow regime to predict tube-wall temperatures accurately.

C.5.1.2 In cross-flow countercurrent air-cooled heat exchanger bundles, the worst condition usually exists at the outlet of the bottom row of tubes, with the tubes in the clean condition. At this location, the air that comes in contact with the tube is at its lowest temperature, and the tube-side fluid is also at the lowest possible temperature. This is usually the critical location, but it can be necessary to consider other locations also. Axial-flow fans do not provide completely even airflow distribution. The designer should add at least 20 % to the air-side heat transfer rate to account for areas of high airflow (see factor f_a in C.5.2). The designer should also ensure good tube-side flow distribution within the tube bundle.

To calculate the tube-wall temperature, it is necessary to determine the air-side and tube-side resistances at each location under consideration. Such information can be obtained from the original manufacturer or another suitable source.

~~C.4.2~~ C.5.2 Symbols

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A total outside surface area of the bottom layer of tubes, in m^2 (ft^2)

A_b outside surface area of the bare tube per unit length, in m^2/m (ft^2/ft)

A_f surface area of the fin per unit length of the tube, in m^2/m (ft^2/ft)

A_i inside surface area of the tube per unit length, in m^2/m (ft^2/ft)

A_o outside surface area of the finned tube per unit length, in m^2/m (ft^2/ft)

f_a air-side heat transfer coefficient multiplier to account for airflow maldistribution (the recommended minimum value is 1.2)

r local overall thermal resistance, in $m^2 \cdot K/W$ ($°F \cdot ft^2 \cdot h/Btu$)

r_c local clean overall thermal resistance, in $m^2 \cdot K/W$ ($°F \cdot ft^2 \cdot h/Btu$)

r_{ds} air-side fouling resistance, in $m^2 \cdot K/W$ ($°F \cdot ft^2 \cdot h/Btu$)

r_{dt} Tube-side fouling resistance, in $m^2 \cdot K/W$ ($°F \cdot ft^2 \cdot h/Btu$)

r_{fs} local air-side resistance, in $m^2 \cdot K/W$ ($°F \cdot ft^2 \cdot h/Btu$)

r_{ft} local tube-side resistance, in $m^2 \cdot K/W$ ($°F \cdot ft^2 \cdot h/Btu$)

r_m total metal resistance of the tube, in $m^2 \cdot K/W$ ($°F \cdot ft^2 \cdot h/Btu$)

r_{mf} fin metal resistance, in $m^2 \cdot K/W$ ($°F \cdot ft^2 \cdot h/Btu$)

r_{mt} tube metal resistance based on the inside surface area of the tube, in m^2 K/W ($°F$ ft^2 h/Btu)

NOTE An exact calculation of r_{mt} requires that the tube metal resistance be based on the logarithmic mean surface area of the tube; however, the relatively insignificant magnitude of the error caused by basing the tube metal resistance on the inside surface area of the tube does not justify the complexity introduced by the use of the logarithmic mean surface area.

T_B bulk temperature of the tube-side fluid at the location where the wall temperature is to be calculated, in °C (°F)

t_B bulk temperature of the air at the location where the wall temperature is to be calculated, in °C (°F)

T_W tube-wall temperature, in °C (°F)

U local overall heat transfer coefficient referred to the outside surface, in W/m^2 K (Btu/h ft^2 °F)

ϕ fin efficiency

ϕ_o efficiency of the finned tube surface

C.4.3 C.5.3 Calculations

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C.5.3.1 Once the various resistances have been determined, the wall temperature can be predicted by prorating the resistances relative to the temperature at the outlet or other critical areas. This can be done using Equations (C.1) to (C.8):

$$U = 1/r \quad \text{(C.1)}$$

$$r = (r_{ft} + r_{dt})(A_o / A_i) + r_{mt}(A_o / A_i) + (1 / \phi_o)(r_{fs} + f_a) + r_{ds} \quad \text{(C.2)}$$

C.5.3.2 Fins do not cover all of the tube surface, and since the exposed bare tube surface may be considered to have an efficiency of 1.00, the efficiency of the finned tube surface is always higher than that of the fins alone. Thus,

$$f_o = 1 - (A_f \; / + A_b)(1 - \phi) \quad \text{(C.3)}$$

C.5.3.2.1 Fin efficiency is a complex calculation. It can, however, be replaced with an equivalent fin metal resistance, designated as r_{mf}. This metal resistance reaches a constant maximum value for an outside resistance above some value determined by fin height, thickness, and thermal conductivity. For standard aluminum fins, 90 % of this value is reached at air-side resistances (r_{fs}) that are lower than those normally encountered. The fin metal resistance for these calculations may be considered constant with negligible error.

The overall resistance equation can, therefore, be rewritten in the following form:

$$r = (r_n + r_{dt})(A_o / A_i) + r_m + (r_{fs} / f_a) + r_{ds} \quad \text{(C.4)}$$

where

$$r_m = r_{mf} + r_{mt}(A_o / A_i)$$

$$r_{mf} = [(1 - f_o) / f_o](r_{fs} / f_a) + r_{ds}$$

C.5.3.2.2 Tables C.6 and C.7 provide values of r_m for tubes of several common materials with an outside diameter of 25,4 mm (1 in) and aluminum fins 0.4 mm (0.016 in.) thick and 15.9 mm ($^5/_8$ in.) high. Other sizes and fin materials require a fin metal (fm) efficiency calculation to define r_{mf} for the combination. For fin efficiency curves, refer to textbooks such as References [123], [134], and [145].

C.5.3.3 Initially, it is best to assume that the unit is clean. Tube-side fouling increases the surface temperature, since the fluid contact is then on the surface of the fouling material. The basic resistance equation can be rewritten in the following form:

$$r_c = r_{ft}(A_o / A_i) + r_m + (r_{fs} / f_a) \quad \text{(C.5)}$$

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The equations are the same for bare-tube exchangers, except that $\phi_o = 1$ and A_o is the outside surface area of the bare tube, A_b. Since the performance of bare-tube exchangers is sensitive to pitch arrangement, the designer should refer to bare-tube correlations such as those described in Reference [156] for air-side heat transfer coefficient calculations.

The overall resistance for bare tubes is, therefore, calculated as follows:

$$r = (r_{ft} + r_{dt})(A_b / A_i) + r_{mt} + (A_b / A_i) + (r_{fs} / f_a) + r_{ds} \quad \text{(C.6)}$$

For a clean bare-tube unit, this equation reduces to

$$r_c = r_{ft}(A_b / A_i) + r_{mt}(A_b / A_i) + (r_{fs} / f_a) \quad \text{(C.7)}$$

C.5.3.4 The tube-wall temperature can be calculated on the basis of a prorated portion of the clean overall resistance:

$$T_w = T_B - (r_{ft} / r_c)(A_o / A_i)(T_B - t_B) \quad \text{(C.8)}$$

Sample calculations are given in C.11.

C.5.3.5 Single-pass, multiple-row air-cooled heat exchangers are more susceptible to freezing and pour-point problems because of variations in the layer-to-layer mean temperature difference, with the bottom row exchanging more heat than any of the upper rows. This means that the mixed outlet fluid temperature cannot be used safely; instead, the bulk tube-side fluid outlet temperature should be calculated for each row of concern.

Two-phase fluids in a single pass with multiple rows require a more complete analysis that recognizes the separation of phases in the header. The problem becomes more complex when the units are not designed with equal flow areas in each pass. With viscous fluids, the problem of extreme flow mal-distribution arises. This is difficult to calculate, and these fluids should be handled in as few parallel passes as possible. A single, continuous serpentine coil is the ideal approach.

C.5.3.6 When the tube-wall temperature is calculated, the following operating questions should be considered.

a) At lower temperatures, how much less airflow is needed to remove the required heat?

b) Does the unit operate with fans off or on?

c) Does the unit have louvers?

d) Has an automatically controlled variable-pitch fan or another means been provided to reduce airflow?

e) Is the unit operating at partial load so that the tube-side flow conditions affect the wall temperature?

~~C.5~~C.6 Heat Losses

~~C.5.1~~ C.6.1 General

C.6.1.1 Air-cooled heat exchangers are usually large pieces of equipment that are not well suited to being enclosed. Where it is necessary that airflow be contained or controlled, louvers or sheet metal panels are normally used. Provision should be made for shutting down, starting up, or holding such equipment at standby conditions during periods of minimum air temperature. Under these conditions, the process fluid can be cooled below its critical process temperature unless airflow through the bundle is nearly stopped

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and an auxiliary source of heat is provided.
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C.6.1.2 Unless the amount of heat that is lost by louver leakage and by conduction through enclosing panels can be determined, there is no certainty that enough heat can be added by auxiliary means. Thus, it is necessary that the problem of evaluating the auxiliary heat source begin with determining how much heat can be lost under a particular set of circumstances. Examples of heat loss calculations are given in C.12.

C.6.1.3 The most important case to consider is that of no process flow with fans off, minimum air temperature and fairly high wind velocity. One should assume that it is necessary to maintain the bundle at least 11 °C to 17 °C (20 °F to 30 °F) above the critical process temperature.

C.6.1.4 A less important case is that of short-duration heat loss when there is no process flow with fans on, minimum air temperature and fairly high wind velocity. These conditions should occur only during the transition period from operation to shutdown or vice versa, so an example of this case is not given in C.12. The equations of the "fans-off" example can be used to find the louver leakage by using the pressure drop that exists with fans on instead of the pressure drop resulting from the effect of the hot-air column.

C.6.1.5 Several factors should be considered when the auxiliary heat source mentioned in C.6.1.1 and C.6.1.2 is installed. A choice should be made about what fluid to use (usually steam but occasionally an antifreeze solution). The location of the heat source should also be decided. A separate coil that is one row deep is usually placed immediately below the process bundle; however, special considerations can dictate a less effective placement, such as inside the recirculation duct. Steam coils located directly below the process bundle have proven to be unreliable and impractical in cold climates where the ambient temperature is less than –29 °C (–20 °F). The preferred heat medium in such cases is an anti-freeze solution. The use of steam space heaters located below the fans in the enclosed plenum of system D air coolers has also been successful. These space heaters are self-contained units, complete with their own motor and fan, and are less prone to freezing problems since they are not located in the high-velocity airstream directly above the main fans.

~~C.5.2~~ C.6.2 Louver Leakage

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Louvers of standard manufacture, maintained in good condition, have a leakage area of not more than 2 % of the face area when closed. This can be reduced to not more than 1 % if special, more costly designs are used. The air leakage rate may be calculated for either case. (See C.12.1.3 or C.12.2.3 for a sample calculation.) Tests on standard louvers indicate that an average louver has only about half the leak area predicted by maximum tolerances.

~~C.5.3~~ C.6.3 Surface Heat Loss

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The heat loss from the sheet metal panels and flooring that form the enclosure is a function of the air velocity both inside and outside, as well as the temperature differential between the enclosed air and the ambient air. (The overall heat transfer coefficient for this surface is calculated for a range of wind velocities in C.12.1.4 and C.12.2.4.) Calculations of this type can also be used to determine the heat loss from the hot air being recirculated through the recirculation duct during normal operation. The heat loss calculation ~~for the duct~~ can be used to assure that the required air temperature to the bundle is maintained when the recirculated air is blended with the cold inlet air.

~~C.6~~C.7 Guidelines

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~~C.6.1~~ C.7.1 General

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Air-cooled heat exchangers are normally designed to dissipate a given heat duty in summer conditions and also dissipate the same heat duty (or more) in winter conditions. Additional measures are taken to assure proper operation during periods of minimum air temperature. These measures include recirculating a fraction of the air so that it mixes with and heats the incoming cold air. Ducts and louvers are required to direct this recirculation.

Provisions to achieve thorough mixing of the recirculated air with the cold inlet air would be prohibitively expensive. The set point for the average temperature of this mixed airstream should, therefore, be above the critical process temperature. For instance, the set point for vacuum steam condensers is usually 1.5 °C to 4.5 °C (35 °F to 40 °F). It is important to measure the average air temperature in these systems with an averaging bulb 4 m to 6 m (12 ft to 20 ft) long that spans the airstream, and not with a sensor that measures temperature at only one point.

~~C.6.2~~ C.7.2 Design Methods

~~C.6.2.1~~ C.7.2.1 System C — Contained Internal Circulation

System C (see Figure C.5) operates in two modes, the summer mode and the winter mode. In the summer mode, both fans move air upward and no air is recirculated. In the winter mode, one fan (normally on the exit end of the unit) moves air downward. This also causes a part of the air that is moved upward through the bundle (on the end opposite the exit) to flow horizontally across the top of the bundle through a bypass louver and then downward through the bundle. Only enough air makes this journey to cause the average temperature of the mixed air entering the bundle on a downward traverse to satisfy a preset value. The duct above the bundle should be adequately sized for the maximum quantity of air that is required to make the journey. A conservative design rule is to size the duct cross-section based on a linear air velocity of 305 m/min (1 000 ft/min), using the quantity of air that passes through the bypass louvers. In no case should the duct cross-section exceed that required to recirculate 100 % of the heated air.

An alternative method that has proved to be adequate is to make the height of the duct space above the top of the side frame one-tenth of the tube length, rounding to the nearest 0.15 m (0.5 ft). This requires a 1.2 m (4 ft) height for tube bundles 12 m (40 ft) in length, and a 1.1 m (3.5 ft) height for tube bundles 11 m (36 ft) in length.

~~C.6.2.2~~ C.7.2.2 System D — External Recirculation

System D (see Figure C.6) operates in only one mode. This means that the air movement is always upward through the bundle. When inlet air temperatures are low enough, however, part of this air leaves the bundle and returns to the fan inlet by passing over the side or the end of the bundle through a duct with a bypass louver. The unrestricted flow area in the exhaust air plenum, measured from the top of the tube bundle side frame to the underside of the outlet louver support beam should not be less than the recirculation duct width.

This external recirculation duct may be conservatively sized using the same rules as for the internal recirculation duct described in C.7.2.1. The application of these rules usually results in a duct with a cross-sectional area equal to 20 % to 30 % of the bundle face area. In cold climates where the ambient temperature is less than −29 °C (−20 °F), or if it is necessary that more than 75 % of the heated air be recirculated, however, the duct cross-sectional area should be a minimum of 30 % of the bundle face area and can approach 40 % of the bundle face area. In calculating the total amount of air to recirculate, a 5 °C (9 °F) margin should be added to the required minimum plenum temperature.

~~C.7~~C.8 Mechanical Equipment

~~C.7.1~~ C.8.1 General

When mechanical equipment is being operated in an extremely cold or hot environment, care should be taken that the equipment is specified and designed for the temperature extremes to which it is exposed. It is possible that two heat exchangers located side by side can have different design temperature considerations if one has only airflow control and the other has an external recirculation system.

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~~C.7.2~~ C.8.2 Design Temperatures

C.8.2.1 Unless otherwise agreed upon, the minimum design temperature for the mechanical equipment should be the minimum design air temperature.

C.8.2.2 Unless otherwise agreed upon, the maximum design temperature for mechanical equipment in the airstream exiting the heat exchanger should be equal to the maximum process or auxiliary heating fluid temperature. The maximum air temperature can occur when the fans are not operating and the louvers are closed.

C.8.2.3 The maximum design temperature for the mechanical equipment in the inlet or recirculation airstream depends on the type of winterization system, as described in C.8.2.3.1 through C.8.2.3.3. Each operating mode (start-up, normal operation, and shutdown) should be examined to determine the design temperature to use.

C.8.2.3.1 In an airflow control system (see Figure C.1 and Figure C.2), the maximum design temperature for equipment in the inlet airstream is the design dry-bulb air temperature.

C.8.2.3.2 In a system with noncontained or contained internal recirculation (see Figure C.3, Figure C.4 and Figure C.5), the maximum design temperature for the equipment in the inlet airstream should be the temperature of the air exiting the reversed-airflow fan during recirculation, plus a safety factor of 14 °C (25 °F).

C.8.2.3.3 Since the air is not completely mixed in an external recirculation system (see Figure C.6), the design temperature for the mechanical equipment in the inlet airstream should be chosen carefully. The danger lies in exposing the mechanical equipment to hot stratified air that has not been mixed with the cooler inlet air. This problem is most prevalent during start-up and during turndown operation.

~~C.7.3~~ C.8.3 Design Temperature Range

Most mechanical equipment operates satisfactorily between air temperatures of −29 °C (−20 °F) and 40 °C (104 °F) without any modifications. However, since material selection and design techniques are not standardized for most components of mechanical equipment, the standardized operating ranges vary among manufacturers.

~~C.7.4~~ C.8.4 Typical Characteristics and Operating Ranges for Standard Mechanical Equipment

~~C.7.4.1~~ C.8.4.1 General

The characteristics and air temperature ranges given in C.8.4 are typical and are not intended to limit the application of any equipment. The suitability of continuously operating a particular piece of equipment at a specified design temperature should be confirmed with the ~~V~~vendor.

~~C.7.4.2~~ C.8.4.2 Fans with Manually Adjustable Pitch in Continuous Operation [–54 °C to 121 °C (–65 °F to 250 °F)]

For best results in cold weather, fans with manually adjustable pitch should have hubs made of ductile iron, aluminum or another material with good ductility. The blade material should exhibit similar characteristics.

~~C.7.4.3~~ C.8.4.3 Fans with Automatically Controlled Variable Pitch in Continuous Operation [–32 °C to 121 °C (–25 °F to 250 °F)]

The criteria in C.8.4.2 for hubs and blades for fans with manually adjustable pitch also apply to automatically controlled variable-pitch fans. Since the automatic pitch device for each manufacturer's fans is different, the

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actual operating temperature range and recommendations for extending the range should be obtained from the manufacturer.

~~C.7.4.4~~ C.8.4.4 Electric Motors [–30 °C to 40 °C (–22 °F to 104 °F)]

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The upper limit on operating temperature for electric motors may be raised by substituting an insulation system and a bearing lubricant with a higher temperature rating. In most cold weather applications, space heaters are provided in the motors to maintain the internal air temperature above the dew point.

