Design and Fabrication of Coke Drums and Peripheral Components in Delayed Coking Units

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Table of Contents

Figures

Tables

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Design and Fabrication of Coke Drums and Peripheral Components in Delayed Coking Units

1 Scope

This technical report includes information and guidance on the practices used by industry practitioners in the design and fabrication of coke drums and peripheral components in delayed coking units. The guidance is general and does not reflect specific details associated with a design offered by licensors of delayed coking technology. For details associated with the design offered by a licensor or services provided by contractors, the licensor or contractor should be consulted for guidance and recommendations for their design details and operating guidance. **This document is a technical report and as such, provides generally used practices in the industry and is not an API Recommended Practice for coke drums in delayed coking units.**

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2 Normative References

No other document is identified as indispensable or required for the application of this technical report. A list of documents associated with API 934-G is included in the bibliography.

3 Terms, Definitions, and Acronyms

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For the purposes of this document, the following definitions apply.

3.1 Terms and Definitions

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For the purpose of this technical report, the following definitions apply.

3.1.1
ASME Code
ASME *Boiler and Pressure Vessel Code,* Section II, Parts A though D, Section V, Section VIII, Division 1 and Division 2, and Section IX, including applicable addenda and Code Cases.

3.1.2
final PWHT
The last post weld heat treatment (PWHT) after fabrication of the vessel and prior to placing the vessel in service.

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3.1.3
fracture ductility
The term used to define the limiting ductility before a fracture occurs as a result of low cycle fatigue as modeled using Coffin-Manson techniques. It is typically defined as follows:

$$\text{fracture ductility} = \ln(100/(100 - RA)$$

Commented [BJJ7]: Service temperature

where

RA is the reduction in area during a tensile test.

3.1.4
Larson-Miller Parameter (LMP)
The formula for evaluating the effect time at temperature has on the heat treatment of steel. This same formula can be used to evaluate the effect time at temperature has on the life of stressed equipment operating in the high temperature creep range.

$$LMP = T \times (C + \log t)$$

where

T is the temperature, in K (Kelvin);

t is time, in hours;

C is a constant normally equal to 20 for ferritic steels.

3.1.5
maximum PWHT
Specified heat treatment of test specimens used to simulate all fabrication of heat treatments including austenitizing, tempering, the final PWHT, a PWHT cycle for possible shop repairs, and a number of extra PWHT for future use by the owner/operator.

NOTE To determine the equivalent time at one temperature (within the PWHT range), the Larson-Miller parameter may be used; results are to be agreed upon by the purchaser and manufacturer.

3.1.6
minimum PWHT
Specified heat treatment of test specimens used to simulate the minimum heat treatments (austenitizing, tempering, and one PHWT cycle).

NOTE To determine the equivalent time at one temperature (within the PWHT range), the Larson-Miller parameter formula may be used; results are to be agreed upon by the purchaser and manufacturer.

3.1.7
manufacturer
The recipient of a direct or indirect purchase order for coke drums, materials, fabricated components, or subassemblies used in the construction of coke drums. In this technical report, a direct order is one issued to a manufacturer by a contractor representing the owner/operator or the owner/operator. An indirect order is one issued to a manufacturer by a vendor (recipient of a direct order).

3.1.8
owner/operator
The owner/operator of the delayed coker unit is located where the coke drums are or will be installed. The owner/operator is represented by a group of people responsible for the reliable operation of the coke drums in a specific facility or site.

3.1.9
owner/operator's quality assurance and quality control authority
The owner/operator's technical representative is responsible for implementing and coordinating the quality assurance and quality control program for the construction of coke drums.

3.1.10
shop inspector
An inspector assigned by the owner-operator's QA and QC authority to supervise all shop inspections during the fabrication of the coke drum while following the quality assurance and quality control program.

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3.2 Acronyms

For the purposes of this technical report, the following acronyms apply.

ACFM	alternating current field measurement
AET	acoustic emission testing
CUI	corrosion under insulation
ESW	electroslag welding
FCAW	flux-cored arc welding
GTAW	gas tungsten arc welding
GMAW	gas metal arc welding
HAZ	heat-affected zone
MDMT	minimum design metal temperature
MT	magnetic particle testing (examination)
NDE	nondestructive examination
PT	dye penetrant testing (examination)
PWHT	post-weld heat treatment
RT	radiographic testing (examination)
SAW	submerged arc welding
SMAW	shielded metal arc welding
TOFD	time of flight diffraction
UT	ultrasonic testing (examination)
VI	visual inspection
WPS	welding procedure specification

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4 Background

4.1 General Information

Delayed coking is a form of thermal cracking used for processing “bottom of barrel” residuum, also called resid. Products of the coking process include sour fuel gas, sour liquefied petroleum gas (LPG), naphtha, light coker gas oil (LKGO), heavy coker gas oil (HKGO), and coke. The coking process in the coke drums can be divided into a number of parts including steam out, heat up, warming with vapors from the adjacent drum, feed introduction, coking, steam stripping, water quenching, un-heading, drilling, and reheading. The unit normally takes the same amount of time for coking and decoking with the total cycle varying between 18 and 36 hours. The unit “decoking” cycle is normally defined as the time from steam out to switching into the next drum, which ranges from 9 hours to 18 hours, depending on coke type and facilities. However, with today’s trends, the push is for higher throughputs leading to shorter, more frequent unit cycles. Running 9 to 12 hour decoking and coking cycles are now common. Shorter cycles result in more thermal cycles experienced by a drum within a year. Additionally, these shorter cycles may cause higher thermal stresses on the drum shell, bottom cone, and skirt-to-shell junction during the feed introduction and water quench steps if these steps are shortened as part of reducing the overall cycle time. In addition, the increase in resid feed density is contributing to a denser coke bed, which contributes to the channeling of cool quench water to the hot coke drum wall. Figure 1 shows a typical drum heating and cooling cycle involving drum preheating, heat up and coking, and quenching.

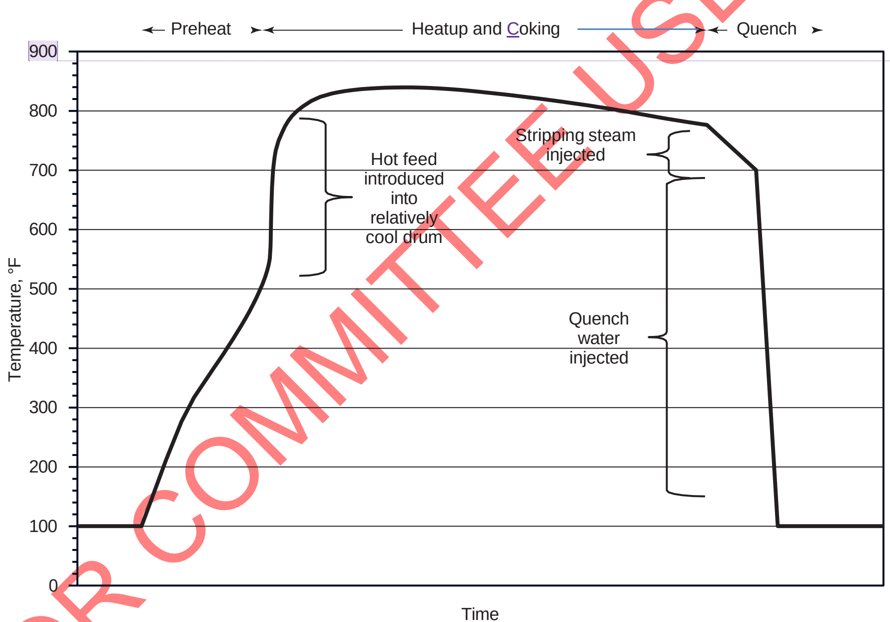

Figure 1—Typical Drum Heating and Cooling Cycle

Delayed coking units produce different forms of coke, such as green or sponge coke and shot coke, both of which are generally poorer grades of coke with higher levels of impurities. These grades are used primarily as fuel in blast furnaces. Higher grades of coke, usually called anode grade and needle coke, are used as carbon anodes in the aluminum and steel industries. Some anode grade coke for use in the aluminum industry is manufactured with a lighter low sulfur resid and a longer, lower temperature on-oil cycle resulting in a less severe cycle for the drums. A significant amount of anode grade coke supplied to the aluminum industry is made from normally-produced sponge coke which is then processed through a calciner unit to reduce impurities to the level needed for anode-grade coke. Anode grade coke used in the steel industry has a “needle” morphology and is manufactured at higher pressures and temperatures, resulting in a harder denser coke that is difficult to cut and remove from the drum.