~~C.7.4.5~~ C.8.4.5 V-belts [–40 °C to 60 °C (–40 °F to 140 °F)] and High-torque-type Positive-drive Belts [–34 °C to 85 °C (–30 °F to 185 °F)]

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Belt life is reduced when belts are operated outside the temperature ranges given in this subclause. Special belts are available for operation above and below these ranges. The life expectancy of special belts can be shorter than that of standard belts.

~~C.7.4.6~~ C.8.4.6 Gear Drives [–18 °C to 77 °C (0 °F to 170 °F)]

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Operation of gear drives below the range given in this subclause requires changing to a lubricant suitable for the temperature and possibly adding an oil heater. Actual temperature ranges and recommendations to extend the temperature range should be obtained from the gear drive manufacturer.

~~C.7.4.7~~ C.8.4.7 Bearings [–45 °C to 121 °C (–50 °F to 250 °F)]

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For bearings, the temperature range in this subclause can be extended by substituting a lubricant suitable for the required temperature range.

~~C.7.4.8~~ C.8.4.8 Steel or Aluminum Louvers [–40 °C to 121 °C (–40 °F to 250 °F)]

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Louvers should be designed for the expected loads during operation at low temperatures. This can require selecting a more ductile material. Snow and ice loads, as well as the effect of ice on the design and operation of the linkage, should be considered in the design. The temperature range can be extended by selecting different bearing materials.

~~C.7.4.9~~ C.8.4.9 Pneumatic Diaphragm Actuators [–40 °C to 82 °C (–40 °F to 180 °F)], Pneumatic Piston Actuators [–34 °C to 79 °C (–30 °F to 175 °F)] and Pneumatic Positioners [–40 °C to 71 °C (–40 °F to 160 °F)]

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The temperature range given in this subclause for pneumatic actuators and positioners can be extended by changing materials of several of the components, including but not limited to diaphragms and O-rings.

~~C.7.5~~ C.8.5 Auxiliary Heating Equipment

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C.8.5.1 When steam coils are used with any of the winterization systems, the maximum design temperature for the exposed mechanical equipment can be determined by the steam saturation temperature. The radiation effect of the steam coil is negligible and may be omitted when the design temperatures of mechanical equipment located below a steam coil are defined. Steam coils are normally used during start-up and shutdown, but not during general operation. A steam trap that fails in the open position should be used to avoid freezing of the steam coil.

C.8.5.2 Other types of auxiliary heating equipment, such as glycol/water coils, heat-transfer fluid coils, electric heaters and space heaters, are being used successfully.

~~C.8~~C9 Start-up and Shutdown Procedures

~~C.8.1~~ C.9.1 General

The procedures in C.9 are intended to supplement users' established procedures, not to replace them. The procedures apply only to air-cooled heat exchangers with some degree of winterization, from the simplest (airflow control only) to the most complex (full external air recirculation). The procedures apply only to start-up and shutdown during cold weather.

~~C.8.2~~ C.9.2 Start-up Procedures

C.9.2.1 Before start-up, any snow or ice or protective coverings that can affect louver or fan operation should be removed. Depending on the particular weather conditions, snow and ice can sometimes be removed by activating the start-up heating coil. Care should be taken not to damage the top louvers. Workers should not walk on the louvers.

C.9.2.2 The instrument air supply should be checked to ensure that it is functioning and free from water.

C.9.2.3 Instruments and control valves should be checked for satisfactory operation.

C.9.2.4 The operation of all louvers, linkages, and automatically controlled variable-pitch fans (if used) should be checked.

C.9.2.5 The louvers should be closed, and the start-up heating coil (if not already activated) should be activated. If the heating system is a steam coil, the steam trap should be checked to ensure that it is functioning satisfactorily. The tube bundle and the air surrounding it should be at a temperature higher than the critical process temperature before the bundle is placed in service.

C.9.2.6 For systems with internal recirculation (see Figure C.3, Figure C.4, and Figure C.5), the control system should be verified as being in the winter mode, that is, with the fan nearest the process outlet pitched to blow air down through the bundle and the other fan pitched to force air up through the bundle. Both fans should be set at their maximum airflow position.

C.9.2.7 For systems with external recirculation (see Figure C.6), the following steps should be taken.

a) When a linkage between the top louvers and the bypass louvers is provided, it should be checked to ensure that the bypass louvers are working as intended.

b) The operation and means of actuation of the inlet louvers should be checked.

c) The exchanger's enclosure should be checked to ensure that no large openings are allowing ambient air into the enclosure.

C.9.2.8 Normal procedures should be followed when the unit is started up; however, certain process conditions can necessitate special start-up requirements. For instance, steam condensers or viscous liquid coolers at moderate temperatures should generally have the process stream introduced at or near the full flowrate. In contrast, process streams at high temperatures should be introduced to the exchanger gradually to minimize high thermal stresses that can cause mechanical failure.

C.9.2.9 The fans should be turned on, the louvers and automatically controlled variable-pitch fans should be placed on automatic control, and the heating coil should be shut off when normal operating conditions are reached. Where steam coils directly below the process bundle are used in freezing climates, they should be drained immediately after start-up.

C.8.3 C.9.3 Shutdown Procedures

C.9.3.1 Before shutdown, the fans should be shut off, the louvers should be closed, and the heating coil, if provided, should be activated.

C.9.3.2 The normal plant procedure for shutdown should be followed.

C.9.3.3 If steam purging is required, caution should be exercised to assure that the condensate is thoroughly drained.

C.9.3.4 The heating coil should be turned off.

C.9.3.5 The normal plant procedures for protecting the equipment during shutdown periods should be followed.

~~C.9Sample Economic Comparison of Indirect (Tempered-water) Versus Direct Air Cooling for Systems Requiring Winterization~~

~~C.10~~ C.10 Calculation of Minimum Tube-wall Temperature

~~C.10.1~~ C.10.1 Sample Calculation of Minimum Tube-wall Temperature for Finned Tubes (SI Units)

~~C.10.1.1~~ C.10.1.1 General

The forced-draft~~draught~~ unit specified in C.~~11~~10.1.2 is designed to cool 52,618 kg/h of gas oil product (with a gravity of 21.4° API and a UOP K of 11.5) from 143 °C to 71 °C, with an air inlet temperature of 32 °C. The designer desires to calculate the minimum tube-wall temperature at the outlet of the bottom row of tubes for an air inlet temperature of –12 °C and a minimum airflow of 66,679 kg/h, which is required to maintain the design process outlet temperature. The pour point of the gas oil is 10 °C.

~~C.10.1.2~~ C.10.1.2 Unit Description

The unit consists of one bay containing one tube bundle that is 2.90 m long, with seven rows and seven passes. The bundle contains 319 carbon steel tubes with an outside diameter of 25.4 mm and a wall thickness of 2.77 mm, arranged in an equilateral triangular pattern on a 63.5 mm pitch. The tubes have 394 aluminum fins per meter; the fins are 15.9 mm high and 0.4 mm thick.

~~C.10.1.3~~ C.10.1.3 Data

The variables for which values are given below are defined in C.5.2.

A_i 0.0624 m²/m

A_o 1.68 m²/m

f_a 1.2

r_{fs} 0.0593 m²·K/W

r_{ft} 0.00685 m²·K/W

r_m 0.00443 $m^2 \cdot K/W$ (from Table C.6)

r_c $r_{ft} (A_o/A_i) + r_m + (r_{fs}/f_a)$

0.00685 (1.68/0.0624) + 0.00443 + (0.0593/1.2)

0.238 $m^2 \cdot K/W$

t_B – 12 °C

T_B 71 °C

T_w $T_B - (r_{ft}/r_c) (A_o/A_i) (T_B - t_B)$

71 – (0.00685/0.238) (1.68/0.0624) [71 – (– 12)]

6.7 °C

The calculated tube-wall temperature is well below the recommended temperature of 23.9 °C (10 °C plus 13.9 °C for the safety margin). Consequently, it is necessary that the designer consider a winterization method that adequately protects this design against pour-point problems. In this situation, systems C or D offer possible solutions to investigate; however, the designer decides to solve this problem in another way, as described in C.~~11~~10.2.

Table C.6 — Values for r_m Referred to the Total Outside Area for a Tube with an Outside Diameter of 25.4 mm and Aluminum Fins 15.9 mm High and 0.4 mm Thick

Tube Material	k[a]	No. of Fins per Meter	Tube Wall Thickness mm					
			0.89	1.24	1.65	2.10	2.77	3.40
			r_m m²·K/W					
Admiralty	121	276	0.00295	0.00301	0.00307	0.00315	0.00326	0.00338
		315	0.00299	0.00306	0.00313	0.00321	0.00334	0.00342
		354	0.00303	0.00310	0.00318	0.00328	0.00342	0.00357
		394	0.00306	0.00314	0.00323	0.00333	0.00349	0.00366
		433	0.00309	0.00318	0.00327	0.00339	0.00356	0.00374
Aluminum	155.6	276	0.00291	0.00295	0.00300	0.00305	0.00313	0.00321
		315	0.00295	0.00299	0.00304	0.00310	0.00319	0.00329
		354	0.00298	0.00303	0.00309	0.00315	0.00325	0.00336
		394	0.00301	0.00306	0.00312	0.00320	0.00331	0.00342
		433	0.00303	0.00309	0.00316	0.00324	0.00336	0.00349
Carbon steel	45.0	276	0.00315	0.00329	0.00345	0.00364	0.00393	0.00422
		315	0.00322	0.00337	0.00356	0.00377	0.00410	0.00443
		354	0.00328	0.00345	0.00366	0.00390	0.00426	0.00463
		394	0.00334	0.00353	0.00376	0.00402	0.00443	0.00483
		433	0.00339	0.00360	0.00385	0.00414	0.00458	0.00503
Stainless steel (Types 302, 304, 316, 321, and 347)	16.08	276	0.00364	0.00399	0.00439	0.00486	0.00558	0.00631
		315	0.00377	0.00416	0.00462	0.00516	0.00597	0.00680
		354	0.00390	0.00434	0.00485	0.00545	0.00636	0.00729
		394	0.00403	0.00451	0.00508	0.00574	0.00674	0.00766
		433	0.00415	0.00467	0.00530	0.00602	0.00712	0.00824

NOTE The tabulated values are based on an assumed maximum air-side resistance (r_{fs}, or $r_{fs} + r_{ds}$) of 0.0264. Assume fin efficiency $\phi = 1$.

[a] k is the thermal conductivity, in watts per (meter Kelvin).

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~~C.10.2~~ C.10.2 Sample Calculation of Minimum Tube-wall Temperature of Bare Tubes (SI Units)

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~~C.10.2.1~~ C.10.2.1 General

The designer decides to design the unit using both finned and bare tubes. The new design features a tube bundle with the upper rows of finned tubes and the lower rows of bare tubes. The amount of air at –12 °C required to satisfy the design process outlet temperature of 71 °C is the same as for the design in C.~~11~~10.1.1. The designer now calculates the minimum tube-wall temperature at the outlet of the bottom row of bare tubes.

~~C.10.2.2~~ C.10.2.2 Unit Description

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This unit consists of one bay containing one tube bundle that is 2.90 m wide and 9.14 m long, with eight rows and eight passes. The top six rows of the bundle contain 273 carbon steel tubes with an outside diameter of 25.4 mm and a wall thickness of 2.77 mm, arranged in an equilateral triangular pattern on a 63.5 mm pitch. These tubes have 394 aluminum fins per meter; the fins are 15.9 mm high and 0.4 mm thick. In addition, the bundle contains 166 carbon steel bare tubes in the bottom two tube rows. These tubes also have an outside diameter of 25.4 mm and a wall thickness of 2.77 mm and are arranged in an equilateral triangular pattern on a 34.9 mm pitch.

~~C.10.2.3~~ C.10.2.3 Data

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The data for the bottom row of bare tubes are as follows.

A_b	0.0798 m^2/m
A_i	0.0624 m^2/m
r_{fs}	0.0629 $m^2 \cdot K/W$
r_{ft}	0.0102 $m^2 \cdot K/W$
r_{mt}	0.000070 $m^2 \cdot K/W$
r_c	$r_{ft}\,(A_b/A_i) + r_{mt} + (r_{fs}/f_a)$
	0.0102 (0.0798/0.0624) + 0.000070 + (0.0269/1.2)
	0.0355 $m^2 \cdot K/W$
T_w	$T_B - (r_{ft}/r_c)\,(_{Ab}/A_i)\,(T_B - t_B)$
	71 – (0.0102/0.0355) (0.0798/0.0624) × [71 – (– 12)]
	40.5 °C
r_{fs}	0.059 $m^2 \cdot K/W$
r_{ft}	0.00415 $m^2 \cdot K/W$
r_c	$r_{ft}\,(A_o/A_i) + r_m + (_{rfs}/f_a)$
	0.00415 (1.68/0.0624) + 0.0044 + (0.059/1.2)
	0.1653 $m^2 \cdot K/W$
t_B	– 0.4 °C (air temperature leaving the bare tube section)
T_B	78.5 °C (gas oil temperature leaving the sixth pass)
T_w	$T_B - (r_{ft}/r_c)\,(A_o/A_i)\,(T_B - t_B)$
	78.5 – (0.00415/0.1653) (1.68/0.0624) × [78.5 – (– 0.4)]
	25.2 °C (> 23.9 °C)

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The calculated tube-wall temperature at the outlet of the bottom row of bare tubes is well above 23.9 °C, and no gas oil freeze-up is anticipated. To verify that the finned section of the bundle is also protected, the designer decides to calculate the tube-wall temperature at the outlet of the sixth pass (the row of finned tubes immediately above the bare tubes). From the thermal design calculations, the designer obtains the following data.

r_{fs} 0.059 $m^2 \cdot K/W$

r_{ft} 0.00415 $m^2 \cdot K/W$

r_c $r_{ft}(A_o/A_i) + r_m + (r_{fs}/f_a)$

0.00415 (1.68/0.0624) + 0.0044 + (0.059/1.2)

0.1653 $m^2 \cdot K/W$

t_B – 0.4 °C (air temperature leaving the bare tube section)

T_B 78.5 °C (gas oil temperature leaving the sixth pass)

T_w $T_B - (r_{ft}/r_c)(A_o/A_i)(T_B - t_B)$

78.5 – (0.00415/0.1653) (1.68/0.0624) × [78.5 – (– 0.4)]

25.2 °C (> 23.9 °C)

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It appears that this design is safe against a potential freeze-up for continuous operation. As in all viscous fluid coolers, however, an auxiliary heating coil is recommended for cold start-up.

~~C.10.3~~ C.10.3 Sample Calculation of Minimum Tube-wall Temperature for Finned Tubes (USC~~ Customary~~ Units)

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~~C.10.3.1~~ C.10.3.1 General

The forced-draft~~draught~~ unit specified in C.~~11~~10.3.2 is designed to cool 116,000 lb/h of gas oil product (with a gravity of 21.4° API and a UOP K of 11.5) from 290 °F to 160 °F, with an air inlet temperature of 90 °F. The designer desires to calculate the minimum tube-wall temperature at the outlet of the bottom row of tubes for an air inlet temperature of 10 °F and a minimum airflow of 147,000 lb/h, which is required to maintain the design process outlet temperature. The pour point of the gas oil is 50 °F.

~~C.10.3.2~~ C.10.3.2 Unit Description

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The unit consists of one bay containing one tube bundle that is 9.5 ft wide and 30 ft long, with seven rows and seven passes. The bundle contains 319 carbon steel tubes with an outside diameter of 1 in. and a wall thickness of 0.109 in., arranged in an equilateral triangular pattern on a 2.5 in. pitch. The tubes have 10 aluminum fins per in.; the fins are $^5/_8$ in. high and 0.016 in. thick.

~~C.10.3.3~~ C.10.3.3 Data

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The variables for which values are given below are defined in C.5.2.

A_i 0.2047 ft^2/ft

A_o 5.5 ft^2/ft

f_a 1.2

r_{fs} 0.3367 (°F)(ft^2)(h)/Btu

r_{ft} 0.0389 (°F)(ft^2)(h)/Btu

r_m 0.0251 Btu^{-1} (from Table C.7)

r_c $r_{ft} (A_o/A_i) + r_m + (r_{fs}/f_a)$

0.0389 (5.5/0.2047) + 0.0251 + (0.3367/1.2)

1.351 (°F)(ft^2)(h)/Btu

t_B 10 °F

T_B 160 °F

T_w $T_B - (r_{ft}/r_c) (A_o/A_i) (T_B - t_B)$

160 – (0.0389/1.351) (5.5/0.2047) (160 – 10)

44 °F

The calculated tube-wall temperature is well below the recommended temperature of 75 °F (50 °F plus 25 °F for the safety margin). Consequently, it is necessary that the designer consider a winterization method that adequately protects this design against pour-point problems. In this situation, systems C or D offer possible solutions to investigate; however, the designer decides to solve this problem in another way, as described in C.1110.4.

C.10.4 C.10.4 Sample Calculation of Minimum Tube-wall Temperature of Bare Tubes (USC Customary Units)

C.10.4.1 C.10.4.1 General

The designer decides to design the unit using both finned and bare tubes. The new design features a tube bundle with the upper rows of finned tubes and the lower rows of bare tubes. The amount of air at 10 °F required to satisfy the design process outlet temperature of 160 °F is the same as for the design in C.1110.3.1. The designer now calculates the minimum tube-wall temperature at the outlet of the bottom row of bare tubes.