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Most delayed coking units in service today produce a fuel-grade coke from heavier crudes with higher asphaltene contents. The current operating trend favors severe conditions of higher temperatures, low pressures, and shorter cycles which favor the formation of shot coke which has a spherical shape and varies in size from 5 mm to over 200 mm in diameter. Experience with shot coke indicates it is more difficult to cool and more prone to water channeling through the coke bed during the quench period.

4.2 API Survey of Experience

4.2.1 General

API conducted four surveys related to coke drums (1968, 1980, 1996, and 2013) before the publication of this technical report. The main findings of these surveys reflect the industry's interest in improving the reliability of these drums. The summaries of the survey results are in 4.2.2 through 4.2.5.

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4.2.2 1968 Survey

- Carbon steel drums bulged far more extensively than C-Mo drums before through wall cracks occurred.
- Through wall cracks occurred in the circumferential direction on the drums. They occurred during quenching, steam cooling, or start-up. Although cracks were extensive on many of the drums, none of the reported failures were catastrophic.
- It appeared that thinner vessels had shorter lives.
- The report showed clearly that both C-Mo and carbon steel drums are increasingly embrittled over time. C-Mo appeared to be more sensitive to embrittlement and cracking.

4.2.3 1980 Survey

- Most of the reported cracking was on drums not included in the 1968 API report. Apparently, many of these drums have been retired.
- A review of service experience shows much less through wall cracking of drums than previously reported.
- The survey included information from ten companies reporting on sixty coke drums.
- Most of the more recent drums are primarily constructed of Cr-Mo rather than carbon steel and C-Mo.
- No advantage of Cr-Mo over C-Mo is apparent, except it appears that Cr-Mo in graphite coke service gives a better life.

4.2.4 1996 Survey

- Fifty-four surveys were returned representing 17 different operating companies and a total of 145 drums.
- The purpose of the survey was to collect data on general information, design, operating information, inspection practices, deterioration experience, and repair procedures.
- 12% of the drums and 41% of companies reported that they have experienced a fire from a through-wall crack and leak in coke drums.
- Not all through wall cracks resulted in fires.
- New drum material selection has shown a trend to increase Cr-Mo alloy content.
- No correlation was found between drum cracking and fill cycle time.
- Drum operating parameters, such as initial quench rate and proofing quench practice, rather than metallurgy changes, appear to have a greater influence on drum cracking.
- Skirt cracking was reported by 73% of the surveyed companies. 43% of these reported cracks propagated into the shell. 89% of the skirts with slots experienced cracking. In-line skirts accounted for 83% of the skirts that did not experience cracking. 75% of the skirts without cracking were skirts that had flush ground welds. Skirts were replaced by 23% of the surveyed companies. Of the 23% that replaced skirts, re-cracking eventually occurred 43% of the time.
- The first bulge appeared sooner than the first through-wall cracks.
- Shell bulging was reported by 57%. Shell cracking was reported by 57%.
- Of the drums that bulged, 87% also experienced cracks. Cracking without bulging was reported only by 6%.
- When cracking was reported, it occurred in the circumferential direction 97% of the time. Most of the

cracks were located in courses 3, 4, and 5 (course 1 is at the bottom).

- Roll bond cladding was used the most, compared with explosion bond and plug weld cladding.
- Shell repairs were performed from the outside by 26% of the refineries. Of the 26% that performed repairs from the outside, 88% experienced recracking at the repairs. Shell repair was performed from the ID by 55% of the respondents. Of the 55% that performed ID repairs, only 21% experienced recracking.

4.2.5 2013 Survey

A new survey on drums in delayed coking units was released and conducted in 2013. The survey contained 73 questions and 45 responses were received. A total of 164 coke drums were included in the survey with over 2,500 years of coke drum service. The results from this recent survey are as follows.

a. This survey contained a range of questions similar to the ones contained in previous surveys; however, there was an attempt to include more detailed questions involving operating practices, inspection and repair methods, and unheading device design to determine their effect on drum cracking and bulging.

b. There was only one trend observed from the survey results correlating design to performance. It was shown that drums with a greater shell thickness or lower diameter-to-thickness ratio had a longer time in service before bulging occurred. The data correlation from the survey results is illustrated in Figure 2 (see next page).

c. Approximately 75 % of respondents reported that their drums' shell, cone, and top of the skirt were fabricated from either 1C-½Mo or 1¼Cr-½Mo. The survey results indicated that all materials showed a propensity to crack and bulge. Only 2 of the 45 respondents reported having experience with vertical plates for the drum shell and, in both cases, the drums were less than 12 years old. It was not possible to determine any trends with vertical plate drums because of the lack of long-term experience with this technology.

d. An evaluation of responses related to the type of coke (i.e., shot, sponge, and needle) and coke hardness showed no relation to the tendency for cracking and/or bulging.

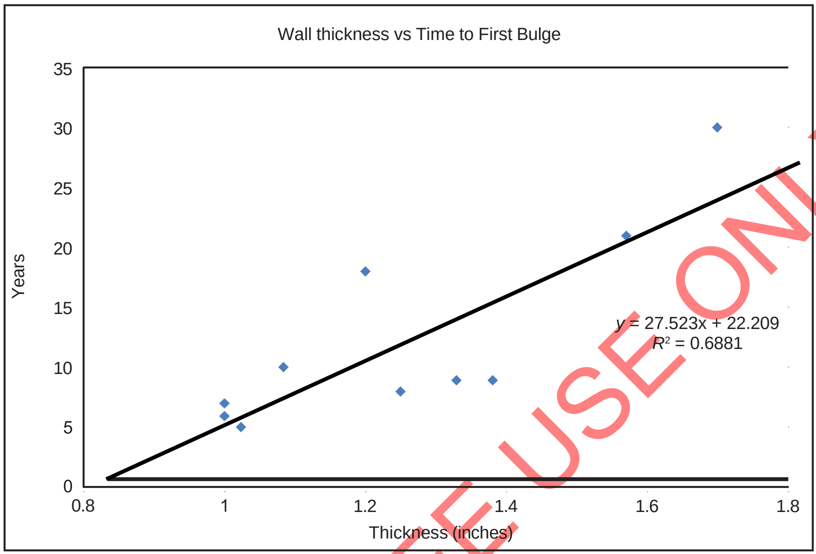
e. There were several questions related to operating practices. Responses to these questions were as follows.

   - Furnace coil outlet temperature ranged from 896°F to 996°F, with the average at 920°F.
   - Almost all respondents indicated a distinct difference between an initial quench rate and a final quench rate. Responses for an initial quench rate ranged from 42 GPM to 350 GPM, while the final quench rate ranged from 400 GPM to 6700 GPM, with a median final quench rate of 1013 GPM. 31 % of the respondents reported that they also add quench water at the top of the drum.
   - 42 of the 45 respondents reported their target metal temperature at the skirt-to-cone transition when adding feed to the drum. The reported temperatures ranged from 120°F to 715°F, with an average temperature of 476°F.
   - 44 of the 45 respondents reported their fill time for the operating cycle. The fill time ranged from 8 hours to 24 hours, with an average time of 15.8 hours.

f. 98% of the respondents indicated that coke drum failures do not result in a major consequence other than a business interruption.

g. Approximately 80% of those that experienced cracks originating in the skirt indicated that skirt cracks did not propagate into either the shell or cone of the drum.

h. 20 of the 45 respondents reported the time in years and, in a few cases, the number of cycles before the first crack was observed in the skirt. The lowest number of years before cracks were observed was 5 years, while the average was 12 years, and the maximum number of years before cracks were observed was 29 years.



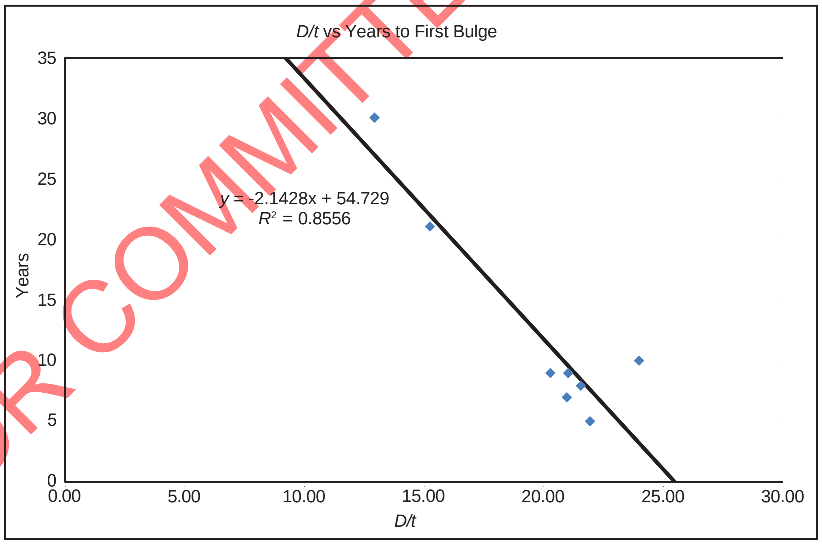


Figure 2—Correlation Between Drum Shell Thickness and *D/t* Ratio and Time to Bulging

i. Several questions involved weld repairs performed on the drum shell, cone, and skirt. Responses indicated the following trends.

- The response rate to questions related to repairs ran at less than 50% for all 45 of the participants in the survey.
- Most who responded reported they repaired cracks mostly using a matching consumable and performed a PWHT or used a temper bead procedure without PWHT, irrespective of the materials of construction. It would appear the decision to perform a PWHT largely was made based on shutdown time constraints.
- For bulges needing repairs, almost all who responded reported that they employed several approaches including window replacement, shell course replacement, and weld overlay. Additionally, almost all reported performing these repairs with and without PWHT.

j. The response to detailed questions regarding the inspection of drums was strong (42 of the 45 survey respondents), indicating that inspection is an important aspect of maintaining drum integrity. The responses included the following:

- 98% reported using laser scanning to detect bulges;
- 78% reported using time of flight diffraction (TOFD) and phased array ultrasonic inspection techniques to detect cracks;
- 86% reported using manual UT primarily to size cracks;
- 64% reported using alternating current field measurement (ACFM) to detect cracks on both the ID and OD surfaces;
- 76% reported using AE during the operating cycle to detect and locate cracking;
- 81% reported using PT and 76% reported using MPT to detect cracks;
- almost 50% of those that responded (19 of the 41 that responded to the question) indicated that they have removable insulation panels on the drum to facilitate inspection.

k. 71% of the respondents indicated that their coke drums were instrumented with either thermocouples and strain gages or both. However, only 20% of those with instrumented drums reported using the information from the thermocouples and/or strain gages to predict cracking and the need for repairs, or to optimize operations during the cycle (such as during hot feed introduction and addition of quench water).

l. Only 25% of the respondents noticed an increase in anchor bolt problems.

4.3 Changes from the Last Publication

Please note that degradation mechanisms, inspection, repair, and operating practice effects on drum reliability which used to be in this technical report are now in API Technical Report 934-J. Going forward TR 934-G will pertain to new drum design and fabrication, while TR 934-J will pertain to in-service issues for existing drums.

5 Design

5.1 General

Coke drums typically are designed to ASME BPVC Section VIII, Division 1. In some cases, the design is checked for thermal fatigue, as discussed below, using the fatigue curves included in BPVC Section VIII, Division 2. Most of the requirements for the design and fabrication of coke drums discussed in the following sections represent commonly employed practices used by owner/operators, contractors, licensors, and fabricators. These practices typically are above the basic requirements included in ASME BPVC Section VIII, Division 1.

5.2 Design Approaches

There are two fundamentally different design approaches taken in the selection of materials for coke drums.

The first and most common approach used today involves the use of 1¼Cr-½Mo, 1Cr-½Mo, or 2¼Cr-1Mo steel, typically supplied as the higher strength Class 2 material with a minimum specified yield strength of 40 or 45 ksi as shown below:

- 1¼Cr-½Mo steel plate meets the requirements of ASTM A387 Grade 11, Class 2, (45 ksi min);
- 1Cr-½Mo steel plate meets the requirements of ASTM A387 Grade 12 (40 ksi min), Class 2; and,
- 2¼Cr-1Mo steel plate meets the requirements of ASTM A387 Grade 22, Class 2, (45 ksi min).

Additionally, selected requirements included in either API 934-C or API 934-E also are imposed by most owner/operators. In addition, there are a few plate suppliers that provide 2¼Cr-1Mo per ASTM 542 Type B4a heat treated to a higher minimum yield strength of 60 ksi.

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The reason for specifying the higher yield strength is to improve the resistance of the drum to bulging during cooling in the drum operating cycle. A higher strength material is more resistant to deformation and bulging as a result of the contraction of the steel against solid coke when the drum cools during each cycle. Based on the stresses resulting from the combination of pressure and weight loads, and the loads associated with the contraction of the drum shell against solid coke during each cycle, it was determined that a higher yield strength material provided the best overall life and resistance to bulging. Drums employing higher strength plate steels tend to display less bulging, which is supported by past survey data. However, past survey data also indicates that drums fabricated from higher strength steels may be more susceptible to cracking earlier in the drum's life.

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The second approach that has more recently been proposed is based on specifying a material that has improved fracture ductility. In this case, the primary concern is localized thermal loads that occur during each operating cycle of the drum. Thermal loads are associated with uneven heating and cooling of the drum. They are displacement-controlled loads unique to coke drums and are much different than the more commonly encountered applied loads, like those due to pressure and weight. In this situation, materials are selected to maximize the fracture ductility to best accommodate displacement-controlled loads without cracking. In general, this involves selecting steels with a lower strength than commonly specified today, and with fine grain size, in order to maximize fracture ductility. This also generally involves the use of less hardenable steels (carbon steel and C-½Mo instead of Cr-Mo steels) so that weld deposit, heat affected zone, and base metal generally have similar strength and ductility levels. Because of the lower yield strength associated with these materials, distortions, such as bulging from ratcheting, will typically be more prevalent. However, steels in this condition typically will accommodate more deformation and bulging before cracking occurs. Additionally, the lower yield strength means that, in general, thicker plates are used for the drum shell. A thicker shell plate will have an increased ability to "conduct away" local thermal variations and have a higher stiffness to resist bulging. It should be mentioned that the responses from the 2013 Survey indicated that drum bulging first occurred later in life when the shell thickness was greater. See Figure 2 (in Section 4.2.5), which illustrates results from the survey showing that coke drums with a thicker shell have a longer time in service before bulging is observed.