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Table C.7 — Values for r_m Referred to the Total Outside Area for a Tube with an Outside Diameter of 1 in. and Aluminum Fins 5/8 in. High and 0.016 in. Thick

Tube Material	k[a]	No. of Fins per in.	Tube Wall Thickness (in.)					
			0.035	0.049	0.065	0.083	0.109	0.134
			r_m (°F·ft²·h/Btu)					
Admiralty	70	7	0.01677	0.01708	0.01745	0.01787	0.01852	0.01918
		8	0.01700	0.01735	0.01777	0.01825	0.01898	0.01943
		9	0.01720	0.01760	0.01806	0.01860	0.01942	0.02025
		10	0.01739	0.01782	0.01833	0.01893	0.01984	0.02076
		11	0.01755	0.01803	0.01859	0.01925	0.02024	0.02125
Aluminum	90	7	0.01655	0.01677	0.01702	0.01732	0.01778	0.01824
		8	0.01675	0.01700	0.01729	0.01763	0.01814	0.01866
		9	0.01692	0.01720	0.01752	0.01790	0.01848	0.01906
		10	0.01708	0.01738	0.01774	0.01816	0.01879	0.01944
		11	0.01722	0.01755	0.01794	0.01840	0.01909	0.01980
Carbon steel	26	7	0.01789	0.01867	0.01959	0.02067	0.02230	0.02396
		8	0.01827	0.01916	0.02020	0.02142	0.02327	0.02515
		9	0.01862	0.01961	0.02078	0.02214	0.02421	0.02631
		10	0.01896	0.02005	0.02134	0.02285	0.02513	0.02745
		11	0.01927	0.02047	0.02188	0.02353	0.02603	0.02858
Stainless steel (Types 302, 304, 316, 321, and 347)	9.3	7	0.02068	0.02263	0.02493	0.02762	0.03169	0.03584
		8	0.02143	0.02364	0.02625	0.02930	0.03392	0.03862
		9	0.02215	0.02463	0.02755	0.03095	0.03611	0.04137
		10	0.02286	0.02559	0.02882	0.03258	0.03829	0.04409
		11	0.02355	0.02654	0.03008	0.03420	0.04045	0.04681

NOTE The tabulated values are based on an assumed maximum air-side resistance (r_{fs}, or $r_{fs} + r_{ds}$) of 0.15. Assume fin efficiency $\phi = 1$.

[a] k is the thermal conductivity, in British thermal units (hour) (square foot) (degree Fahrenheit) per foot.

~~C.10.4.2~~ C.10.4.2 Unit Description

The unit consists of one bay containing one tube bundle that is 9.5 ft wide and 30 ft long, with eight rows and eight passes. The top six rows of the bundle contain 273 carbon steel tubes with an outside diameter of 1 in. and a wall thickness of 0.109 in., arranged in an equilateral triangular pattern on a 2.5 in. pitch. These tubes have 10 aluminum fins per in.; the fins are 5/8 in. high and 0.016 in. thick. In addition, the bundle contains 166 carbon steel bare tubes in the bottom two tube rows. These tubes also have an outside diameter of 1 in. and a wall thickness of 0.109 in. and are arranged in an equilateral triangular pattern on a 1 3/8 in. pitch.

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~~C.10.4.3~~ C.10.4.3 Data

The data for the bottom row of bare tubes are as follows.

A_b 0.2618 ft^2/ft

A_i 0.2047 ft^2/ft

r_{fs} 0.153 (°F)(ft^2)(h)/Btu

r_{ft} 0.058 (°F)(ft^2)(h)/Btu

r_{mt} 0.0004 (°F)(ft^2)(h)/Btu

r_c $r_{ft}\,(A_b/A_i) + r_{mt} + (r_{fs}/f_a)$

0.058 (0.2618/0.2047) + 0.0004 + (0.153/1.2)

0.202 (°F)(ft^2)(h)/Btu

T_w $T_B - (r_{ft}/r_c)\,(A_b/A_i)\,(T_B - t_B)$

160 – (0.058/0.202) (0.2618/0.2047) (160 – 10)

105 °F

r_{fs} 0.3356 (°F)(ft^2)(h)/Btu

r_{ft} 0.0236 (°F)(ft^2)(h)/Btu

r_c $r_{ft}\,(A_o/A_i) + r_m + (r_{fs}/f_a)$

0.0236 (5.5/0.2047) + 0.025 1 + (0.3356/1.2)

0.939 (°F)(ft^2)(h)/Btu

t_B 31.3 °F (air temperature leaving the bare tube section)

T_B 173.4 °F (gas oil temperature leaving the sixth pass)

T_w $T_B - (r_{ft}/r_c)(A_o/A_i)(T_B - t_B)$

173.4 – (0.0236/0.939) (5.5/0.2047) × (173.4 – 31.3)

77.4 °F (> 75 °F)

The calculated tube-wall temperature at the outlet of the bottom row of bare tubes is well above 75 °F, and no gas oil freeze-up is anticipated. To verify that the finned section of the bundle is also protected, the designer decides to calculate the tube-wall temperature of the outlet of the sixth pass (the row of finned tubes immediately above the bare tubes). From the thermal design calculations, the designer obtains the following data.

r_{fs} 0.3356 (°F)(ft^2)(h)/Btu

r_{ft} 0.0236 (°F)(ft^2)(h)/Btu

r_c $r_{ft}(A_o/A_i) + r_m + (r_{fs}/f_a)$

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0.0236 (5.5/0.2047) + 0.0251 + (0.3356/1.2)

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0.939 (°F)(ft^2)(h)/Btu

t_B 31.3 °F (air temperature leaving the bare tube section)

T_B 173.4 °F (gas oil temperature leaving the sixth pass)

T_w $T_B - (r_{ft}/r_c)(A_o/A_i)(T_B - t_B)$

173.4 – (0.0236/0.939) (5.5/0.2047) × (173.4 – 31.3)

77.4 °F (> 75 °F)

It appears that this design is safe against a potential freeze-up for continuous operation. As in all viscous fluid coolers, however, an auxiliary heating coil is recommended for cold start-up.

~~C.11~~ C.11 Sample Calculation of Heat Losses

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~~C.11.1~~ C.11.1 Sample Calculation of Heat Losses (SI Units)

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~~C.11.1.1~~ C.11.1.1 General

In the examples in C.~~12~~11.1, it is necessary to establish the temperature differential between the ambient air and the enclosed air. In the calculation determining the minimum heat-input requirement for an auxiliary heating coil, the temperature of the air enclosed in the plenum surrounding the process coil should be the temperature to which it is desired to warm the process bundle.

Within a heated enclosure, air near the top is hotter than air near the bottom. An inside air temperature is assumed for the top of the enclosure as well as the bottom. These assumed air temperatures are not recommended air temperatures but are simply assumed values used to illustrate the calculation procedure.

Be aware that the louver area is assumed to be the same as the face area of the tube bundle; this is not always the case.

~~C.11.1.2~~ C.11.1.2 Nomenclature

~~C.11.1.2.1~~ C.11.1.2.1 Symbols

A_l louver leakage area, in square meters. (In the calculations below, A_l is assumed to be 2 % of the tube bundle face area.)

c_p average specific heat capacity, in kJ/(kg·K) (taken as 1.005 for air)

F_p pressure promoting leakage, in meters of fluid

g acceleration due to gravity, equal to 9.807 m/s^2

h height of the hot air column, in meters

K local heat transfer coefficient, in W/(m^2·K)

ϕ heat loss per unit time, in W

R gas constant, in J/(mol·K)

T temperature, in °C

U thermal transmittance, in W/(m^2·K)

v velocity, in m/s

q_m flow per unit time, in kg/h

ρ density of air, in kg/m^3

~~C.11.1.2.2~~ C.11.1.2.2 Subscripts

o relating to conditions outside the air-cooled heat exchanger

I relating to conditions inside the air-cooled heat exchanger

C.11.1.3 C.11.1.3 Louver Leakage

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C.1211.1.3.1 Air that is warmer than ambient air and is contained in an unsealed enclosure tries to rise within that enclosure and exerts a pressure on the upper surface. This causes leakage when the upper surface consists of non-sealing louver blades. The pressure promoting leakage may be expressed as given in Equation (C.9):

$$F_p = [h(\rho_o - \rho_i)]/\rho_i \quad \text{(C.9)}$$

The velocity through the leak areas (assuming a loss of 1.5 velocity heads) is as given in Equation (C.10):

$$v = (2gF_p/1.5)^{1/2} \quad \text{(C.10)}$$

The rate at which warm air leaks through the louvers is as given in Equation (C.11):

$$q_m = 3\,600\, v\rho_i A_i \quad \text{(C.11)}$$

The rate of heat loss due to louver leakage is as given in Equation (C.12):

$$\phi = q_m c_p (T_i - T_o) \quad \text{(C.12)}$$

A sample calculation of heat loss due to louver leakage is presented in C.1211.1.3.2.

C.1211.1.3.2 Assume the following conditions: A totally enclosed air-cooled heat exchanger is 4.27 m wide, 10.97 m long, and 2.44 m high. The inside air temperature T_i is 37.78 °C, and the outside air temperature T_o is –17.78 °C. Assuming that the perfect-gas laws apply, the air density can be determined from Equation (C.13):

$$\rho = (Mp)/(RT) \quad \text{(C.13)}$$

where

M is relative molecular mass of air, equal to 28.96;

p is the absolute pressure, in kilopascal;

R is the gas constant, equal to 8.31 J/(mol·K);

T is temperature, in Kelvin's.

Therefore, the outside air density is

$$\rho_o = [(28.96)\,(101.33)] / [(8.31)\,(-17.78 + 273.15)]$$
$$= 1.383 \text{ kg/m}^3$$

The inside air density is

$$\rho_i = [(28.96)\,(101.33)] / [(8.31)\,(37.78 + 273.15)]$$
$$= 1.136 \text{ kg/m}^3$$

The pressure promoting leakage through the louvers is determined using Equation (C.9) as follows:

$$F_p = [h(\rho_o - \rho_i)] / \rho_i$$
$$= [2.44\,(1.383 - 1.136)] / 1.136$$
$$= 0.531 \text{ m of air.}$$

The velocity through the louver leakage area resulting from this pressure is calculated using Equation (C.10) as follows:

$$v = (2gF_p/1.5)^{1/2}$$
$$= [(2)\ (9.807)\ (0.531)/1.5]^{1/2}$$
$$= 2.63 \text{ m/s.}$$

The air leakage rate through the louvers is calculated using Equation (C.11) as follows:

$$q_\text{m} = 3600\ v\rho_i A_\text{i}$$
$$= (3600)\ (2.63)\ (1.136)\ [(0.02)\ (4.27)\ (10.97)]$$
$$= 10{,}076 \text{ kg/h.}$$

The rate of heat loss resulting from louver leakage is then determined using Equation (C.12) as follows:

$$\phi = q_\text{m} c_p\ (T_\text{i} - T_\text{o})$$
$$= (10{,}076)\ [(1.005)\ (1000/3600)]\ [37.78 - (-17.78)]$$
$$= 156{,}300 \text{ W.}$$

~~C.11.1.4~~ C.11.1.4 Surface Heat Loss

C.~~12~~11.1.4.1 The heat lost by convection from the exterior surfaces of the plenum is a function of temperature difference, wind velocity, and surface area. For velocities less than 4,88 m/s, Equation (C.14) from Reference [12~~3~~] is recommended for determining the heat transfer coefficient for airflow parallel to flat surfaces:

$$K = 7.88 + 0.21v \qquad \text{(C.14)}$$

NOTE This equation is derived for vertical surfaces; for simplicity, however, it is used here for all surfaces, since the majority is vertical.

For velocities of 4.88 m/s and higher, the Equation (C.15) is recommended:

$$K = 7.17(v)^{0.78} \qquad \text{(C.15)}$$

A sample calculation of heat loss by convection from an air-cooled heat exchanger is presented in C.~~12~~11.1.4.2.

C.~~12~~11.1.4.2 Assume the following conditions: A totally enclosed air-cooled heat exchanger is 5.49 m wide, 10.97 m long, and 4.88 m high (from grade to the top of the louvers). The inside air temperature varies linearly from 37.78 °C at the top to 10.0 °C at the bottom. The outside air temperature is –17.78 °C. The inside air velocity is 0.61 m/s. The outside wind velocity is 9.14 m/s.

The thermal transmittance, U, is calculated as follows:

$$K_\text{i} = 7.88 + 0.21v$$
$$= 7.88 + (0.21)\ (0.61)$$
$$= 8.01 \text{ W/m}^2\cdot\text{K}$$

$$K_\text{o} = 7.17\ (v)^{0.78}$$
$$= 7.17\ (9.14)^{0.78}$$

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$= 40.26\ \mathrm{W/m^2 \cdot K}$

$U = 1/[(1/K_i) + (1/K_o)]$

$= 1/[(1/8.01) + (1/40.26)]$

$= 6.68\ \mathrm{W/m^2 \cdot K}$

The total surface heat loss is determined as follows:

$\phi = UA\,(T_i - T_o)$

$= 6.68\ \{[(5.49)\ (10.97)]\ [37.78 - (-17.78)] + ...$

$...+ [(4.88)\ (5.49 + 5.49 + 10.97 + 10.97)]\ [(37.78 + 10)/2 - (-17.78)]\}$

$= 67{,}000\ \mathrm{W}$

~~C.11.1.5~~ C.11.1.5 Total Heat Loss Calculation

~~C.11.1.5.1~~ C.11.1.5.1 Forced ~~-draft~~draft~~Draught~~ with External Recirculation

Assume that an enclosure is 5.49 m wide, 10.97 m long, and 5.49 m high. The dimensions of the top louver area are 4.27 m by 10.97 m. Inlet air louvers are located on the sides near the bottom. There is a hot air column that is 2.74 m high between the heating coil and the top louvers. Assume an outside air temperature of –17.78 °C and an inside air temperature that varies linearly from 37.78 °C above the heating coil to 10.0 °C at the bottom of the enclosure.

The heat loss through the top louvers may be calculated as follows:

$\rho_o = 1.383\ \mathrm{kg/m^3}$

$\rho_i = 1.136\ \mathrm{kg/m^3}$

The pressure promoting leakage resulting from the effect of the hot air column above the heating coil is determined as follows:

$F_{p1} = [h(\rho_o - \rho_i)] / \rho_i$

$= [2.74\ (1.383 - 1.136)] / 1.136$

$= 0.596$ m of air

The air density at the average temperature below the heating coil is

$\rho_i = (\mathrm{M}p)/(\mathrm{R}T)$

$= [(28.96)\ (101.33)] \div \{(8.31)\ [(37.78 + 10.0)/2 + 273.15]\}$

$= 1.189\ \mathrm{kg/m^3}$

The pressure promoting leakage below the heating coil is determined by

$F_{p2} = [h(\rho_o - \rho_i)] / \rho_i$

$= [2.74\ (1.383 - 1.189)] / 1.189$

$= 0.447$ m of air

The total pressure promoting leakage is the sum of the pressures above and below the heating coil:

$F_{pd} = F_{p1} + F_{p2}$

$= 0.596 + 0.447$

$= 1.043$ m of air

This pressure drop, however, assumes no restriction of the inlet air to the exchanger. Since the entire exchanger is enclosed, it is necessary that the entering air come through the inlet louvers. It is necessary that the quantity of inlet air equal the quantity of exhaust air. It can be assumed that the effective pressure promoting leakage, F_p*, is equally divided between the inlet and the exhaust louvers. Therefore,

$F_p^* = 1.043/2$

$= 0.522$ m of air

The velocity through the louver leak area is

$v = (2gF_p^*/1.5)^{1/2}$

$= [(2)\ (9.807)\ (0.522)/1.5]^{1/2}$

$= 2.61$ m/s

The rate of heat loss resulting from louver leakage is then

$\phi = q_m c_p\ (T_i - T_o)$

$= [(3600)\ (2.61)\ (1.136)]\ [(0.02)\ (4.27)\ (10.97)] \times$..
...$\times$ [(1.005) (1000/3600)] [37.78 – (–17.78)]

$= 155{,}100$ W

The thermal transmittance, U, is 6.68 W/m^2·K. The rate of surface heat loss is

$\phi = UA\ (T_i - T_o)$

$= 6.68\ (2.74)\ (5.49 + 5.49 + 10.97 + 10.97) \times [37.78 - (-17.78)]$ +...
...+ 6.68 (2.74) (5.49 + 5.49 + 10.97 + 10.97)$\times$ [(37.78 + 10.0)/2 – (– 17.78)] +...
...+ 6.68 [(5.49) (10.97)] [(37.78 – (– 17.78)]

$= 80{,}900$ W.

~~C.11.1.5.2~~ C.11.1.5.2 Forced ~~-~~draft~~Draught~~ Without Louvers

This case is discussed to show that heat loss is from four to eight times greater without top louvers than when louvers are present. This loss is caused by an unimpeded natural draft~~draught~~ of air through the tube bundle. Under such conditions, it is reasonable to assume an air velocity of 15.24 m/min at the bundle face. Assume the following air-cooled heat exchanger geometry, as used in the example in C.~~12~~11.1.3: A totally enclosed air-cooled heat exchanger is 4.27 m wide, 10.97 m long, and 2.44 m high. Also assume that the air is heated from –17.78 °C to 37.78 °C.

The heat loss is calculated as follows.

The rate of warm air loss through the bundle is

$q_m = 3600\ v\rho_i A$

$= (3600)\ (15.24/60)\ (1.136)\ [(4.27)\ (10.97)]$

$= 48{,}700$ kg/h

This leads to the following rate of heat loss:

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$\phi = q_m c_p (T_i - T_o)$

$= (48{,}700)\ [(1.005)\ (1000/3600)]\ [(37.78 - (-17.78)]$

$= 754{,}700$ W

For other designs that can require analysis, it is recommended that the principles shown in these examples be applied.

C.11.2 C.11.2 Sample Calculation of Heat Losses (USC Customary Units)

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C.11.2.1 C.11.2.1 General

In the examples in C.1211.2, it is necessary to establish the temperature differential between the ambient air and the enclosed air. In the calculation determining the minimum heat input requirement for an auxiliary heating coil, the temperature of the air enclosed in the plenum surrounding the process coil should be the temperature to which it is desired to warm the process bundle.

Within a heated enclosure, air near the top is hotter than air near the bottom. An inside air temperature is assumed for the top of the enclosure as well as the bottom. These assumed air temperatures are not recommended air temperatures but are simply assumed values used to illustrate the calculation procedure.

Be aware that the louver area is assumed to be the same as the face area of the tube bundle; this is not always the case.