5.3 Materials Selection Including Plate Material, Welding Consumables, and Cladding

5.3.1 General

Five materials typically have been used for plates to fabricate coke drums. These are carbon steel, C-½Mo, 1Cr-½Mo, 1¼Cr-½Mo and more recently, 2¼Cr-1Mo. By far, the most commonly used materials today for coke drums are 1¼Cr-½Mo and 1Cr-½Mo. The use of Cr-Mo steels over carbon steel and C-½Mo has occurred as furnace outlet temperatures have moved above the 900°F (482°C) to 940°F (504°C) range, favoring the use of steels with improved strength at higher temperatures. However, some refiners still prefer replacing carbon steel and C-½Mo drums in kind because of their experience and ease of repair. Other refiners have moved in a different direction, using higher alloy steels, such as 2¼Cr-1Mo and even 3Cr-1Mo-¼V, which are much more difficult to repair in the field.

1Cr-½Mo, and more predominantly, 1¼Cr-½Mo plates have been selected for drums designed using the fatigue curves in Section VIII of the ASME Code, as further discussed in Section 5.5. 1Cr-½Mo steel is favored by some licensors and owner/operators over 1¼Cr-½Mo steel because the properties of repair welds, especially those performed without PWHT, are expected to be better. More recently, 2¼Cr-1Mo plates have been selected for coke drums in a limited number of cases since this steel has better crack arrest properties, higher toughness, and can more readily achieve a higher minimum specified yield strength, when one is specified. Additionally, with some recent fabrication of drums, it has been specified that all plates used for a single drum shall not have a variation in yield strength greater than 6 ksi between adjoining plates. This requirement has been used for the lay-out of plates in the shop and not as part of the specification in the purchase order of the plates. This has been specified in order to minimize the strength mismatch between adjoining plates in a single drum. See Figure 12 for a typical coke drum plate layout indicating plate yield strengths and thicknesses. In order to comply with a requirement to minimize the variation of the yield strength to less than 6 ksi between adjoining plates, it is necessary to layout individual plates with their respective mill certificates to ensure the strength variation requirement for adjoining plates is met.

In some more recent designs, as discussed in 5.2, the emphasis has been placed on maximizing fracture ductility and not yield strength. In this case, C-½Mo manufactured to a fine grain practice has been specified. This means the steel is normalized with the possible addition of a tempering step after normalizing. Additionally, the C-½Mo has toughness requirements, typically requiring a minimum average Charpy impact value of 40 ft-lb (55 J) at 32°F (0°C) and meeting the Charpy impact levels at the minimum design metal temperature (MDMT), as defined in the ASME Code Section VIII Division 1 (paragraph UG-20). The primary reason for specifying C-½Mo versus the more commonly specified 1Cr-½Mo and 1¼Cr-½Mo is that it maintains good high temperature ductility in the weld heat affected zone (HAZ), unlike 1¼Cr-½Mo heat treated to a higher strength level, which displays a reduced ductility in the weld HAZ in high-temperature service. Additionally, C-½Mo weld repairs pose fewer difficulties than Cr-Mo weld repairs. The one concern associated with the use of C-½Mo that operates at temperatures above 850°F (454°C) for long periods of time is graphitization and/or spheroidization. Graphitization and/or spheroidization can result in a loss of high-temperature strength and does represent a potential concern with the use of C-½Mo for drum construction. Additionally, “eyebrow” graphitization in the HAZ of welds is likely to create a zone of low ductility that may crack in service. While spheroidization has been observed, to date no evidence of graphitization has been reported. Due to the cyclic nature of coke drum service, the continuous time at temperature is relatively short, and since graphitization occurs slowly, it is thought to be unlikely to occur in this service.

For coke drums it is preferred to specify welding consumables with yield and tensile strengths that match, or are a near match, to plate properties. This is particularly important when high displacement controlled thermal loads are imposed on a drum. This presents a particular challenge when using 1Cr-½Mo, 1¼Cr-½Mo and 2¼Cr-1Mo steels for drums because these steels are more hardenable than carbon or C-½Mo steels and it is more difficult to match the strength of the consumables with the plate material. This is a particular concern when repair welding is necessary. However, when higher minimum plate yield stress properties are specified, the welding consumable/plate yield strength matches can be easier to achieve.

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Commented [DC24R23]: Leave this as-is and hopefully someone can comment during balloting.

Most coke drums are clad with a layer of corrosion resistant alloy (CRA) to prevent high temperature sulfidation. The most commonly used cladding material is Type 410S stainless steel. There are, however, a minimal number of drums clad with Type 405 stainless steel. Both steels contain a nominal 12% chromium to resist sulfidation and have a specified low carbon level that allows back cladding restoration without PWHT.

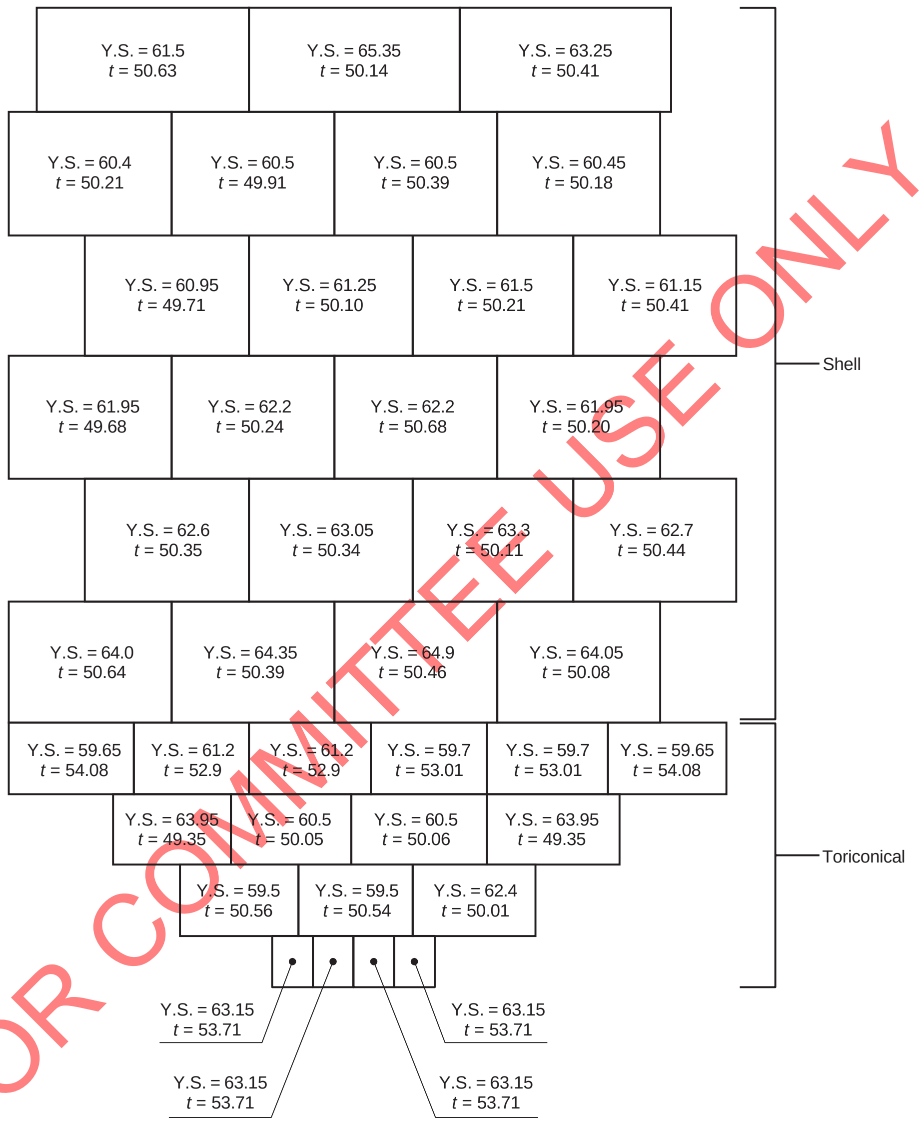

Figure 12—A Typical Sectional Plate Layout Used to Minimize Plate Strength and Thickness Mismatch

Types 405 and 410S stainless steels have a thermal coefficient of expansion compatible with the commonly used steels for coke drums. In situations where an austenitic stainless steel, like Type 304 stainless steel, has been used for the cladding, the large thermal coefficient of expansion for this steel has resulted in accelerated cracking of the cladding.

Typically, cladding on coke drum plates is applied either by a hot rolling process or explosive bonding during the plate manufacturing process. The 12Cr cladding applied by either of these processes is specified by ASME Standard SA-263.

Alloy 625 also has been used for weld overlay (in lieu of cladding) in some coke drums. This alloy has a higher strength compared to Type 410S or Type 405 stainless steel. In addition, when compared to 300 series stainless steels, the thermal coefficient of expansion of Alloy 625 more closely matches the carbon and Cr-Mo steels used for coke drums. In several cases, Alloy 625 has been used to overlay bottom cones in coke drums because overlay plates in some circumstances can be supplied faster than clad plates. Experience indicates that Alloy 625 appears to provide superior corrosion and erosion-corrosion resistance that is needed in some cases for the bottom cone. Type 410S and Type 405 stainless steels possess inferior erosion and corrosion resistance and have been known to wear away in the bottom cone from coke erosion when the coke is dumped from the drum. Alloy 625 also has been used for overlay repair welds in cases where a 12Cr cladding has experienced severe corrosion.

It is necessary to restore the cladding on all ID surfaces at seam welds to provide corrosion protection on the inside surface of the coke drum. The most commonly used welding consumables to restore Types 410S or 405 stainless steel cladding at weld seams are Ni-based welding consumables, using either GMAW, GTAW, SMAW, FCAW, SAW, or ESW welding processes. These welding consumables provide the best combination of properties (strength, corrosion resistance, weldability, and coefficient of thermal expansion) suitable for restoration welds on Types 410S and 405 stainless steel cladding on coke drums.

5.3.2 Compositional Controls for 1¼Cr-½Mo Plate and Welding Consumables

1¼Cr-½Mo is the most commonly specified material for coke drums, as indicated in the most recent survey of owner/operators. Special compositional controls have been specified by some owner/operators for both the plate and welding consumables in order to minimize embrittlement, which can occur during extended service at high temperatures. Compositional controls to minimize harmful low melting point metal impurities are typically imposed on 1¼Cr-½Mo plate, forgings, and welding consumables . These are expressed as the X-bar factor[(1)] as follows:

$$\text{X-bar} = (10P + 5Sb + 4Sn + As)/100 < 15 \text{ ppm}$$

where

P, Sb, Sn, and As are in ppm

Additionally,

- C is 0.15 wt% max;
- P is 0.012 wt% max;
- S is 0.007 wt% max;
- Cu is 0.20 wt% max; and
- Ni is 0.30 wt% max.

1. Bruscato, R. M: "Embrittlement factors for estimating temper embrittlement in 2.25Cr:1Mo, 3.5Ni-1.75Cr-0.5Mo-0.1V and 3.5Ni steels"; ASTM conference, Miami, Florida, 1987.

5.4 Thickness Considerations

Coke drums operate at relatively low pressures (normally less than 50 psig) and as a result, the major applied load that needs to be considered is the weight load. In the past, it was common to vary the coke drum thickness to provide a thickness based on pressure and weight load considerations. This resulted in coke drums fabricated from thinner plates in the top sections, where weight loads are lowest compared with the bottom sections where thicker plates were used to accommodate higher weight loads. This practice resulted in a stress concentration at each location in the drum where the thickness transitioned from a higher thickness to a lower thickness. When these areas with a transition from one thickness to another are subjected to a thermal load, the stresses will concentrate at these changes in thickness and accelerate crack initiation and propagation. As a result, the best practice is to use a single thickness for the shell of a drum. Typically, the shell thickness is greater than required to accommodate the combined loads of pressure and weight. A thicker wall can be used to provide external pressure resistance instead of using external vacuum support rings, thus justifying the thicker wall, while also benefiting from reduced bulging tendencies. As shown in surveys of industry experience (see 4.2), drums with a greater single thickness for the shell provide an improved life. Typically, the bottom cone on a coke drum is thicker than the shell. Most require a gradual taper between the thickness of the shell and cone, more gradual than the minimum 3 to 1 taper required by the ASME Code. A 10 to 1 taper is frequently specified in order to minimize the stress concentration at the transition between the drum shell and bottom cone.

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5.5 Fatigue Design Considerations

The cyclic nature of pressure and thermal loads should be considered in the design of coke drums. Cyclic loading is accounted for in the design process by performing a fatigue analysis. The ASME Code, Section VIII, Division 2 provides the means for performing a fatigue analysis, although the upper limit on the fatigue design curves is set at 700°F (371°C) because of a concern for time-dependent creep at higher temperatures. In the case of a coke drum, it may be possible to use these curves since the highest loads experienced by a coke drum are most likely to occur when the drum is cooling down and the metal temperature is below 700°F (371°C). This can be established when evaluating the thermal loads experienced by a coke drum during each operating cycle.

In the ASME Code, Section VIII, Division 2, fatigue curves are presented in two forms: fatigue curves that are based on smooth bar test specimens and fatigue curves that are based on test specimens that include weld details of quality consistent with the fabrication and inspection requirements of this code. For coke drum design it is recommended that the welded joint curves be used for the design of all welded joints, and smooth bar curves be used for components without welds.

Stresses and strains produced by any load or thermal condition that does not vary during the cycle need not be considered in a fatigue analysis if the fatigue curves utilized in the evaluation are adjusted for mean stresses and strains. In the ASME Code, Section VIII, Division 2, the smooth bar design fatigue curves are based on smooth bar test specimens and are adjusted for the maximum possible effect of mean stress and strain; therefore, an adjustment for mean stress effects is not required. The welded joint fatigue curves in this code are based on welded test specimens and include explicit adjustments for thickness and mean stress effects.

The ASME Code, Section VIII, Division 2 also contains requirements to evaluate the effects of ratcheting. A rigorous evaluation of ratcheting normally requires an elastic-plastic analysis of the component; however, under a limited number of loading conditions, an approximate analysis can be utilized based on the results of an elastic stress analysis.

A fracture mechanics approach to fatigue may also be performed in accordance with API 579-1/ASME FFS-1, Part 9. The advantage of a fracture mechanics approach is that if existing flaws are found, even on a new drum, an estimate of the growth rate can be determined and used to plan future inspection and repair activities. The difficulties in performing a fracture mechanics assessment are similar to those in performing a fatigue analysis; i.e. one needs to define all of the loads, and in particular, the thermal loads which are typically difficult to determine in the case of coke drums.

A probabilistic analysis can be used to account for the uncertainty in the cyclic nature of the pressure and thermal loading conditions. This analysis can be based on either fatigue initiation, as defined in the ASME Code, Section VIII, Division 2, or a fracture mechanics approach, as defined in API 579-1/ASME FFS-1. In either case, the advantage of the probabilistic assessment is that it can be used for the analysis of random loading conditions and provide input for a risk assessment in accordance with API 580.