C.11.2.2 C.11.2.2 Nomenclature

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C.11.2.2.1 C.11.2.2.1 Symbols

A_l louver leakage area, in square feet. (In the calculations below, A_l is assumed to be 2 % of the tube bundle face area.)

c_p average specific heat capacity, in British thermal units per (pound) (degree Fahrenheit) (taken as 0.24 for air)

F_p pressure promoting leakage, in feet of fluid

g acceleration due to gravity, equal to 32.17 ft/s^2

h height of the hot air column, in feet

K local heat transfer coefficient, in British thermal units per (hour) (square foot) (degree Fahrenheit)

ϕ heat loss per unit time, in British thermal units per hour

R gas constant, in (cubic feet) (pounds per square in. absolute) per (pound-mole) (degrees Rankine)

T temperature, in degrees Fahrenheit

U thermal transmittance, in British thermal units per (hour) (square foot) (degree Fahrenheit)

v velocity, in feet per second

q_m flow per unit time, in pounds per hour

ρ density of air, in pounds per cubic foot

C.11.2.2.2 C.11.2.2.2 Subscripts

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o relating to conditions outside the air-cooled heat exchanger

i relating to conditions inside the air-cooled heat exchanger

C.11.2.3 C.11.2.3 Louver Leakage

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C.1211.2.3.1 Air that is warmer than ambient air and is contained in an unsealed enclosure tries to rise within that enclosure and exerts a pressure on the upper surface. This causes leakage when the upper surface consists of non-sealing louver blades. The pressure promoting leakage may be expressed as follows:

$$F_p = [h(\rho_o - \rho_i)] / \rho_i \quad (C.16)$$

The velocity through the leak areas (assuming a loss of 1.5 velocity heads) is

$$v = (2gF_p/1.5)^{1/2} \quad (C.17)$$

The rate at which warm air leaks through the louvers is

$$q_m = 3600\, v\rho_i A_i \quad (C.18)$$

The rate of heat loss due to louver leakage is

$$\phi = q_m c_p (T_i - T_o) \quad (C.19)$$

A sample calculation of heat loss due to louver leakage is presented in C.1211.2.3.2.

C.1211.2.3.2 Assume the following conditions: A totally enclosed air-cooled heat exchanger is 14 ft wide, 36 ft long, and 8 ft high. The inside air temperature T_i is 100 °F, and the outside air temperature T_o is 0 °F. Assuming that the perfect-gas laws apply, the air density can be determined from Equation (C.20):

$$\rho = (Mp) / (RT) \quad (C.20)$$

where

M is the relative molecular mass of air, equal to 28.96;

p is the pressure, in pounds per square in. absolute;

R is the gas constant, equal to10.73 (cubic feet) (pounds per square in. absolute) per (pound-mole) (degrees Rankine);

T is temperature of air, in degrees Rankine.

Therefore, the outside air density is

$$\rho_o = [(28.96)\ (14.70)] / [(10.73)\ (0 + 459.67)]$$
$$= 0.0863\ \text{lb/ft}^3$$

The inside air density is

$$\rho_i = [(28.96)\ (14.70)] / [(10.73)\ (100 + 459.67)]$$
$$= 0.070\ 9\ \text{lb/ft}^3$$

The pressure promoting leakage through the louvers is determined using Equation (C.16) as follows:

$$F_p = [h(\rho_o - \rho_i)] / \rho_i$$
$$= [8\ (0.0863 - 0.0709)] / 0.0709$$
$$= 1.738\ \text{ft of air}$$

The velocity through the louver leakage area resulting from this pressure is calculated using Equation (C.17) as follows:

$$v = (2gF_p/1,5)^{1/2}$$
$$= [(2)\ (32.17)\ (1.738)/1.5]^{1/2}$$
$$= 8.63\ \text{ft/s}$$

The air leakage rate through the louvers is calculated using equation (C.18) as follows:

$$q_m = 3600\ v\rho_i A_i$$
$$= (3600)\ (8.63)\ (0.0709)\ [(0.02)\ (14)\ (36)]$$
$$= 22.203\ \text{lb/h}$$

The rate of heat loss resulting from louver leakage is then determined using Equation (C.19) as follows:

$$\phi = q_m c_p\ (T_i - T_o)$$
$$= (22,203)\ (0.24)\ (100 - 0)$$
$$= 532,900\ \text{Btu/h.}$$

~~C.11.2.4~~ C.11.2.4 Surface Heat Loss

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C.~~12~~11.2.4.1 The heat lost by convection from the exterior surfaces of the plenum is a function of temperature difference, wind velocity, and surface area. For velocities less than 16 ft/s, the following equation from Reference [12~~3~~] is recommended for determining the heat transfer coefficient, K, for airflow parallel to flat surfaces:

$$K = 0.99 + 0.21v \qquad \text{(C.21)}$$

NOTE This equation is derived for vertical surfaces; for simplicity, however, it is used here for all surfaces, since most are vertical.

For velocities of 16 ft/s and higher, Equation (C.22) is recommended:

$$K = 0.5\ (v)^{0.78} \qquad \text{(C.22)}$$

A sample calculation of heat loss by convection from an air-cooled heat exchanger is presented in C.1211.2.4.2.

C.1211.2.4.2 Assume the following conditions: A totally enclosed air-cooled heat exchanger is 18 ft wide, 36 ft long, and 16 ft high (from grade to the top of the louvers). The inside air temperature varies linearly from 100 °F at the top to 50 °F at the bottom. The outside air temperature is 0 °F. The inside air velocity is 2 ft/s. The outside wind velocity is 30 ft/s.

The thermal transmittance, U, is calculated as follows:

$$K_i = 0.99 + 0.21v$$
$$= 0.99 + (0.21)\ (2)$$
$$= 1.41\ \text{Btu/(h·ft}^2\text{·°F)}.$$

$$K_o = 0.5\ (v)^{0.78}$$
$$= 0.5\ (30)^{0.78}$$
$$= 7.09\ \text{Btu/(h·ft}^2\text{·°F)}.$$

$$U = 1/[(1/K_i) + (1/K_o)]$$
$$= 1/[(1/1.41) + (1/7.09)]$$
$$= 1.176\ \text{Btu/(h·ft}^2\text{·°F)}.$$

The total surface heat loss rate is determined as follows:

$$\phi = UA\ (T_i - T_o)$$
$$= (1.17)\ \{(18)\ (36)\ (100 - 0) + (16)\ (18 + 18 + 36 + 36)\ [(100 + 50)/2 - 0]\}$$
$$= 227{,}400\ \text{Btu/h}.$$

C.11.2.5 C.11.2.5 Total Heat Loss Calculation

C.11.2.5.1 C.11.2.5.1 Forced -draftDraught with External Recirculation

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Assume that an enclosure is 18 ft wide, 36 ft long, and 18 ft high. The dimensions of the top louver area are 14 ft by 36 ft. Inlet air louvers are located on the sides near the bottom. There is a hot air column that is 9 ft high between the heating coil and the top louvers. Assume an outside air temperature of 0 °F and an inside air temperature that varies linearly from 100 °F above the heating coil to 50 °F at the bottom of the enclosure.

The heat loss through the top louvers may be calculated as follows:

$$\rho_o = 0.0863\ \text{lb/ft}^3$$
$$\rho_i = 0.0709\ \text{lb/ft}^3$$

The pressure promoting leakage resulting from the effect of the hot-air column above the heating coil is determined as follows:

$$F_{p1} = [h(\rho_o - \rho_i)]\ /\ \rho_i$$

= [(9) (0.0863 – 0.0709)] / 0.0709

= 1.95 ft of air.

The air density at the average temperature below the heating coil is

$\rho_i = (Mp)/(RT_i)$

= [(28.96) (14.7)] ÷ {(10.73) [(100 + 50)/2 + 459.67]}

= 0.0742 lb/ft^3.

The pressure promoting leakage below the heating coil is determined by

$F_{p2} = [h(\rho_o - \rho_i)] / \rho_i$

= [9 (0.0863 – 0.0742)] / 0.0742

= 1.47 ft of air.

The total pressure promoting leakage is the sum of the pressures above and below the heating coil:

$F_{pd} = F_{p1} + F_{p2}$

= 1.95 + 1,47

= 3.42 ft of air.

This pressure drop, however, assumes no restriction of the inlet air to the exchanger. Since the entire exchanger is enclosed, it is necessary that the entering air come through the inlet louvers. It is necessary that the quantity of inlet air equal the quantity of exhaust air. It can be assumed that the effective pressure promoting leakage, F_p* is equally divided between the inlet and exhaust louvers. Therefore

$F_p* = 3.42/2$

= 1.71 ft of air

The velocity through the louver leak area is

$v = (2gF_p*/1.5)^{1/2}$

= $[(2) (32.17) (1.71)/1.5]^{1/2}$

= 8.56 ft/s

The heat loss resulting from louver leakage is, then,

$\phi = q_m c_p (T_i - T_o)$

= [(3600) (8.56) (0.0709)] [(0.02) (14) (36)] [(0.24) (100 – 0)]

= 528,600 Btu/h

The thermal transmittance, U, is 1.176 Btu/(h·ft^2·°F). The surface heat loss is

$\phi = UA (T_i - T_o)$

= 1.176 [(9) (18 + 18 + 36 + 36) (100 – 0)]

+ 1.176 {(9) (18 + 18 + 36 + 36) [(100 + 50) /2 – 0]}

+ 1.176 [(18) (36)] (100 – 0)

= 276,200 Btu/h

~~C.11.2.5.2~~ C.11.2.5.2 Forced-draft~~Draught~~ without Louvers

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This case is discussed to show that heat loss is from four to eight times greater without top louvers than when louvers are present. This loss is caused by an unimpeded natural draft~~draught~~ of air through the tube bundle. Under such conditions, it is reasonable to assume an air velocity of 50 ft/min at the bundle face. Assume the following air-cooled heat exchanger geometry, as used in the example in C.~~12~~11.2.3: A totally enclosed air-cooled heat exchanger is 14 ft wide, 36 ft long, and 8 ft high. Also assume that the air is heated from 0 °F to 100 °F.

The heat loss is calculated as follows: The warm air loss through the bundle is

q_m = 3600 $v \rho_i A$

= (3600) (50/60) (0.0709) [(14) (36)]

= 107,200 lb/h.

This leads to the following heat loss:

$\phi = q_m c_p (T_i - T_o)$

= (107,200) (0.24) (100 – 0)

= 2,572,000 Btu/h

For other designs that can require analysis, it is recommended that the principles shown in these examples be applied.

Annex D
(informative)

Recommended Procedure for Airflow Measurement of Air-cooled Heat Exchangers

D.1Scope

This annex provides standardized guidelines for the conduct, analysis, and report of airflow measurement on air-cooled heat exchanger fans at the Vvendor's site. Additional information and procedures may be found in ISO 3744.

D.2Equipment Required

All instruments should be calibrated at the instrument manufacturers' recommended intervals.

The instruments should be as specified in Table D.1.

Table D.1 — Instruments

Parameter Being Measured	Instrument
Velocity	Digital anemometer with a minimum head diameter of 70 mm (2 ¾ in.); this may be a propeller type or rotating vane type.
Static pressure	Standard type static pressure probe designed to minimize velocity effect.
Temperature	"K" type digital thermometer
Power	Wattmeter

D.3Procedure

D.3.1 Ambient Conditions

D.3.1.1 Rain

If rain or precipitation is occurring, the test should not be conducted.

D.3.1.2 Wind

Wind velocity should be measured at the start and end of the airflow test using a rotating vane anemometer. This measurement should be taken at a location that is upwind and unobstructed. If wind velocity is greater than 16 km/h (10 mph), the test should not be conducted. Record wind speed on an airflow test form data sheet.

D.3.1.3 Air Temperature Through the Fan

Ambient air temperature should be taken at a minimum distance of 1 m (3 ft) away from any heat exchangers or equipment that can affect the reading. This should be done before and after the airflow test is completed. Record temperature on an airflow test form data~~-~~sheet.

This annex is intended to provide guidance for airflow testing at the ~~V~~vendor's site. When the fan is in service, the air temperature through the fan differs from ambient. This is especially true of induced~~-~~-draft-~~draught~~ units that have an increased temperature due to the heat exchanger when in use. If an airflow test is being done while the heat exchanger is in service, the air temperature should be taken in one of two locations depending on the draft~~draught~~ type. For a forced~~-~~-draft~~draught~~ unit, the temperature measurement should be taken in the plane 150 mm (6 in.) below the fan ring. For an induced~~-~~-draft~~draught~~ unit, the temperature should be taken 150 mm (6 in.) above the fan ring.

D.3.1.4 Relative Humidity

Relative humidity can be obtained from a nearby weather station or with a hygrometer. Record relative humidity on an airflow test form data~~-~~sheet.

D.3.1.5 Atmospheric Pressure

Barometric pressure can be obtained from a nearby weather station or airport and corrected for the difference in elevation of the barometer from the unit being tested. Record atmospheric pressure on an airflow test form data~~-~~sheet.

D.3.1.6 Elevation

Elevation from sea level can be obtained from the site map of the location at which the testing is being conducted. Record elevation on an airflow test form data~~-~~sheet.

D.3.2 Fan Measurements

D.3.2.1 Fan Speed

Fan speed is measured at the fan shaft using a mechanical contact tachometer. Record fan speed on an airflow test form data~~-~~sheet.

D.3.2.2 Tip Clearance

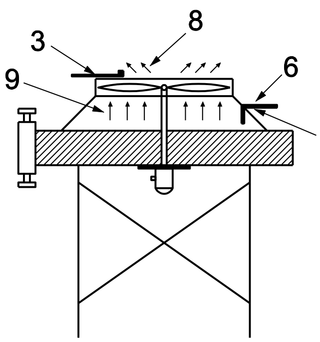
The fan blade tip clearance should be measured for at least 25 % of the blades. Record tip clearance on an airflow test form data~~-~~sheet.

D.3.2.3 Blade Pitch

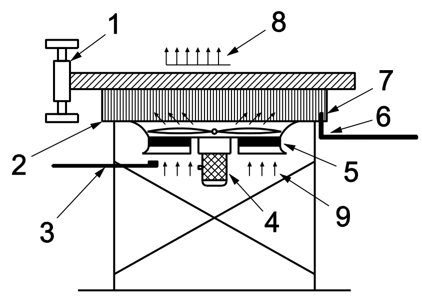
The fan blade pitch angle should be measured for at least 25 % of the blades using a protractor. The pitch should be measured at the location on the blade specified by the fan manufacturer. Record blade pitch on an airflow test form data~~-~~sheet.

D.3.3 Static Pressure

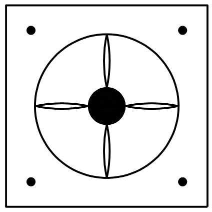
The static pressure drop should be measured with a manometer at the four corners of the fan plenum by means of probes. Figure D.1 shows the location of the test holes for both induced and forced~~-~~-draft~~draught~~ units. It is recommended that the holes be drilled in the plenum prior to starting the test. Record the four static pressure readings on an airflow test form data~~-~~sheet.



a) Induced -draftdraught



b) Forced -draftdraught



c) Top or bottom view

Key

1	heater	6	static pressure probe (four corners)
2	plenum	7	drilled hole [8 mm ($^5/_{16}$ in.)], four off
3	anemometer	8	exhaust air with yaw
4	motor	9	inlet air
5	inlet bell		

Figure D.1 — Static Pressure Probe Locations

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D.3.4 Fan Driver Power

Test measurements are made at the input power using a wattmeter. Record this on an airflow test form data-sheet.

D.3.5 Air Velocity

D.3.5.1 Determining Plane of Velocity Measurements

Air velocity measurements should be taken in a plane parallel to the fan. For a forced--draftdraught unit, this plane should be below the fan, as close as possible to the fan ring or inlet bell to negate the effects of ambient wind. For an induced--draftdraught unit, this plane should be above the fan, as close to the fan as possible to negate the effects of ambient wind.

The anemometer is held parallel to the plane of the fan during the reading. This velocity reading can be affected by the yaw of the fan. If the angle between the observed direction of air flow and the anemometer axis is more than 5 degrees, it is necessary to make corrections to the velocity readings. See paragraph D.4.2.2.

D.3.5.2 Determining Location of Velocity Measurements

It is necessary to take the air velocity at several locations within this plane, as flow is not uniform throughout the fan diameter. Measurements should be taken in four quadrant traverses at 90 degree angles from each other. The location of the traverse may be rotated ± 5 degrees to avoid beams or other obstructions that can affect airflow measurements. The number of measurements per traverse can be determined using Table D.2. The plane with locations of the measurement points is shown in Figure D.2 for five velocity bands. D.4.2.1 shows the calculation to determine the area of each velocity band, and the distance in from the fan ring at which each of the velocity measurements should be taken.

Table D.2 — Location of Measurement Points

Fan Diameter *D* m (ft)	Number of Measurements per Quadrant (also Number of Velocity Bands Created)
≤ 1.2 (≤ 4)	3
≤ 1.8 (≤ 6)	4
≤ 4.9 (≤ 16)	5
≤ 6.1 (≤ 20)	6
≤ 7.3 (≤ 24)	7

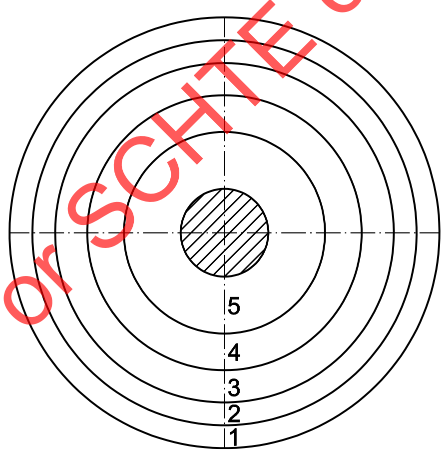

Figure D.CC.C.C.211 — Location of Measurement Points

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Field Code Changed

D.3.5.3 Test

Anemometer should be placed at each location for no less than 30 s to determine average velocity reading. Record this on an airflow test form data-sheet.