In-service assessments of fatigue life are further discussed in API Technical Report 934-J.

5.6 Skirt and Vessel Support Details

5.6.1 Skirt-to-Bottom Head Attachment

The area in coke drums most susceptible to cracking is the weld at the skirt-to-bottom head attachment. The reason for this is that the skirt-to-bottom head attachment weld undergoes significant stress cycling as the drum heats up and the skirt tends to draw the heat away from the attachment weld area, and conversely, as the drum cools during the quench cycle, the hotter skirt tends to provide heat input into the attachment weld causing a temperature gradient between the bottom head and the skirt during both the heat up and quench cases. In both cases, the skirt resists the expansion and subsequent contraction of the coke drum and this resistance acts through the attachment weld. Essentially, the larger the temperature gradient between the drum shell/cone and the skirt, the larger the stress in the attachment weld. The skirt also tends to stiffen the skirt attachment system and generally, the thicker the skirt, the stiffer the skirt attachment system, leading to further stresses in the attachment weld. The skirt attachment weld also acts as a stress riser; thereby increasing the local alternating stress levels in the weld that result from the heat-up and quench cycles, leading to premature local cracking.

In earlier coke drum designs, the attachment of the skirt to the drum bottom head consisted of a simple fillet weld, as indicated in Figure 13. This type of weld provides a very large stress concentration factor at the inside crotch of the skirt-to-shell/cone attachment leading to premature operational fatigue cracking. To overcome this problem, designers came up with a modified weld system, as indicated in Figure 14, having an internal weld crotch radius of at least 0.5 in. (13 mm), which significantly reduced the stress concentration factor. Typically, a sharp internal crotch weld can produce a stress concentration factor as high as 5 while a radiused internal crotch weld will produce a stress concentration factor that is half of that value.

An evolution of the internally radiused crotch weld was the integral forging attachment concept indicated in Figure 15. In this case, the internal crotch radius can be further increased to reduce the internal stress concentration factor. However, there is a trade-off limit, as a larger internal crotch radius can make the attachment system much stiffer and this has the effect of increasing the local stress intensities and reducing the overall fatigue life of the skirt attachment system.

Typically, depending on the available fabricating facilities and the drum sizes, skirt attachment forgings can be fabricated from forged (rolled) rings which are subsequently machined, or as an alternative, rings can be fabricated from rolled forged bar segments, welded together and then machined to the necessary drum profiles, as indicated in Figure 16. In either case, the forged ring approach has the advantage of replacing nearly all of the strain-sensitive skirt attachment welds with solid base metal, as the welds joining the cone and shell sections to the forging are removed from the critical highly stressed attachment areas, thus providing higher operational fatigue lives at the actual attachment area. Potential problems with the forged-ring design include the difficulty of access to inspect the cone weld and the integrity and repairability of ring-segment welds.

Another skirt attachment approach is wrapping the skirt around the outside of the shell, as indicated in Figure 16. This type of construction is preferred by some because it also removes the strain-sensitive skirt-to-shell attachment weld from the area of high stresses. The attachment weld is usually located approximately 6 in. (150 mm) above the drum's lower tangent line. Generally, this type of fabrication can be difficult to accomplish, as the gap between the shell and the inside of the skirt has to be kept to a minimum to minimize stress concentrations. The skirt and shell have to be truly round for the skirt to be shrunk in the shell with minimal gaps between them.

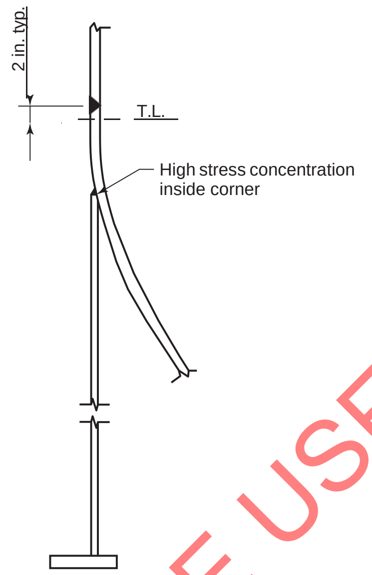

Figure 13—Typical Skirt-to-Shell Fillet Weld Detail Used in Earlier Drum Construction

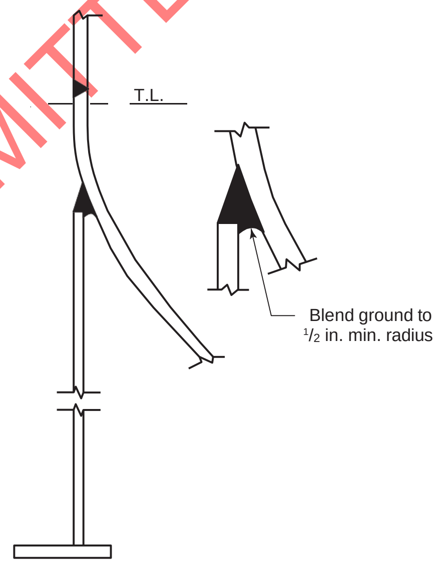

Figure 14—Skirt-to-Shell Detail of a Modified Fillet Weld with an Internal Weld Crotch Radius to Reduce Stress at the Weld

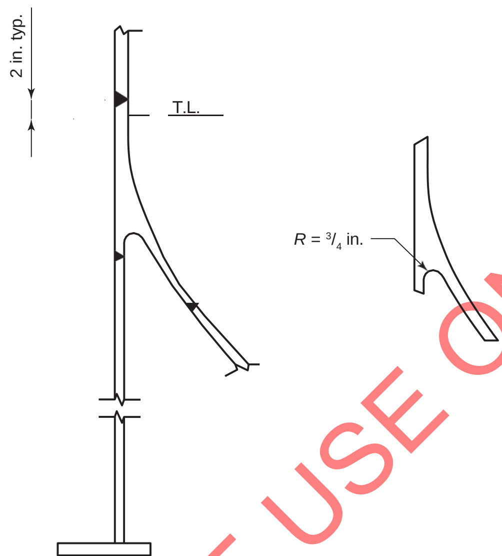

Figure 15—Forged Skirt-to-Shell Attachment Detail Removes Welds from High Stress Areas

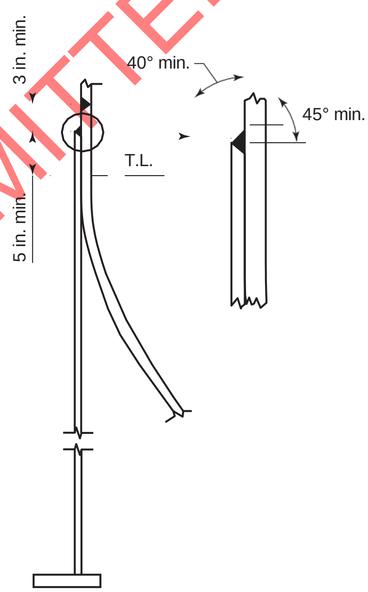

Figure 16—Skirt-to-Shell Attachment Weld is Moved Up On the Shell From the Tangent Line to Remove the Weld From the High Stress Area

5.6.2 Keyholes in the Skirt

Keyholes are vertical slits in the skirt that provide added flexibility to the skirt to expand and contract during heat up and cool down. There are two types of keyholes, namely those that penetrate through the skirt-to-cone weld and those whose upper extremity terminates below the skirt-to-cone weld. The latter keyholes are more prevalent on coke drums. The upper extremity of these keyholes is located typically 2 in. to 3 in. (51 mm to 76 mm) from the skirt-to- cone or skirt-to-shell attachment weld. These slits add flexibility to the skirt and help to provide improved fatigue life of the attachment weld. Keyholes are usually about 10 in. to 15 in. (254 mm to 381 mm) long and are located 6 in. to 12 in. (152 mm to 305 mm) apart along the upper circumference of the skirt within the skirt hot box area (see 5.7 for a description of the hot box details). For keyholes that are located totally under the skirt attachment weld, circular holes are drilled through the skirt thickness at the top and bottom of the slit (prior to slit cutting) to reduce stress concentrations provided by the otherwise sharp extremities of the slit, hence the name keyholes. For keyholes that penetrate through the skirt attachment weld, circular stress relief holes are drilled at the lower extremity of the keyhole only.