D.4 Calculations

D.4.1 Symbols

A_{BAND} Area enclosed in each velocity band

A_{FR} Area inside the fan ring

A_{NET} Net free area

A_{SD} Area of seal disc (or hub plate if there is no seal disc)

D_{FR} Diameter of the fan ring

D_{SD} Diameter of the seal disk

F_{DES} Designed volumetric airflow

F_{MEAS} Volumetric airflow

F_{CORR} Volumetric airflow corrected for density

e Air-Cooled Heat Exchanger (ACHE) manufacturer's power exponent (typically ranges from 2.7 to 3.2)

h Hydraulic head (determined by ACHE manufacturer, typically ranges from 1.7 to 2.2)

L_{MP} Distance from fan ring to measuring point

N_{bands} Number of velocity bands (selected using Table D.2)

η_{ACHE} Efficiency of the fan, including motor and drive losses

η_{DRIVE} Efficiency of the drive

η_{MOTOR} Efficiency of the motor

η_{TOT}	Total efficiency of the fan
η_{STATIC}	Static efficiency of the fan
P_{DES}	Static pressure, design
P_{MEAS}	Static pressure, measured
P_{TOT}	Total pressure, measured
ρ_{DESIGN}	Design density
ρ_{MEAS}	Density
R_{BAND}	Radius from center of fan to center of velocity ring
θ	Angle of yaw (offset of flow direction from vertical axis of measurement)
V_{AVG}	Average of all velocity measurements taken (12 for 3 velocity bands, 16 for 4 bands, etc.)
V_{CORR}	Velocity corrected for yaw
V_{MEAS}	Velocity
W_{MEAS}	Power
π	Constant, equal to 3.1415926

D.4.2 Equations

D.4.2.1 Determining Location of Air Velocity Measurements

$$A_{FR} = \pi \times D_{FR}^2 / 4$$

$$A_{SD} = \pi \times D_{SD}^2 / 4$$

$$A_{NET} = A_{FR} - A_{SD}$$

$$A_{BAND} = A_{NET} / N_{bands}$$

$$R_{BAND1} = \sqrt{[(A_{FR} - 0.5\, A_{BAND}) / \pi]}$$

$R_{BAND2} = \sqrt{[(A_{FR} - 1.5\, A_{BAND}) / \pi]}$

$R_{BAND3} = \sqrt{[(A_{FR} - 2.5\, A_{BAND}) / \pi]}$

$R_{BAND4} = \sqrt{[(A_{FR} - 3.5\, A_{BAND}) / \pi]}$

$R_{BAND5} = \sqrt{[(A_{FR} - 4.5\, A_{BAND}) / \pi]}$

$R_{BAND6} = \sqrt{[(A_{FR} - 5.5\, A_{BAND}) / \pi]}$

$R_{BAND7} = \sqrt{[(A_{FR} - 6.5\, A_{BAND}) / \pi]}$

$L_{MP} = 0.5\, D - R_{BAND}$

D.4.2.2 Correcting for Yaw

It is generally recognized that velocity measurements having less than 5 degree yaw produce results within 1 % uncertainty, which should be acceptable for testing within the context of this annex. For desired accuracies greater than 1 %, or for corrections of yaw angles greater than 5°, corrections can be made based on the instrument manufacturer's correction-calibration curve or one specially developed by the testing agency.

D.4.2.3 Data Reduction

It is necessary to reduce multiple readings taken over time (wind speed, air temperature), or taken at different locations (static pressure, power, air velocity) to a single set of numbers by arithmetic averaging. If velocity measurements are corrected for yaw, the corrected values should be used to obtain the average.

D.4.2.4 Determining Fan Airflow

$F_{MEAS} = A_{NET} \times V_{AVG}$

D.4.2.5 Absorbed Fan Shaft Power

$W_{FAN} = W_{INPUT} \times \eta_{DRIVE} \times \eta_{MOTOR}$

D.4.2.6 Correcting for Design Conditions

Most often, the testing done at the ~~V~~vendor's facility is not done under the same conditions for which the fan is designed for use in the field. It is likely that the elevation, humidity, or temperature will be different. After the test has been done, these calculations can be used to modify the result to take in to account the density change due to these differences.

Correction to measured airflow rate and horsepower based on differences in air density and fan speed should be ideally made based on the individual fan and ACHE provider calculations where the proper system head matching is made between the fan aerodynamic characteristics and the ACHE hydraulic characteristics. This also includes a correction for differences between design and test pitch.

A method to estimate these corrections can be applied based on the standard fan laws using generalized flow exponents, where a constant blade pitch is assumed, as follows.

Airflow rate correction:

$F_{CORR} = F_{MEAS} \times (P_{DESIGN}/P_{MEAS})^{1/h} \times (\rho_{DESIGN}/\rho_{MEAS}) \times (V_{RPM,DESIGN}/V_{RPM,MEAS})$

Power correction:

$W_{CORR} = W_{FAN} \times (F_{CORR}/F_{MEAS})^{e}$

Project corrected test performance to design flow condition:

$F_{PROJ\text{-}DES} = F_{CORR}$

$W_{PROJ\text{-}DES} = W_{CORR} \times (F_{DES}/F_{CORR})^{e}$

D.4.2.7 Determining Fan Efficiency

$\eta_{STATIC} = (F_{MEAS} \times P_{STATIC}) / (6356 \times W_{FAN})$

$\eta_{TOT} = (F_{MEAS} \times P_{TOT}) / (6356 \times W_{FAN})$

$\eta_{ACHE} = (F_{MEAS} \times P_{TOT}) / (6356 \times W_{INPUT})$

The conversion factor 6356 is used when F is in cubic feet per minute, P is in inches of water, and W is in horsepower.

Annex E
(informative)

Measurement of Noise from Air-cooled Heat Exchangers

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E.1 General

E.1.1 Purpose

This annex gives guidance on standard procedures for measuring and reporting sound-pressure levels (L_p) and sound-power levels (L_W) for air-cooled heat exchangers.

E.1.2 Scope

This procedure applies to air-cooled heat exchangers, including both forced- and induced-draft type units. The procedures are based on testing complete air-cooled exchangers and are not intended for testing individual components such as fans, motors, gears, and so forth. Separate procedures are given for the following types of tests:

a) test of an isolated single-bay air-cooled exchanger for determining sound-power levels and sound-pressure levels in accordance with E.2;

b) test procedures for conducting noise tests on a single bay of installed air-cooled exchangers (normally multi-bay installations) in accordance with E.3.

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E.1.3 Instrumentation

The required instrumentation and applicable specifications that are used to perform the measurements required are shown in Table E.1.

Table E.1 — Required Instrumentation and Applicable Specifications

Instrument	Specification
Sound level meter, including microphone, type I precision	ANSI S1.4
Octave band filter, type E, class II	—
Acoustic calibrator of coupler type	ANSI S1.4-1983 (R2006)
Wind screen	ANSI S1.4-1983 (R2006)

E.1.4 Nomenclature

The symbols and abbreviations are used in this annex are given in Table E.2.

Table E.2 — Symbols and Abbreviations

Abbreviation or Symbol	Definition
B	Measuring distance from surface
D	Fan diameter
dB	Unit of measure for sound level
dB(A)	Decibel weighted to correspond to standard "A" scale
H	Height of geometric center
hp	Horsepower
Hz	Hertz, sound frequency
l	Length of bay
L_p	Sound-pressure level
$\overline{L_p}$	Mean sound-pressure level
$\overline{L_{p,\text{cyl}}}$	Mean sound-pressure level for cylinder
$\overline{L_{p,\text{hemi}}}$	Mean sound-pressure level for hemisphere
L_W	Sound-power level
$L_{W,\text{bay}}$	Sound-power level for test bay
$L_{W\cdot\text{design}}$	Sound-power level at design power
$L_{W\cdot\text{fan}}$	Sound-power level per fan
$L_{W\cdot\text{hemi}}$	Sound-power level for hemisphere
$L_{W\cdot\text{test}}$	Sound-power level at test motor horsepower
N	Number of fans per bay
n	Number of measurement positions per source
P_{test}	Test power
P_{design}	Design power
R	Radius of hemisphere and cylinder
S	Surface area (measurement surface)
S_{o}	Reference area of 1 m^2
W	Width of one bay

E.2 Procedure for Conducting Noise Tests on an Isolated Single Bay

E.2.1 Procedure for Obtaining Noise Test Data

E.2.1.1 Description of Test Set-up

The more accurate noise tests on air-cooled heat exchangers are those that are performed on a single bay without interference from nearby noise or structures. Such accuracy is usually precluded on an operating installation but is attainable at the point of assembly. Units that have typical overall dimensions of from 4 m (13.1 ft) to 6 m (19.7 ft) wide, 7 m (23 ft) to 12 m (39.4 ft) long, 2 m (6.6 ft) to 5 m (16.4 ft) high are discussed here.

For testing, the unit should be supported above grade high enough for reasonable air access during the test. An elevation 3 m (9.8 ft) to 6 m (19.7 ft)from grade to air inlet is usually adequate to minimize ground effects. There are several optional pieces of equipment that influence noise to a negligible degree and such pieces may be omitted from the assembly for noise test purposes. Included in this category are louvers, walkways, and recirculation chambers. (The presence or absence of recirculation walls has little effect on the total noise emitted but can cause noise to be emitted in a different direction or at a different location.)

In many cases, tests are conducted as units and completed immediately prior to shipment. However, if noise levels are critical and a large number of units is involved, consideration should be given to testing a single unit early enough to permit design changes.

E.2.1.2 Test Conditions

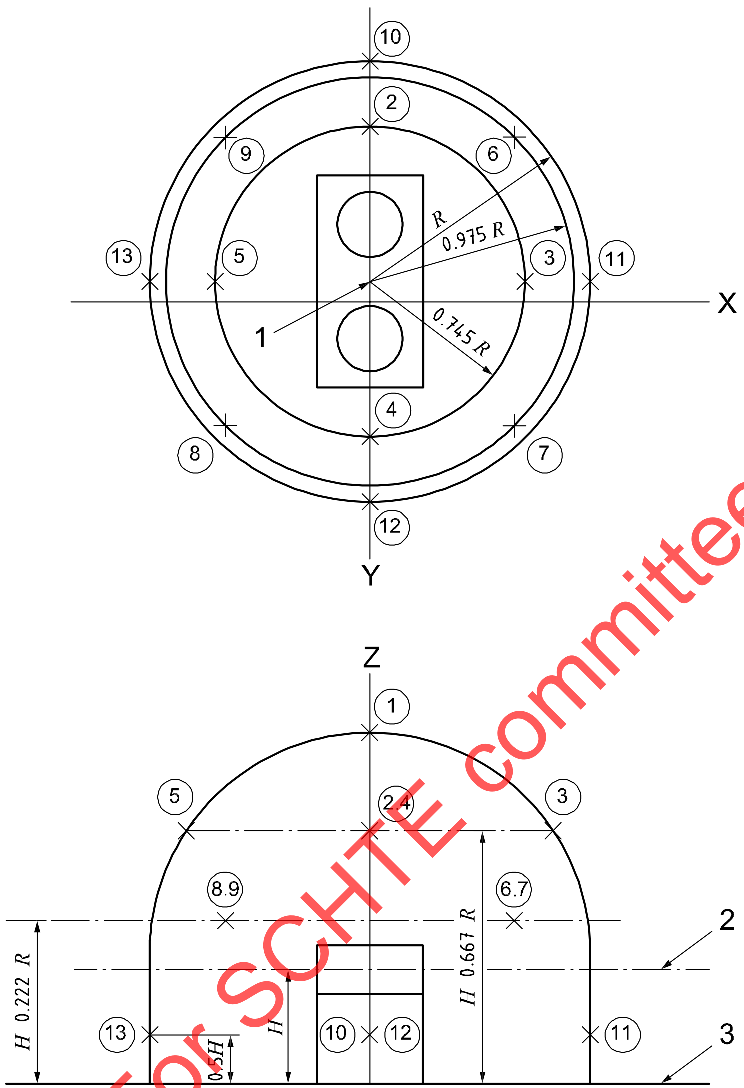
The equipment should be operating as near as is practical to design fan tip speed and motor horsepower. Since It is necessary to run most tests at conditions other than design conditions, it is desirable to agree beforehand on the corrections to make for these variables. If the customer requires, the blade angle can be set to duplicate design horsepower when temperature or elevation differs appreciably from design. Refer to E.2.2.1.1 if it is necessary to make corrections for test conditions that differ from design conditions.

E.2.1.3 Location of Test Measuring Points

A radius of 10 m (32.8 ft) used to define imaginary hemispherical and cylindrical surfaces surrounding the equipment being tested is recommended. The test measuring points should be located on this surface. There should be nine points on the hemisphere and four points on the cylinder. (See Figure E.1 and Table E.3 for the location of these test points.)

The geometric center is located at the center of the unit on a plane midway between the air inlet and air outlet for both forced- and induced-draft units. A radius of 10 m (32.8 ft) is recommended; however the radius can range from 9 m (29.5 ft) to 12 m (39.4 ft) with little effect on results. The test points should be far enough from the equipment to minimize near field distortions, yet near enough to allow positioning the microphone at the various points on the imaginary enclosing surface. All fans should be running during these tests.

In addition to the above readings, which are used to calculate L_W, a set of readings at a single point should be taken below each fan. On forced-draft units, the point should be on a horizontal plane 1 m (3.3 ft) below the lower edge of the fan ring. The maximum reading attainable on this plane should be taken by placing the microphone no closer than 1 m (3.3 ft) from the motor, machinery mount, or other members. On induced-draft units, this measurement point should be on a horizontal plane 1 m (3.3 ft) below the finned tubes. The maximum reading attainable on this plane should be taken while placing the microphone no closer than 1 m (3.3 ft) from the motor, machinery mount, or other members. [The noise meter should be reading dB(A) while finding the maximum noise point.] All fans should be running during these readings. These data are taken for future reference in correlating L_W and sound level data and for estimating noise levels directly below the unit.



Key

1 geometric center

2 geometric center plane

3 grade

× test point location

Figure E.1 — Isolated Single Bay Noise Measurement Points

Table E.3 — Isolated Single Bay Noise Measurement Points

Position	X	Y	Z
1	0.0	0.0	+1.000*R*
2	0.0	+0.745R	+0.667*R*
3	+0.745*R*	0.0	+0.667*R*
4	0.0	-0.745*R*	+0.667*R*
5	–0.745*R*	0.0	+0.667*R*
6	+0.689*R*	+0.689*R*	+0.222*R*
7	+0.689*R*	-0.689*R*	+0.222*R*
8	–0.689*R*	-0.689*R*	+0.222*R*
9	–0.689*R*	+0.689*R*	+0.222*R*
10	0.0	+1.000*R*	–0.500*H*
11	+1.000*R*	0.0	–0.500*H*
12	0.0	–1.000*R*	–0.500*H*
13	–1.000*R*	0.0	–0.500*H*

R indicates the radius: *H* indicates the geometric center plane.

E.2.1.4 Checklist

A noise test is usually run immediately before a unit is shipped. Therefore, it is necessary to perform all required steps and record all pertinent data, since it is impractical to recall the equipment and rerun the test at a later date. The following steps should aid operators in preparing for a test.

a) Prepare all drawings and data forms prior to the test. Lay out the test points in the x, y plane and paint spots on the working surface. Then, it is necessary to measure only the z dimension during the test.

b) Check that all noise test equipment is in working order and calibrated. A discharged battery, a faulty connection or similar problem has invalidated many tests.

c) Check that equipment necessary to position the microphone at all test points is on hand prior to beginning the test.

d) Check the weather forecast. The test should not be run during rain or while winds are above 3 m/s (7 mph).

e) Do a preliminary check of motor amperes and volts to assure the operation of motors near design speed.

f) Start the unit and check it for any unusual noises or problems. Is either fan running backwards? Is there any unusual belt noise, gear noise, motor noise, or bearing noise? Are there any loose parts rattling?

Be aware that toothed sheaves with lobed or toothed belts create a dominant noise in the 1000 Hz to 2000 Hz range.

E.2.1.5 Recording of Data

Prior to recording the data, a preliminary survey should be conducted with the sound level meter on the dB(A) setting. If the noise levels for either the hemisphere or cylinder differ by more than 6 dB(A), either additional measurement positions should be used or the hemisphere and cylinder radius should be increased. If the large difference results from the background noise, it can be necessary to record background noise at each measuring point. If it is not possible to measure the noise emission at a particular point because of high background noise, either the source of the background noise should be reduced or eliminated or the measurement from a similar point may be used. The latter procedure is not recommended; when it is used, the details and the point should be noted in the test report.

Record all data as required on the data sheet (see E.2.3.2 and E.2.3.3). The calibration readings should be recorded at the start and finish of a noise test. Background readings should be taken at every fifth test point (more often if either party feels conditions warrant it). All sound level readings should be taken with the meter set to the "slow" response and with a wind screen over the microphone.

E.2.2 Calculations and Interpretation

E.2.2.1 Reducing Test Data

E.2.2.1.1 Correction for Background Noise

If the test point reading exceeds the background level by more than 10 dB, no correction of the test point reading is required. When the difference between the noise level and the background is less than 3 dB, the measurements have no significance and valid test results cannot be obtained. If the difference between the test point reading and the background level is greater than 3 dB but less than or equal to 10 dB, the measured noise level should be corrected according to Table E.4. This data reduction process is repeated for the overall average value and each octave band reading for all thirteen measurement points on both the hemisphere and cylinder.

Table E.4 — Background Correction Values

Difference (reading minus background)	<3	3	4	5	6	7	8	9	10	>10
Correction, dB	n.a.	–3.0	–2.2	–1.7	–1.3	–1.0	–0.7	–0.6	–0.5	0.0

This data reduction for one measurement point "X" can be demonstrated by an example as follows:

Table E.5 — Background Correction Values — Example for One Measurement Point "X"

Octave band center frequency, Hz	Ave(A)	31.5	63	125	250	500	1000	2000	4000	8000
Background measurement	68.0	63.6	64.8	53.4	53.7	69.1	62.0	52.3	52.8	52.5
Test measurements at point X	80.5	89.1	86.8	81.1	76.4	76.2	71.9	69.2	75.4	71.3

E.2.2.1.2 Determining Mean Sound-pressure Levels

Correct the test point readings at each location for background noise as shown above. Then determine the mean sound-pressure level for both the hemisphere and the cylinder. The mean sound-pressure level values are determined using the following calculations for two different categories.

a) If the maximum difference between the "n" values being averaged is greater than 6 dB, L_p is derived from the following logarithmic averaging:

$$\overline{L_p} = 10 \times \log\left\{\left(1/n\right) \times \sum\left[\log^{-1}\left(L_{p,n}/10\right)\right]\right\}$$

b) If the maximum difference between the "n" values to be averaged is 6 dB or less, L_p can be optionally derived from the following, simplified arithmetic averaging:

$$\overline{L_p} = \sum\left(L_{p,n}/n\right)$$

This should be done for both the hemisphere and the cylinder such that the following mean sound-pressure levels are determined:

c) $\overline{L_{p,\text{hemi}}}$, where n = 9 test points

$\overline{L_{p,\text{cyl}}}$, where n = 4 test points

E.2.2.1.3 Calculate Sound-power Level

Convert the representative $\overline{L_p}$ to L_W. This is done separately for the hemisphere and for the cylinder using the following expression.

$$L_W = \overline{L_p} + \left[10 \times \log\left(S/S_o\right)\right]$$

where

S is the surface area of the hemisphere or cylinder, in square meters;

S_o is the reference area of 1.0 m^2;

A_{hemi} is the area of the hemisphere in square meters, equal to 6.28 x R^2;

A_{cyl} is the area of the cylinder in square meters, equal to 6.28 x R x H;

The following individual L_W levels are then determined:

$L_{W\cdot\text{hemi}}$ for $S = A_{\text{hemi}}$

$L_{W\cdot\text{hemi}}$ for $S = A_{\text{cyl}}$

The total L_W for the test bay is then arrived at by logarithmic addition:

$$L_{W\cdot bay} = 10 \times \log \{[\log^{-1}(L_{W\cdot hemi}/10) + \log^{-1}(L_{W\cdot cyl}/10)\}$$

The sound-power level per test fan can then be backed out for reference purposes as follows:

$$L_{W\cdot fan} = L_{W\cdot bay} - 10 \times \log(n)$$

where

n is the number of fans per bay actually operating during the test.

E.2.2.1.4 Design Versus Test Horsepower

Since a test is seldom run with the motor at design horsepower, it is necessary to adjust test conditions to design conditions.

If a watt meter or plant power factor data are not available, the following approximation for test horsepower can be used:

To convert sound-power level calculated at test motor horsepower ($L_{W\cdot test}$ at P_{test}) to predicted sound-power level at design power ($L_{W\cdot design}$ at P_{design}) use the following equation:

$$L_{W\cdot design} = L_{W\cdot test} + 10 \times (\log P_{design} - \log P_{test})$$

Test horsepower should be within 15 % of design horsepower to use this equation.

E.2.2.2 Application of Reduction Procedures

E.2.2.2.1 Background Noise

Adjust test point readings for background noise level. Prepare a tabulation of adjusted values for each position. The example in Table E.4 illustrates the procedure.

E.2.2.2.2 Sound-pressure Level

Consider a test in which an imaginary cylinder has the following dimensions: R equals 10 m and H equals 4.88 m with adjusted test point readings of 81.9 dB, 74.8 dB, 80.8 dB, and 75.4 dB in one octave band and adjusted test point readings of 51.8 dB, 53.8 dB, 52.9 dB, and 52.3 dB in another octave band.

In the first case, the maximum difference in values being averaged is 7.1 (81.9 – 74.8); therefore, the representative L_p equals 79.3.

In the second case, the maximum difference in values to be averaged is 2.0 (53.8 – 51.8); therefore, the representative L_p equals 52.7.

E.2.2.2.3 Sound-power Level

Convert representative L_p for the cylinder in the first case to L_W. From E.2.2.2.2, L_p equals 79.3 dB.

$$L_W = L_p + 10 \log(2\pi RH)$$

$$= 79.3 + 10 \log(2 \times \pi \times 10 \times 4{,}88)$$
$$= 79.3 + 10 \log 306{,}6$$
$$= 79.3 + 24{,}9$$

$= 104.2$ dB

Determine the sound-power level per bay, assuming that the hemispherical sound-pressure level equals 106 and the cylindrical sound-pressure level equals 104.2.

$$L_{W\text{,bay}} = 10 \log (6.6114 \times 10^{10})$$
$$= 10 \times 10.82$$
$$= 108.2 \text{ dB}$$

Determine the sound-power level per fan in a two-fan bay if the sound-pressure level per bay is 108.2.

$$L_W = 108.2 – 10 \log 2$$
$$= 108.2 – 3$$
$$= 105.2 \text{ dB}$$

E.2.2.2.4 Design Versus Test Horsepower

If nameplate horsepower is 25 (18.4 kW), nameplate voltage is 460, nameplate amperage is 31, test voltage is 470, and test amperage is 27, then test horsepower is 22.3 (16.4 kW).

If design horsepower is 23.7 (17.4 kW), test horsepower is 22.3 (16.4 kW), and test sound-power level per fan is 105.2 dB, determine adjusted sound-power level per fan at design horsepower.

$$L_{W\text{,design}} = 105.2 + 10 (\log 23.7 – \log 22.3)$$
$$= 105.2 + 10 (1.3747 – 1.3488)$$
$$= 105.2 + (10 \times 0.0264)$$
$$= 105.5 \text{ dB}$$

E.2.3 Reporting of Data

E.2.3.1 General Requirements

The noise test report should include a summary sheet with the main results, a description of the equipment tested, and the noise test data.

E.2.3.2 Summary

The summary should make reference to this standard.

The principal results of the test should be reported on one sheet. These results should be supported by the test data, calculations and sketches. All calculations and interpretation of data should be in accordance with E.2.2. The calculations should be appended to the noise test report.

The test results should include the following.

a) The overall sound-power levels and the octave band sound-power levels should be tabulated.

b) Measurements taken at special locations for future reference in correlating sound-power level and sound level data and for estimating noise levels below the unit should be shown separately.

c) Corrected and uncorrected noise levels should be reported.

E.2.3.3 Requirements for Data Sheets

Data sheets should include the following.

a) A sketch of the test layout and microphone locations should be provided. Special measuring locations should be noted on the sketch.

b) A description of the equipment tested and its operating conditions should be provided.

c) Details of the measuring equipment including make, model, and serial number should be recorded.

d) A tabulation of all test data [dB(A) and octave band sound-pressure levels] should be provided, which includes:

— sound level measurements at each test point;

— background sound level measurements at selected points;

— sound level measurements at special locations.

E.3 Procedure for Conducting Noise Tests on Installed Units

E.3.1 Procedure for Obtaining Noise Test Data

E.3.1.1 Description and Requirements of Test

In E.3 is covered procedures for noise testing on installed units. However, it should be noted that a more accurate test procedure for the determination of noise levels of air-cooled heat exchangers is given in E.2. The procedure in E.2 is usually not satisfactory for application on installed air-cooled heat exchangers in operating plants.

The test procedure outlined in E.2 is ideally suited for shop test situations and employs measurements of sound-pressure levels of an imaginary hemisphere and cylinder having a radius of about 10 m (32.8 ft). This large measuring distance, 10 m (32.8 ft), is impractical for installed exchanger situations and yields inaccurate results because of noise interference from other operating plant equipment and the measurement location interference of nearby equipment. In order for a noise test procedure for use on installed multi-bay operating units to yield reasonably accurate results, the noise reading locations should:

a) be within easy reach using the sound level meter, microphone (with wind screen), microphone cable, and short extension pole;

b) be 1 m (3.3 ft) from the fan and tube bundle to minimize interference from other plant noise sources; the 1 m (3.3 ft) measuring distance of sound-pressure level reading has been widely used to determine sound-power levels;

c) provide representative average sound-pressure levels for the imaginary projected surface of the fan and tube bundle, at a 1 m (3.3 ft) distance, so that the sound-power level of the individual exchanger and the entire exchanger bank can be determined by calculation;

d) be far enough away from the adjacent exchanger bays so that the background noise level is a minimum of 3 dB (preferably 6 dB) below the level of the test bay. It is normally necessary to shut down the adjacent bays to reduce sufficiently the ambient noise level of the test bay in order to yield more accurate results.

The following noise test procedure for installed operating equipment to determine sound- power levels should yield an accuracy of plus or minus 3 dB compared to the more accurate shop test procedure in E.2. The degree of accuracy is heavily influenced by the background noise level at the time of the test. Every effort should be made to reduce background noise levels to a minimum by making the test before plant start-up or by shutting down adjacent exchangers during the test.

The test accuracy can be detrimentally affected when the air-cooled heat exchanger is located very close to grade or directly adjacent to buildings. These situations increase the sound- pressure levels because sound reflection causes erroneous readings.

E.3.1.2 Test Conditions

The equipment should be operating as near as is practical to design fan tip speed and motor horsepower. Since it is necessary to run most tests at conditions other than design conditions, it is desirable to agree beforehand on the corrections to make for these variables. For example, the blade angle can be set to duplicate design horsepower. (Refer to E.3.2.2.1 if It is necessary to make corrections because test conditions differ from Design conditions.)

E.3.1.3 Location of Test Measuring Points

Figure E.2 and Figure E.3 show the recommended measuring locations for induced- and forced-draft unit applications, respectively.

To avoid excessive noise contribution from the fan drive, the microphone should be placed no closer than 1 m from the motor, machinery mounts, or other members.

E.3.1.4 Checklist

A noise test on operating equipment should usually be run over a short period of time, particularly if adjacent operating bays are shut down to reduce background noise for improved test accuracy. Therefore, the recording of all pertinent data should be accomplished as quickly as possible.

The following steps should aid operators in preparing for tests.

a) Prepare all drawings and data forms prior to the test.

b) Check that all noise test equipment is in working order and calibrated. A discharged battery, a faulty connection, or similar problem has invalidated many tests.

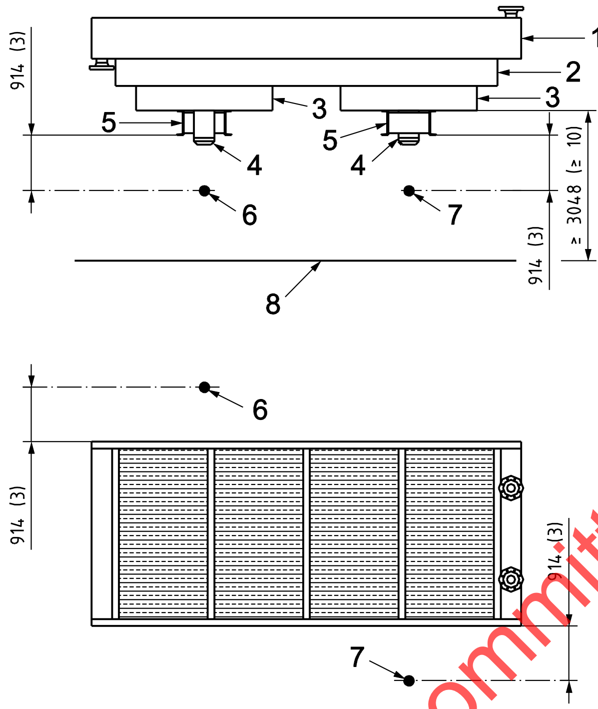
c) Check that equipment necessary to position the microphone at all test points is on hand prior to beginning the test.

d) Check the weather forecast. The test should not be run during rain or while winds are above 3 m/s (7 mph).

e) Do a preliminary check of motor amperes and volts to assure the operation of motors near design speed.

f) Check the unit for any unusual noises or problems. Is there any unusual belt noise, gear noise, motor noise, or bearing noise? Are there any loose parts rattling?

Dimensions in millimeters (feet)



Key

1 plenum side frame
2 plenum
3 fan ring
4 motor
5 machinery mount
6 measurement location #1
7 measurement location #2
8 ground level

Figure E.2 — L_p Measurement Locations — Forced -draft~~Draught~~ Unit (2-fan Bay)

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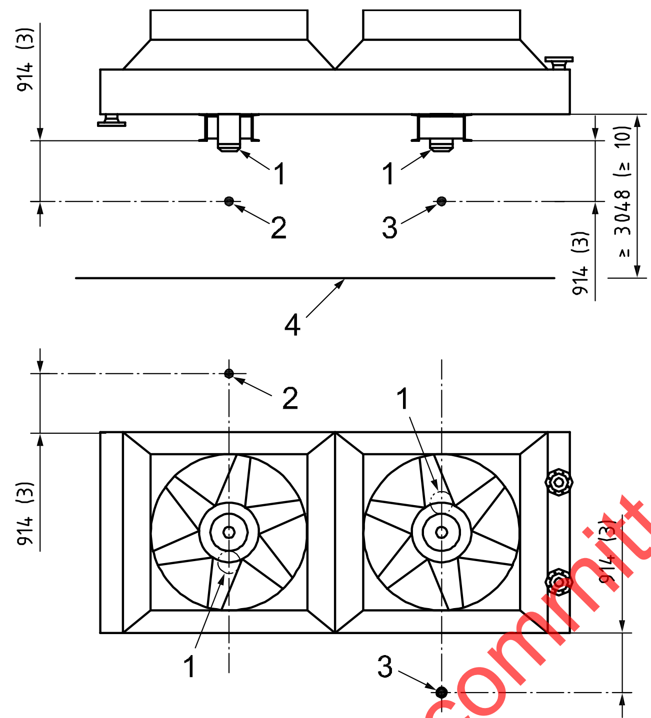
g) Check that there are no intermittent noise sources or steam leaks adjacent to the test location that can cause inaccurate test readings.

h) Be aware that toothed sheaves with lobed or toothed belts create a dominant noise in the 1 000 Hz to 2 000 Hz range.

E.3.1.5 Recording of Data

Prior to recording the data, a preliminary survey should be conducted with the sound level meter on the dB(A) setting. If the noise levels differ by more than 6 dB(A) across any radiating surface, additional measurements should be taken. A subjective impression by ear should be made to decide whether the noise is from the source under test or another source. If it is not possible to obtain valid noise data from a particular surface because of background noise, it will be necessary to reduce or eliminate the source of the background noise. The only other option is to conduct the test on another bay of identical design and construction.

Dimensions in millimeters (feet)



Key

1 motor

2 measurement location #1

3 measurement location #2

4 ground level

Figure E.3 — L_p Measurement Locations — Induced -draftDraught Unit (2-fan Bay)

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Record all data as required on the data sheet (see E.3.3). The calibration readings should be recorded at the start and finish of a noise test. Background readings should be taken at points 1, 4, 5, and 8 and at additional locations if conditions warrant. All sound level readings should be taken with the meter set to the "slow" response and with a wind screen over the microphone.

E.3.2 Calculations and Interpretation

E.3.2.1 Reducing Test Data

E.3.2.1.1 Correction for Background Noise

If the overall test point reading exceeds the background level by more than 10 dB, no correction of the test point reading is required. When the difference between the noise level and the background is less than 3 dB, the measurements have no significance and valid test results cannot be obtained. If the difference between the test point reading and the background level is greater than 3 dB but less than or equal to 10 dB in any octave band center frequency, the measured noise level should be corrected according to Table E.6.

This procedure is explained by way of the following example:

Table E.6 — Background Noise Correction Values

Difference (reading minus background)	<3	3	4	5	6	7	8	9	10	>10
Correction, dB	n.a.	–3.0	–2.2	–1.7	–1.3	–1.0	–0.7	–0.6	–0.5	0.0

This data reduction for one measurement point "X" can be demonstrated by an example as shown in Table E.7.

Table E.7 — Background Noise Correction Values — Example Using One Measurement Point "X"

Octave band center frequency, Hz	Ave(A)	31.5	63	125	250	500	1000	2000	4000	8000
Background measurement	68.0	63.6	64.8	53.4	53.7	69.1	62.0	52.3	52.8	52.5
Test measurements at point X	80.5	89.1	86.8	81.1	76.4	76.2	71.9	69.2	75.4	71.3

Table E.8 — Background Noise Correction Values — Example Using Measurement Point "*n*"

Octave band center frequency, Hz	Ave(A)	31.5	63	125	250	500	1000	2000	4000	8000
Background measurement	68.0	63.6	64.8	53.4	53.7	69.1	62.0	52.3	52.8	52.5
L_p **Measurements at point "*n*"**	80.5	89.1	86.8	81.1	76.4	76.2	71.9	69.2	75.4	71.3
Measurement minus background	12.5	25.5	22.0	27.7	22.7	7.1	9.9	16.9	22.6	18.8
Correction for background	0.0	0.0	0.0	0.0	0.0	–1.0	–0.6	0.0	0.0	0.0
Background-corrected L_p	80.5	89.1	86.8	81.1	76.4	75.2	71.3	69.2	75.4	71.3

E.3.2.1.2 Determining Mean Sound-pressure Levels

Adjust test point readings at each location for background noise. Determine L_p for both fans and bundles for the overall dB(A) plus each of the nine frequencies.

The mean sound-pressure level values are determined using the following equations.

If the maximum difference between values being averaged is greater than 6 dB, L_p is derived from the following equation:

$$\overline{L_p} = 10 \times \log \{ (1/n) \times \sum [\log^{-1}(L_{p,n}/10)] \}$$

If the maximum difference between values to be averaged is 6 dB or less, L_p is derived from the following equation:

$$\overline{L_p} = \sum [L_{p,n}] / n$$

E.3.2.1.3 Sound-power Level

Convert the mean sound-pressure levels to sound-power levels. This is done for each of the nine frequencies plus the overall dB(A) and is done separately for each fan and bundle. To convert L_p to L_W, use the following equation:

$$L_W = L_p + 10 \log (S/S_o)$$

where

S is the projected surface area as defined in Figure E.2 and Figure E.3, expressed in square meters;

S_o is a reference area of 1 m^2.

Be aware that the 20 degree divergence angle is an empirical means of causing the near field test results to match closely with the far field test results.

$$A_{fans} = N (\pi/4) [D + (2 \times \tan 20° \times B)]^2$$

$$= N (3.1416/4) [D + (1.73 \times B)]^2$$

Sound-power level per bay equals the sum of L_W for fans plus bundles.

To add L_W, sound-power level per fan can be determined as follows:

$$L_{W\cdot fan} = L_{W\cdot bay} - 10 \log N$$

E.3.2.1.4 Design Versus Test Horsepower

Since a test is seldom run with the motor at design horsepower, it is necessary to adjust test conditions to design conditions. In most cases, the following approximation for test horsepower can be used:

To convert sound-power level calculated at test motor horsepower ($L_{p\cdot test}$ at P_{test}) to predicted sound-power level at design power ($L_{W\cdot design}$ at P_{test}) use the following equation:

$$L_{W\cdot design} = L_{W\cdot test} + 10 (\log P_{design} - \log P_{test})$$

Test horsepower should be within 15 % of design horsepower to use this equation.