The keyhole slits are usually 0.125 in. to 0.25 in. (3 mm to 6 mm) wide and are normally plasma arc cut, water jet cut, or machine cut after the skirt has been rolled. The relief holes, normally 0.75 in. to 1 in. (19 mm to 25 mm) in diameter, are usually drilled in the flat skirt plate prior to rolling. Sharp edges or corners of the slits and keyholes are chamfered with a pencil grinder to remove sharp corners to minimize the resulting stress concentration. Flame cutting by a hand-held oxy-acetylene torch is not normally preferred, as this method usually does not lead to straight-cut slits. For typical skirt keyhole details, refer to Figure 17.

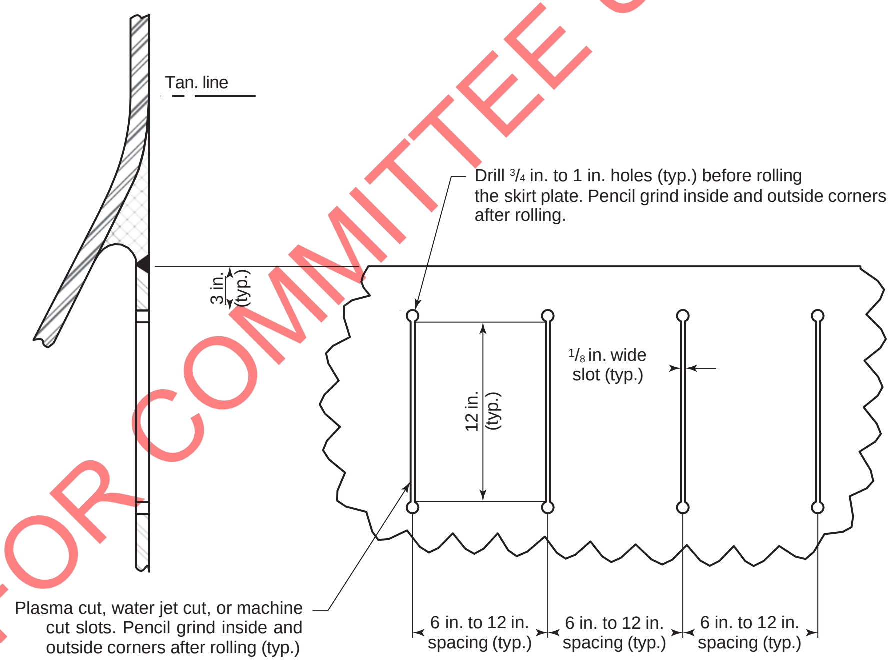

Figure 17—Typical Details for Coke Drum Skirt Keyholes

Keyholes that do not penetrate through the skirt attachment weld need to be located close to the skirt attachment weld to provide optimum stress reduction on the skirt weld. However, keyhole relief holes inevitably crack during coke drum operation and these cracks need to be repaired. Most of the cracks initiate in the upper keyholes, however, cracks also form in the lower keyholes. The optimum distance between the top of the stress relief hole and the lower edge of the skirt-to-cone attachment weld is usually no more than 3 in. (76 mm), maximum, to permit future crack repairs to take place. Designers have maintained that it is better and easier to repair cracked skirt keyholes than to repair cracked skirt attachment welds.

Keyhole relief holes are sometimes rolled in a manner similar to rolling heat exchanger tubes to provide a residual compressive stress on the inside surface of the keyhole to enhance the fatigue life of the keyhole. The beneficial effect of a rolled keyhole from the induced surface compressive stress is significantly reduced when the coke drum is PWHT'd. Keyhole rerolling after PWHT in a wraparound skirt, as indicated in Figure 15, is difficult to properly achieve because of the close proximity of the skirt to the shell. Also, repairs to cracks in the skirt keyholes are difficult in a wraparound skirt because the welding will encroach onto the adjacent coke drum shell.

5.7 Insulation Details (including Hot Box details)

Drums in coking units operate at elevated temperatures and as a result, require insulation on the outside surface. Insulation systems typically include two layers of insulating material 4.5 in. to 6 in. (115 mm to 150 mm) thick. Additionally, since coke drums require frequent inspection and maintenance at welds and other areas of high stress concentration on the drum, in many cases the insulation support system must allow for easy removal of the insulation during downtimes. Figure 18 provides an overview of the insulation systems that can be installed on drums in coking units.

The following materials have been used for insulation systems on drums in coking units:

a. calcium silicate; } Used on drum heads
b. expanded perlite; }
c. mineral wool - typical for the shell and other areas where corrosion under insulation (CUI) is not a concern;
d. high temperature fiberglass - typically only used at joints;
e. aerogel, especially in areas where CUI has been experienced;
f. ceramic fiber - in most cases, not cost-effective;
g. preassembled multi-layer mineral wool insulation fixed onto stainless steel weather sheathing panels with a stainless steel foil layer between the insulation and the drum. The individual panel assemblies are screwed to the insulation support rings and can be readily removed for drum inspection. Vertical panel seals are folded over each other to provide weather tightness.

The maximum operating temperature for mineral wool and high temperature fiberglass is 800°F (427°C). The insulation material may be used in the form of blankets or prefabricated panels. Insulation blankets are usually attached to the coke drums by pins or studs welded directly to the coke drums or by rings attached to clips that are welded to the drums. More recently, prefabricated removable insulation panels are used to insulate the coke drums.