E.3.2.2 Application of Reduction Procedures

E.3.2.2.1 Background Noise

Adjust test point readings for background noise level. Prepare a tabulation of adjusted L_p values for each test position. The example in Table E.9 illustrates the procedure.

Table EDD.D.D.11 — Background Noise Correction Values

Field Code Changed

Difference (reading minus background)	<3	3	4	5	6	7	8	9	10	>10
Correction, dB	n.a.	–3.0	–2.2	–1.7	–1.3	–1.0	–0.7	–0.6	–0.5	0.0

This data reduction for one measurement point “X” can be demonstrated by an example as shown in Table E.10.

Table DD.D.D.22 — Background Noise Correction Values — Example Using One Measurement Point “X”

Field Code Changed

Octave band center frequency, Hz)	Ave(A)	31,5	63	125	250	500	1000	2000	4000	8000
Background measurement	68.0	63.6	64.8	53.4	53.7	69.1	62.0	52.3	52.8	52.5
Test measurements at point X	80.5	89.1	86.8	81.1	76.4	76.2	71.9	69.2	75.4	71.3

Table DD.D.D.33 — Background Noise Correction Values — Example Using Measurement Point “*n*”

Field Code Changed

Octave band center frequency, Hz	Ave(A)	31.5	63	125	250	500	1000	2000	4000	8000
Background measurement	68.0	63.6	64.8	53.4	53.7	69.1	62.0	52.3	52.8	52.5
L_p **Measurements at point “*n*”**	80.5	89.1	86.8	81.1	76.4	76.2	71.9	69.2	75.4	71.3
Measurement minus background	12.5	25.5	22.0	27.7	22.7	7.1	9.9	16.9	22.6	18.8
Correction for background	0.0	0.0	0.0	0.0	0.0	–1.0	–0.6	0.0	0.0	0.0
Background-corrected L_p	80.5	89.1	86.8	81.1	76.4	75.2	71.3	69.2	75.4	71.3

E.3.2.2.2 Sound- pressure Level

Consider a test in which the fans have adjusted, overall test point readings of 86,6 dBA, 87,7 dBA, 86,6 dBA, and 85,5 dBA at one point and 88,6 dBA, 82,7 dBA, 90,8 dBA, and 88,6 dBA at another point.

In the first case, the maximum difference in values to be averaged is 2.2 (87.7 – 85.5); therefore, it is not necessary to apply a correction for the background

In the second case, the maximum difference in values being averaged is 8.1 (90.8 – 82.7); therefore, it is necessary to correct for the backgrounds.

E.3.2.2.3 Sound- power Level

Convert L_p for the fans in the first case to L_W. From E.3.2.2.2, L_p equals 86.6 dB. Assume two fans 3.66 m in diameter.

If L_p for the bundle in the first case is 84.7, l equals 9.15 m, and W equals 4.88 m, bundle L_W is

$$L_W = 84.7 + 10 \log (9.15 \times 4.88)$$

$$= 101.2 \text{ dB}$$

Determine the sound- power level per bay.

In the first case, the sound- power level per fan is determined as follows:

$$L_{W\text{,fan}} = 104.3 - 10 \log 2$$

$$= 101.3 \text{ dB}$$

E.3.2.2.4 Design Versus Test Horsepower

If nameplate horsepower is 25, nameplate voltage is 460, nameplate amperage is 31, test voltage is 470, and test amperage is 27.

If design horsepower is 23.7, test horsepower is 22.3, and test L_W per fan is 102.4, determine adjusted L_W per fan at design horsepower:

$$L_{W\text{,design}} = 102.4 + 10 (\log 23.7 - \log 22.3)$$

$$= 102.4 + 0.3$$

$$= 102.7 \text{ dB}$$

E.3.3 Reporting of Data

E.3.3.1 General Requirements

The noise test report should include a summary sheet with the main results, a description of the equipment tested, and the noise test data.

E.3.3.2 Summary

The summary should make reference to this standard.

The principal results of the test are reported on one sheet. These results are supported by the test data, calculations, and sketches which follow. All calculations and interpretation of data should be in accordance with E.3.2. The calculations should be appended to the noise test report. The test results should include tabulated overall sound- power levels and the octave band sound- power levels.

Measurements taken at special locations, such as for hearing conservation purposes or for future reference, should be shown separately. Corrected and uncorrected noise levels should be reported.

E.3.3.3 Requirements for Data Sheets

Data sheets should include the following:

a) sketch of the test layout and microphone locations should be provided; special measuring locations should be noted on the sketch;

b) description of the equipment tested and its operating conditions should be provided;

c) details of the measuring equipment including make, model, and serial number;

d) A tabulation of all test data [dB(A) and octave band sound pressure levels], which should include:

- sound level measurements at each test point;
- background sound level measurements at selected points;
- sound level measurements at special locations.

ANNEX F

(informative)

Viscous and High Pour Point Fluids in Air-cooled Heat Exchangers

F.1 Scope

This annex presents design features and other considerations that contribute to satisfactory functioning of air-cooled heat exchangers operating with viscous and high pour point fluids.

F.2 Viscous and High Pour Point Problem Areas

F.2.1 General

The purposes of ~~F.2~~this annex ~~are~~is as follows:

a) to identify operating concerns for Viscous and High Pour Point Fluids in air-cooled heat exchangers;

b) to outline general design data requirements for Viscous and High Pour Point Fluids and guidelines for supplying such data;

c) to review heat losses and general problem areas;

d) to establish process categories that can require Viscous and High Pour Point Fluids and safety margins for each category.

F.2.2 Main Concerns with Viscous and High Pour Point Fluids

F.2.2.1 Viscous and High Pour Point fluids are generally classified as fluids which have viscosity >~~XX~~10cP or pour points ~~less~~greater than 75~~XX~~°F/~~XX~~24°C. With these fluids, special consideration needs to be given to ensure proper operation due to the physical phenonum of the air cooler. In both situations, the wall of the tube will have a colder process fluid. If not accounted for correctly, the bulk of the fluid may bypass the cold tube wall and result in under cooling of the fluid. Another concern in air coolers is the possibility of maldistribution within the exchanger that can result in increased pressure drop and under cooling within the exchanger.

Viscous fluids typically have laminar thermal boundary layers. These boundary layers result in larger temperature differences between the bulk fluid and the wall. In an air cooler, these differences can have several outcomes.

Depending on the wall temperature compared to the pour point, the fluid on the inside of the tube may solidify, reducing the heat transfer from the bulk fluid to the wall, increase pressure drop down the tube with the reduced flow area, or reduced flow down tube compared to other tubes. In the case where flow down the tube is reduced, the reduction in flow may result in total tube plugging as the process fluid solidifies. The reduced heat transfer efficiency in the tube will result in an decrease in exchanger preformance, resulting in the air cooler oulet temperature increasing. Normal response to hot outlet temperature where the flow rate on the airside is increased via fan control will result in decreased performance as more flow "bypasses" the cold wall temperature.

The base design of an air cooler is parallel flow paths via the multiple tubes in each path. Viscous fluids flowing through these parallel paths with different cooling performance can result in maldistribution between tubes. Tubes with decreased flow can reach the pour point even when the bulk outlet temperature is in an acceptable range. Variation between the flow in parallel tubes can vary drastically and this flow mal-

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distribution is a major factor in many cases of diminished performance of air coolers with viscous and high-oour-point fluids.

Liquids of high viscosity have been one of the more difficult fluids to adequately design for, and this difficulty increases as the ambient temperature decreases.

At present, only general guidelines exist for avoiding such mal-distribution. These guidelines are as follows:

a) The bulk viscosity of the process fluid at the outlet temperature should not exceed 50 mPa·s (50 cP).

b) The ratio of wall viscosity to bulk viscosity should not exceed 3:1.

The following additional factors should be given extra emphasis in both design and fabrication for this type of service.

a) Air-side flow distribution and temperature distribution should be as uniform as possible. External recirculation over only one side can cause non-uniform air flow and air temperature to the bundle. Over the end recirculation or recirculation over both sides should, therefore, be considered.

b) Air bypassing the bundle between the side frames and tubes should be minimized by conforming to a maximum gap of 10 mm (3/8 in.) as specified in 7.1.1.8.

c) Allowable process fluid pressure drop should be high. Pressure drops of 275 kPa (40 psi) or higher are common. The tube diameter and velocity should be established to avoid laminar flow where possible. Since such designs tend to be controlled by the low tube side heat transfer coefficient, utilizing higher pressure drop and higher velocity normally results in an appreciable reduction in required surface area, offsetting the cost of a larger pump.

d) Tube-side flow should be uniformly distributed within the headers. This can require additional nozzles and/or external insulation of the headers.

e) Where laminar flow cannot be avoided, tube inserts should be considered (with the purchaser's approval), to increase turbulence, at the expense of additional pressure drop.

There can be cases in which successful operation can be achieved while violating these guidelines. However, when successful experience is lacking, it is risky to ignore these recommendations. Alternative designs that should be considered include indirect systems and air-cooled heat exchangers with serpentine coils.

~~**From Annex C**~~

~~**F.2.2.2** When a viscous fluid is flowing through a number of parallel paths, local variations in cooling can cause a drastic reduction in velocity in some of the flow paths. This phenomenon is called "unstable flow". Unstable flow is caused when, under certain conditions of bulk viscosity, wall viscosity and pressure drop, the increase in pressure drop resulting from a higher viscosity (caused by the additional cooling allowed by a lower velocity) offsets the decrease in pressure drop resulting from the lower velocity. This can occur only when the fluid is in laminar flow.~~

~~**F.2.2.3** When unstable flow occurs, the velocities in parallel tubes within a pass can differ by as much as 5:1. As a result, the exchanger's overall tube-side pressure drop can increase by up to 100 % and the heat removal can decrease to less than 50 % of that possible if the fluid were equally distributed among the tube paths. This flow mal-distribution is a major factor in many cases of diminished performance of viscous and high-pour-point fluid coolers.~~

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F.2.2.4 Liquids of high viscosity have been one of the more difficult fluids to adequately design for, and this difficulty increases as the ambient temperature decreases.

F.2.2.5 At present, only general guidelines exist for avoiding such mal-distribution. These guidelines are as follows:.

- The bulk viscosity of the process fluid at the outlet temperature should not exceed 50 mPa·s (50 cP).
- The ratio of wall viscosity to bulk viscosity should not exceed 3:1.

F.2.2.6 The following additional factors should be given extra emphasis in both design and fabrication for this type of service.

- Air-side flow distribution and temperature distribution should be as uniform as possible. External recirculation over only one side can cause non-uniform air flow and air temperature to the bundle. Over the end recirculation or recirculation over both sides should, therefore, be considered.
- Air bypassing the bundle between the side frames and tubes should be minimized by conforming to a maximum gap of 10 mm (3/8 in.) as specified in 7.1.1.8.
- Allowable process fluid pressure drop should be high. Pressure drops of 275 kPa (40 psi) or higher are common. The tube diameter and velocity should be established to avoid laminar flow where possible. Since such designs tend to be controlled by the low tube side heat transfer coefficient, utilizing higher pressure drop and higher velocity normally results in an appreciable reduction in required surface area, offsetting the cost of a larger pump.
- Tube-side flow should be uniformly distributed within the headers. This can require additional nozzles and/or external insulation of the headers.
- Where laminar flow cannot be avoided, tube inserts should be considered (with the Ppurchaser's approval), to increase turbulence, at the expense of additional pressure drop.

There can be cases in which successful operation can be achieved while violating these guidelines. However, when successful experience is lacking, it is risky to ignore these recommendations. Alternative designs that should be considered include indirect systems and air-cooled heat exchangers with serpentine coils.

F.2.3 Safety margins

So many variables are involved in the process streams that establishing a fixed safety margin (the tube-wall temperature minus the critical process temperature) is difficult. Each problem should be analyzed on an individual basis.

In the absence of more specific information, the safety margins of 14°C/25°F should be added to the critical process temperature to determine the specified minimum tube-wall temperature.

See Annex C.3 (Methods for Winterization) for guidance on configuring a viscous or high pour point fluid.

Scope

Action: D. Slingerland – Complete section

F.2.4 Guidance

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Annex G
(informative)

Air-cooled Heat Exchanger Datasheets

EDITORS NOTE: THE DATASHEETS INCLUDE ARE IN TABLE FORMAT. THESE WILL BE REVISED AND PRODUCED AS EXCEL FILES. AT THE SAME TIME CHANGES MARKED (AND HIGHLIGHTED) WILL BE INCORPORATED).

The following datasheets are provided to assist designers, vendors, and purchasers in specifying the data necessary for the design of air-cooled heat exchangers for petroleum, petrochemical, and natural gas services. Entries that are not relevant to air-cooled heat exchangers should be annotated as "N/A."

Completion of the datasheet is a joint responsibility of the purchaser and vendor. The purchaser (owner or contractor) is responsible for the process data, which define the purchaser's explicit requirements.

After the exchanger has been fabricated, the vendor should complete the datasheets to make a permanent record that accurately describes the equipment "as-built".

Additional datasheets may be required to define the air-cooled heat exchanger and examples are included in this annex.

— Page 2: Header details, mechanical equipment, controls air-side, and shipping. These are used if the designer/user requires such levels of detail to define the materials for individual components.

~~— Page 3: Additional remarks, sketches, etc.. These are used for additional remarks if sufficient space is not available on page 1, for schematic sketches to illustrate required features of the design and tube lay-outs, and if necessary, to provide this information to the manufacturer.~~

— Page 3: Additional process information necessary if condensing fluids with a range of physical properties occur.

— Page 4: Additional split header box information.

— Page 5: Additional cyclic service design data. This is required only for exchangers where the unit is subject to cyclic service.

— Page 6: Additional noise datasheet.

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Commented [CW102]: These are the old datasheets. To be revised as EXCEL files.
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Commented [CW103]: Kelvion suggested - "Ladders, walk-ways, platforms" has simply "Yes" or "No" tic boxes. The scope should be able to be listed here. I.e., Ladders: Qty, Header Walkways: One End, Both Ends, etc.
For discussion.
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AIR-COOLED HEAT EXCHANGER DATA SHEET (SI UNITS)

Job No.	______	Item No.	______
Page	1 of 2	By	______
Date	______	Revision	______
Proposal No.	______	Contract No.	______
Inquiry No.	______	Order No.	______

Manufacturer	______	Heat exchanged, kW	______
Model No.	______	Surface/item-finned tube, m²	______
Customer	______	Bare tube, m²	______
Plant location	______	MTD, eff., °C	______
Service	______	Transfer rate-finned, W/m²·K	______
Type draft	O Induced O Forced	Bare tube, service, W/m²·K	______
Bay size (W × L), m ______	No. of bay/items ______	Clean, W/m²	______

Basic design data

Pressure design code	______		Structural code	______	
Tube bundle code stamped	O Yes	O No	Flammable service	O Yes	O No
Heating coil code stamped	O Yes	O No	Lethal service	O Yes	O No
			Toxic service	O Yes	O No

Performance data — Tube side

		maximum process operating temperature	In	Out
Fluid name	______	Temperature, °C	______	______
Total fluid entering, kg/h	______	Total flow rate (liq./vap.), kg/h	/	/
Dew/bubble point, °C	/	Water/steam, kg/h	/	/
O Pour point O Freeze point, °C	______	Noncondensable, kg/h	/	/
Latent heat, kJ/kg	______	Relative molecular mass. (vap./non-cond.)	/	/
Inlet pressure O kPa (ga) O kPa (abs)	______	Density (liq./vap.), kg/m³	/	/
Pressure drop (allow./calc.), kPa	/	Specific heat (liq./vap.), kJ/kg·K	/	/
Velocity (allow./calc.), m/s	/	Thermal conductivity (liq/vap.), W/m·K	/	/
Inside foul res., m²·K/W	______	Viscosity (liq./vap.), mPa·s	/	/

Performance data — Air side

Air inlet temperature (design dry bulb), °C	______	Face velocity, m/s	______
Air flow rate/item, (kg/h) (m³/h)	______	Min. design ambient temp., °C	______
Mass velocity (net free area), kg/s·m²	______	Altitude, m	______
Air outlet temperature, °C	______	Static pressure, kPa	______
Air flowrate/fan, m³/h	______		

Design, materials and construction

Design pressure, kPa (ga)	______	**Heating coil**	
Test pressure, kPa (ga)	______	No. of tubes ______	O.D., mm ______
Design temperature, °C	______	Tube material	______
Min. design metal temperature, °C	______	Fin material and type	______
		Thickness, mm	______
Tube bundle add tube-to-tubesheet joint choice		Pressure design code	______
Size (W × L), m	______	Stamp? O Yes	O No
No./bay ______	No. of tube rows ______	Heating fluid ______	Flow, kg/s ______
Bundles in parallel ______	In series ______	Temperature (in/out), °C	/
Structure mounting	O Grade O Pipe rack O Other	Inlet pressure, kPa (ga)	______
Pipe-rack beams (distance C-C)	______	Pressure drop (allow./calc.), kPa	/
Ladders, walkways, platforms	O Yes O No	Design temp., °C, des. press., kPa (ga)	/
Structure surf. prep./coating	______	Inlet/outlet nozzle, DN	/
Header surf. prep./coating	______	**Header**	
Louver to be moved to page 2 and added to other Louver information		Type	______
Material	______	Material	______
Action control:	O Auto O Manual	Corr. allow., mm	______
Action type:	O Opposed O Parallel	No. of passes*	______

* Give tube count of each pass if irregular.

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Commented [SDF104]: J. Allison – Review datasheet for missing technical content. Review 7.1.11.X (before table XX) Also consider specifications for split headers, how many rows, etc.

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Commented [SDF105]: G. Starks – Possible question on what values should be populated into the datasheet

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AIR-COOLED HEAT EXCHANGER DATA SHEET (SI UNITS)

Job No.		Item No.	
Page	2 of 2	By	
Date		Revision	
Proposal No.		Contract No.	
Inquiry No.		Order No.	

Header (continued)	No./bundle ___ Length, m ___
Slope, mm/m ___	Pitch, mm ___
Plug material	Layout ___
Gasket material	**Fin**
Nozzle No. Size, DN Rating and facing	Type ___
Inlet ___ ___ ___	Material ___
Outlet ___ ___ ___	Stock thickness, mm ___
Vent ___ ___ ___	Selection temperature, °C ___
Drain ___ ___ ___	O.D., mm. ___ No./m ___
Misc. conn's: TI ___ PI ___	Customer specification ___
Chemical cleaning ___	Unfinned area of extruded finned tube ends protected by: metallizing / sleeves / coating
Min. wall thickness, mm ___	
Tube	
Material ___	
O.D., mm. ___ Min. wall thickness, mm. ___	

Mechanical equipment

Fan	Speed, r/min ___ Service factor ___
Manufacturer & model ___	Enclosure ___
No./bay ___ Speed, r/min ___	Volt ___ Phase ___ Cycle ___
Diameter, m ___ No. of blades ___	Fan noise level (allow./calc.), dB(A), @m ___ / ___
Angle ___	
Pitch adjustment: O Manual O Auto	**Speed reducer**
Blade material ___ Hub material ___	Type ___
kW/fan.@des.temp. ___ @min.amb. ___	Manufacturer & model ___
Max. allow./calc.tip speed, m/s ___ / ___	No./bay ___
	Service factor ___ Speed ratio ___ /1
Driver	Support: O Structure O Pedestal
Type	Vibration Monitoring device: O Yes - Type O No
Manufacturer & model ___	Enclosure ___
No./bay ___ Driver kW ___	

Controls air-side

Air recirculation: O None O Internal O External	**Louvers:** O Inlet O Outlet O Bypass
Over: O Side O End add both sides and both ends	Positioner: O Yes O No
Degree control of outlet process temp.	Signal air pressure, kPa (ga)
(max. cooling), +/– °C ___ / ___	From ___ To ___
Action on control signal failure ___	From ___ To ___
Fan pitch: O Minimum O Maximum O Lockup	Supply air pressure, kPa (ga)
Louvers: O Open O Close O Lockup	Max. ___ Min. ___
Actuator air supply ___	Max. ___ Min. ___
Fan: O None O Positioner O Bias relay	

Shipping

Plot area (W × L), m ___	Total ___
Bundle mass, kg ___	Shipping, kg ___
Bay ___	Add additional rows for miscellaneous information

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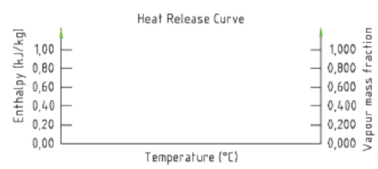
Company	HAIRPIN HEAT EXCHANGER ADDITIONAL PROCESS INFORMATION DATASHEET (SI UNITS)	Engineering contractor
P.O. No.:	Doc. No.:	Page 4 of

1	Client:	Location:
2	Process unit:	Item No.:
3	Job No.:	Fabricator:
4		
5		

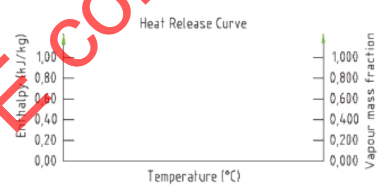
6	Fluid name:		Ref. pressure 1:		kPa (abs)
7	Pressure kPa (abs)	Temp. °C	Enthalpy kJ/kg		Vapour mass fraction
8					
9					
10					
11					
12					
13					
14					
15					



Enthalpy (kJ/kg) —■— Vapour mass fraction

	Density vapour	Density liquid	Viscosity vapour	Viscosity liquid	Thermal conductivity vapour	Thermal conductivity liquid	Specific heat vapour	Specific heat liquid	Surface tension	Liquid critical pressure	Liquid critical temp.
16											
17	kg/m³	kg/m³	mPa·s	mPa·s	W/m·K	W/m·K	kJ/(kg·K)	kJ/(kg·K)	N/m	kPa (abs)	°C
18											
19											
20											
21											
22											
23											
24											

25	Fluid name:		Ref. pressure 2:		kPa (abs)
26	Pressure kPa (abs)	Temp. °C	Enthalpy kJ/kg		Vapour mass fraction
27					
28					
29					
30					
31					
32					
33					
34					
35					



Enthalpy (kJ/kg) —■— Vapour mass fraction

	Density vapour	Density liquid	Viscosity vapour	Viscosity liquid	Thermal conductivity vapour	Thermal conductivity liquid	Specific heat vapour	Specific heat liquid	Surface tension	Liquid critical pressure	Liquid critical temp.
36											
37	kg/m³	kg/m³	mPa·s	mPa·s	W/m·K	W/m·K	kJ/(kg·K)	kJ/(kg·K)	N/m	kPa (abs)	°C
38											
39											
40											
41											
42											
43											
44											

Rev. No.	Description	Date	Prepared by	Reviewed by

AIR-COOLED HEAT EXCHANGER ADDITIONAL PROCESS INFORMATION DATA SHEET (SI UNITS)		
	Job No.	Item No.
	Page: 1 of 1	By
	Date	Revision
	Proposal No.	Contract No.
	Inquiry No.	Order No.

1 DESIGN CONSIDERATIONS FOR EVALUATION OF SPLIT HEADER REQUIREMENT

	Case[a]	Process Side				Air Side	
		Flow Condition[b]	Fluid Temperature		Pressure[d]	Flow Conditions[b]	Fluid Temperature
			Inlet	Outlet[c]			Inlet
			°C	°C	kPa (ga)		°C
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							

20 Additional operating conditions provided should consider restraint relief requirements of 7.1.6.1.3

21 a A case which may affect header design (e.g. steam-out, upset, etc.).

22 b F = flowing (specify flow rate), S = stagnant, E= empty

23 c Outlet temperature if known, thermal designer determines for other conditions

24 d Specify design pressure for operating conditions. Use maximum actual pressure at other conditions

25 Notes

26

38

27

40

Commented [SDF106]: Need to update DS to include process conditions (from API 660). Action: D. Slingerland

Commented [SDF107]: Need to update datasheet to indicate the type of control system used on the air cooler (i.e. VFD, on/off). Action: J. Allison

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Commented [SDF108]: Add comment/reference to 7.1.6.1.3. Action: D. Slingerland

AIR-COOLED HEAT EXCHANGER CYCLIC DATA SHEET (SI UNITS)

Job No.	Item No.
Page: 1 of 1	By
Date	Revision
Proposal No.	Contract No.
Inquiry No.	Order No.

Description of Cyclic Service Operation

Condition	Time (h/min)	Duration (h/min)	Composition	Flow rate (kg/h)
Initial	0.0			

Condition	Time (h/min)	Duration (h/min)	Temperature (°C)	Pressure [kPa(g)]
Initial	0.0			

Notes

AIR-COOLED HEAT EXCHANGER NOISE DATA SHEET	Job No. ______ Item No. ______ Page: 1 of 1 By ______ Date ______ Revision ______ Proposal No. ______ Contract No. ______ Inquiry No. ______ Order No. ______

1	Noise data	Purchaser specification	Purchaser specification	Vendor guarantee	Vendor guarantee
2	Octave bands center	L_p at designated location	L_W per fan	L_p at designated location	L_W per fan
3	63				
4	125				
5	250				
6	500				
7	1000				
8	2000				
9	4000				
10	8000				
11	dB(A)				
12	Overall unit L_W				
13	dB(A)				
14	Unless otherwise specified: L_p is the sound pressure level measured in dB, reference 2×10^{-5} N/m^2. L_W is the sound power level measured in dB, reference 1×10^{-12} W. For forced-draft fns, the L_p is measured at the centerline of the fan 1 m below the inlet of the fan. For induced-draft fans, the L_p is measured 1 m below the bundles. Noise of equipment shall include noise from speed reducer and motor. The upper tolerance for noise levels is 0 dB(A). Tonal noise is defined as having a single octave band equal to more than 6 dB above the adjacent bands. If tonal noise is present, then the specified overall noise levels shall be interpreted as 5 dB(A) more stringent.				
15	Description of designated location:				
16	Specification of special requirements (with/without acoustic measures, special low-noise fans):				
17					
18					
19					
20					

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AIR-COOLED HEAT EXCHANGER DATA SHEET (US CUSTOMARY UNITS)

Job No.		Item No.	
Page	1 of 2	By	
Date		Revision	
Proposal No.		Contract No.	
Inquiry No.		Order No.	

Manufacturer		Heat exchanged, Btu/h	
Model No.		Surface/item-finned tube, ft^2	
Customer		Bare tube, ft^2	
Plant location		MTD, eff., °F	
Service		Transfer rate-finned, Btu/(h·ft^2·°F)	
Type draft O Induced O Forced		Bare tube, service, Btu/(h·ft^2·°F)	
Bay size (W × L), ft	No. of bay/items	Clean, Btu/h·ft^2·°F	

Basic design data

Pressure design code		Structural code	
Tube bundle code stamped	O Yes O No	Flammable service	O Yes O No
Heating coil code stamped	O Yes O No	Lethal/toxic service	O Yes O No

Performance data — tube side

			In	Out
Fluid name		Temperature, °F		
Total fluid entering, lb/h		Total flow rate (liq./vap.), lb/h	/	/
Dew/bubble point, °F	/	Water/steam, lb/h	/	/
O Pour point O Freeze point, °F		Noncondensable, lb/h	/	/
Latent heat, Btu/lb		Rel molecular mass (vap./non-cond.)	/	/
Inlet pressure O psig O psia		Density (liq./vap.), lb/ft^3	/	/
Pressure drop (allow./calc.), psi	/	Specific heat (liq./vap.), Btu/lb·°F	/	/
Velocity (allow./calc.), ft/s	/	Thermal conductivity (liq/vap.), Btu/(h·ft·°F)	/	/
Inside foul res., h·ft^2·°F/Btu		Viscosity (liq./vap.), cP	/	/

Performance data — air side

Air inlet temperature (design dry-bulb), °F		Face velocity, sfpm	
Air flowrate/item, (lb/h) (scfm)		Min. design ambient temp., °F	
Mass velocity (net free area), lb/h·ft^2		Altitude, ft	
Air outlet temperature, °F		Static pressure, inches water	
Air flowrate/fan, acfm			

Design, materials and construction

Design pressure, psig		**Heating coil**	
Test pressure, psig		No. of tubes	O.D., in.
Design temperature, °F		Tube material	
Min. design metal temperature, °F		Fin material and type	
		Thickness, in.	
Tube bundle		Pressure design code	
Size (W × L), ft		Stamp? O Yes O No	
No./bay	No. of tube rows	Heating fluid	Flow, lb/h
Bundles in parallel	In series	Temperature (in/out), °F	/
Structure mounting	O Grade O Pipe rack O Other	Inlet pressure, psig	
Pipe-rack beams (distance C-C)		Pressure drop (allow./calc.), psi	/
Ladders, walkways, platforms	O Yes O No	Design temp., °F, des. press., psig	/
Structure surf. prep./coating		Inlet/outlet nozzle, nps	/
Header surf. prep./coating		**Header**	
Louver		Type	
Material		Material	
Action control:	O Auto O Manual	Corrosion allow., in.	
Action type:	O Opposed O Parallel	No. of passes*	

* Give tube count of each pass if irregular.

AIR-COOLED HEAT EXCHANGER DATA SHEET (US CUSTOMARY UNITS)

Job No.		Item No.	
Page	2 of 2	By	
Date		Revision	
Proposal No.		Contract No.	
Inquiry No.		Order No.	

Header (continued)

Slope, in./ft ______

Plug material

Gasket material

Nozzle	No.	Size, NPS	Rating and facing
Inlet			
Outlet			
Vent			
Drain			

Misc. conn's: TI ______ PI ______

Chemical cleaning ______

Min. wall thickness, in. ______

Tube

Material ______

O.D., in. ______ Min. wall thickness, in ______

No./bundle ______ Length, ft ______

Pitch, in. ______

Layout ______

Fin

Type ______

Material ______

Stock thickness, in. ______

Selection temperature, °F ______

O.D., in. ______ No./in. ______

Customer specification ______

Mechanical equipment

Fan

Manufacturer and model ______

No./bay ______ Speed, rpm ______

Diameter, ft ______ No. of blades ______

Angle ______

Pitch adjustment: O Manual O Auto

Blade material ______ Hub material ______

kW/fan.@des.temp. ______ @min.amb. ______

Max. allow./calc.tip speed, fpm ______ / ______

Driver

Type

Manufacturer and model ______

No./bay ______ Driver hp ______

Speed, r/min ______ Service factor ______

Enclosure ______

Volt ______ Phase ______ Cycle ______

Fan noise level (allow./calc.), dB(A) @ft ______ / ______

Speed reducer

Type ______

Manufacturer & model ______

No./bay ______

Service factor ______ Speed ratio ______ /1

Support: O Structure O Pedestal

Vib. switch: O Yes O No

Enclosure ______

Controls air-side

Air recirculation: O None O Internal O External

Over: O Side O End

Degree control of outlet process temp.

(max. cooling), +/– °F ______ / ______

Action on control signal failure ______

Fan pitch: O Minimum O Maximum O Lockup

Louvers: O Open O Close O Lockup

Actuator air supply ______

Fan: O None O Positioner O Bias relay

Louvers: O Inlet O Outlet O Bypass

Positioner: O Yes O No

Signal air pressure, psig

From ______ To ______

From ______ To ______

Supply air pressure, psig

Max. ______ Min. ______

Max. ______ Min. ______

Shipping

Plot area (W × L), ft ______

Bundle mass, lb ______

Bay ______

Total ______

Shipping, lb ______

AIR-COOLED HEAT EXCHANGER ADDITIONAL PROCESS INFORMATION DATA SHEET (US CUSTOMARY UNITS)		
	Job No.	Item No.
	Page: 1 of 1	By
	Date	Revision
	Proposal No.	Contract No.
	Inquiry No.	Order No.

Line							
1	DESIGN CONDITIONS FOR SPLIT HEADER DESIGN						
2	Case[a]	Process Side				Air Side	
3		Flow Condition[b]	Fluid Temperature		Pressure[d]	Flow Conditions[b]	Fluid Temperature
4			Inlet	Outlet[c]			Inlet
5			°F	°F	psig		°F
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21	a	A case which may affect header design (e.g. steam-out, upset, etc.).					
22	b	F = flowing (specify flow rate), S = stagnant, E= empty					
23	c	Outlet temperature if known, thermal designer determines for other conditions					
24	d	Specify design pressure for operating conditions. Use maximum actual pressure at other conditions					
25	Notes						
26							
27							
28							
29							

AIR-COOLED HEAT EXCHANGER CYCLIC DATA SHEET (US CUSTOMARY UNITS)		
	Job No.	Item No.
	Page: 1 of 1	By
	Date	Revision
	Proposal No.	Contract No.
	Inquiry No.	Order No.

Description of Cyclic Service Operation

Condition	Time (h/min)	Duration (h/min)	Composition	Flow rate (lb/h)
Initial	0.0			

Condition	Time (h/min)	Duration (h/min)	Temperature (°F)	Pressure (psig)
Initial	0.0			

Notes

AIR-COOLED HEAT EXCHANGER NOISE DATA SHEET	Job No.	Item No.
	Page: 1 of 1	By
	Date	Revision
	Proposal No.	Contract No.
	Inquiry No.	Order No.

1	**Noise data**	**Purchaser specification**	**Purchaser specification**	**Vendor guarantee**	**Vendor guarantee**
2	Octave bands center	L_p at designated location	L_W per fan	L_p at designated location	L_W per fan
3	63				
4	125				
5	250				
6	500				
7	1000				
8	2000				
9	4000				
10	8000				
11	dB(A)				
12	Overall unit L_W				
13	dB(A)				
14	Unless otherwise specified: L_p is the sound pressure level measured in dB, reference 2×10^{-5} N/m². L_W is the sound power level measured in dB, reference 1×10^{-12} W. For forced-draft fans, the L_p is measured at the centerline of the fan 1 m below the inlet of the fan. For induced-draft fans, the L_p is measured 1 m below the bundles. Noise of equipment shall include noise from speed reducer and motor. The upper tolerance for noise levels is 0 dB(A). Tonal noise is defined as having a single octave band equal to more than 6 dB above the adjacent bands. If tonal noise is present, then the specified overall noise levels shall be interpreted as 5 dB(A) more stringent.				
15	Description of designated location:				
16	Specification of special requirements (with/without acoustic measures, special low-noise fans):				
17					
18					
19					
20					

Company	AIR-COOLED HEAT EXCHANGER SPLIT HEADER BOX INFORMATION DATA SHEET (US CUSTOMARY UNITS)	Engineering contractor
P.O. No.:	Doc. No.:	Page X of

Client:	Location:
Process unit:	Item No.:
Job No.:	Fabricator:

DESIGN CONDITIONS FOR SPLIT HEADER BOX DETERMINATION

Case Descscription [a]	Process Flow Rate [b] (lb/hr)	Process Inlet Temperature [b] (°F)	Ambient Air Temperature (°F)	Air Flow (On / Off)	Maximum Duty Performance (Yes / No)	Controlled Process Outlet Temperature Set-point (°F)	Process Control Method [c]	Air Flow Control Method [d]	Louver Position [e]	Action on Control Failure [f]	Predicted Process Outlet Temperature [g] (°F)	Process Inlet - Outlet Temperature Differential (°F)

Determine the process fluid outlet temperaure and temperature range (peocess inlet temperature minus the outlet temperature) for the consideration of split-header boxes in accordance w the clause (X.X.X).

[a] A case w hich may affect design (e.g. steam-out, upset, pow er failure, turn-dow n, alternate operating case, etc.)

[b] For process conditions not represented by the thermal/hydraulic design basis, the Purchaser shall provide all relevent process data to allow for the case to be evaluated.

[c] None / Hot-flow by-pass / Air flow control

[d] Manual Louvers / Automatic Louvers / Fans On-Off / Fan Tw o Speed (%) / Fan Variable Speed (%)

[e] Open / Closed / Set by control action

[f] Maximum Cooling / Minimum Cooling / Last Position (applies to louver position and/or fan speed control)

[g] Process outlet temperature predicted by the air cooled heat exchanger designer for the operating condition considered.

Notes:

Rev. No.	Revision	Date	Prepared by	Reviewed by

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