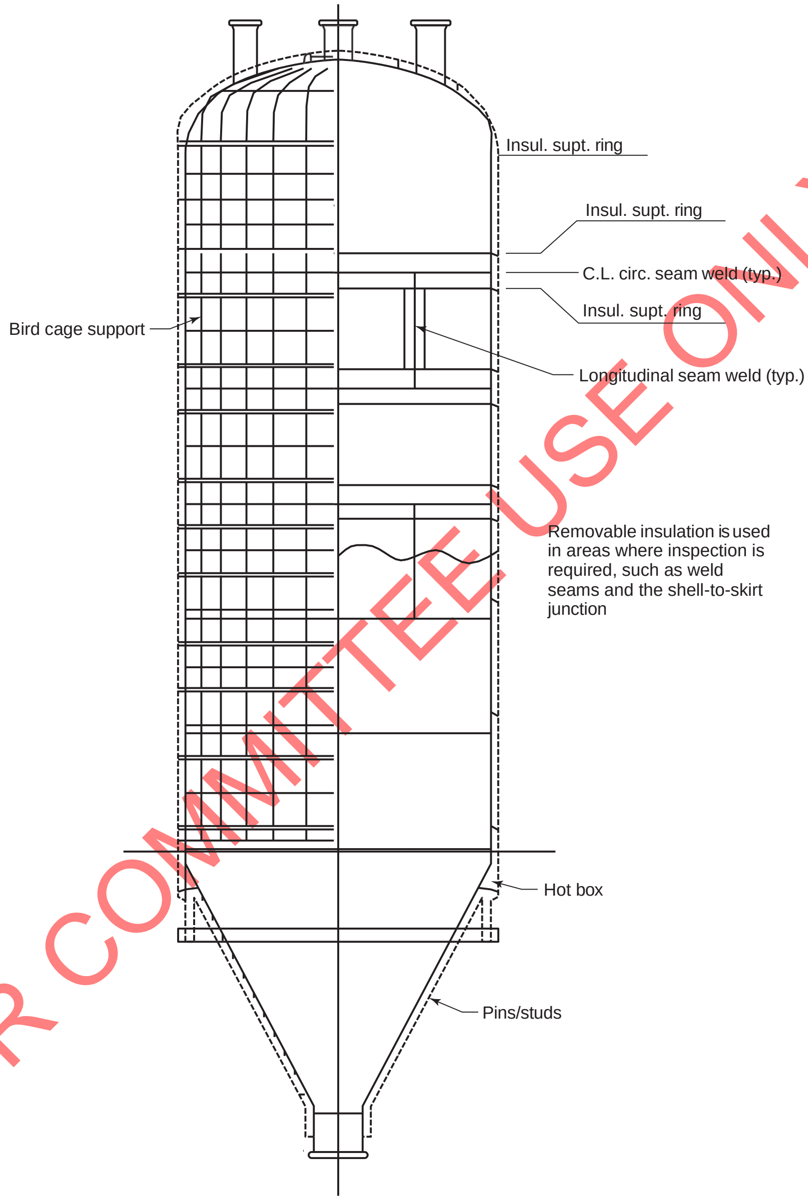

Figure 18—General Details for the Insulation System on Drums in Coking Units

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The following types of insulation supports have been used.

a. Pins/studs welded to the shell, heads, and cones (see Figure 19).

b. Clips welded to the shell with segmented rings connected to the clips by bolts (see Figure 20) - Two types of insulation can be supported by segmented rings:

  - non-removable type of insulation;
  - removable type of insulation to allow for inspection of welds.

c. Clips welded to the shell supporting floating rings (see Figure 21) - This insulation system has floating rings that support an insulation panel with a gap between the shell and inner layer of insulation that allows for the growth of the shell without affecting the insulation. In addition, this type of insulation allows for the easy removal of panels to permit easy access for inspection and maintenance.

d. Bird cage type supports - Bird cage support straps are supported from a ring or individual strap supports welded to the top head. Clips supporting the insulation are welded or bolted to the straps. The only welding in this insulation system is between the top ring or individual strap supports and the drum head. The insulation support rings can be floating or slotted. Figure 22 shows a bird cage type of insulation support system with floating rings.

Solid insulation support rings should not be fillet welded directly to the drum shell. This creates a rigid fatigue crack initiation point and has been the location of numerous cracks in drums with this design.

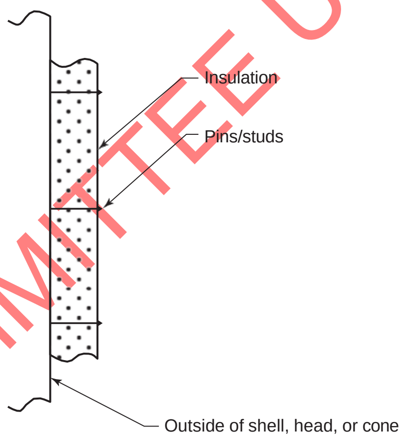

Figure 19—Insulation Support System with Pins/studs Welded to the Shell, Heads, and Cones

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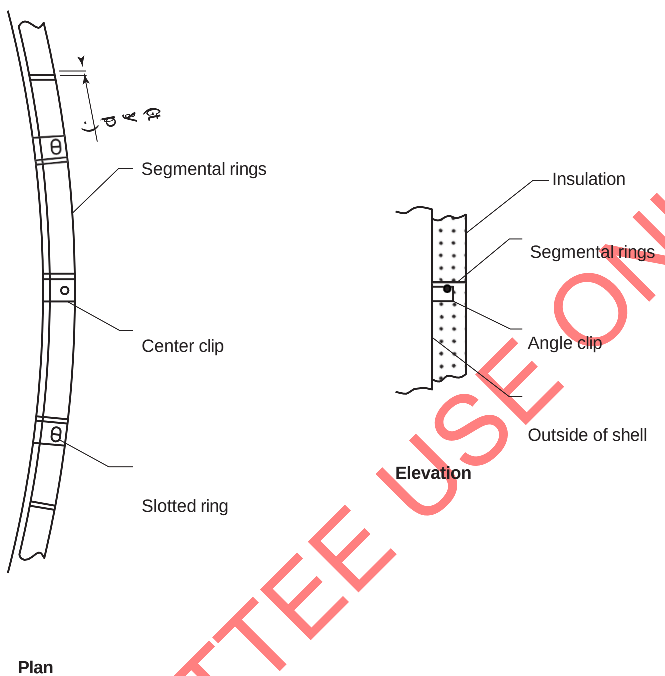

Figure 20—Insulation Support System with Clips Welded to the Shell With Segmented Rings Connected to the Clips by Bolts

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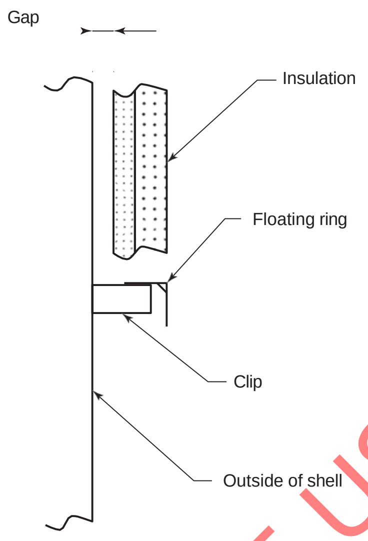

Figure 21—Insulation Support System with Clips Welded to the Shell Supporting Floating Rings

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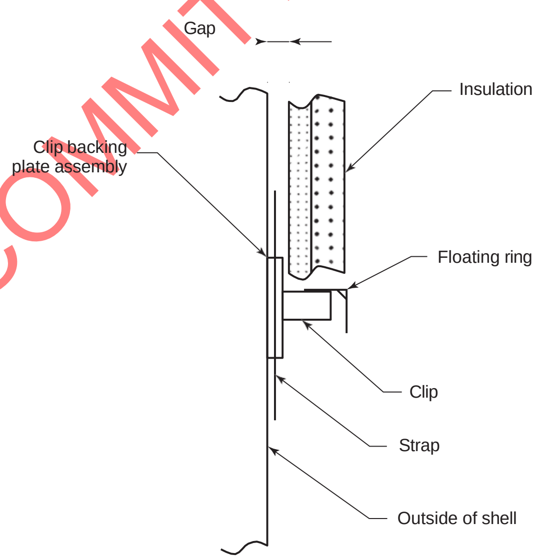

Figure 22—Insulation Support System with Bird Cage Type Supports with a Floating Ring

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Figure 23 illustrates typical insulation details at the skirt-to-shell connection. Coke drums typically have a "hot box" at the skirt-to-shell junction. The purpose of the hot box is to allow for radiant heat transfer between the coke drum cone and the skirt. It is necessary to minimize the large thermal gradients between the shell/cone and the top of the skirt. The hot box is essentially dead air space that helps by radiant heat transfer to heat the skirt during the feed cycle and cool the skirt during the quench cycle. As indicated in the sketch, a typical hot box vertical height is around 24 in. (610 mm) and the extent of the external skirt insulation extends typically a minimum of 18 in. (457 mm) below the bottom of the hot box.

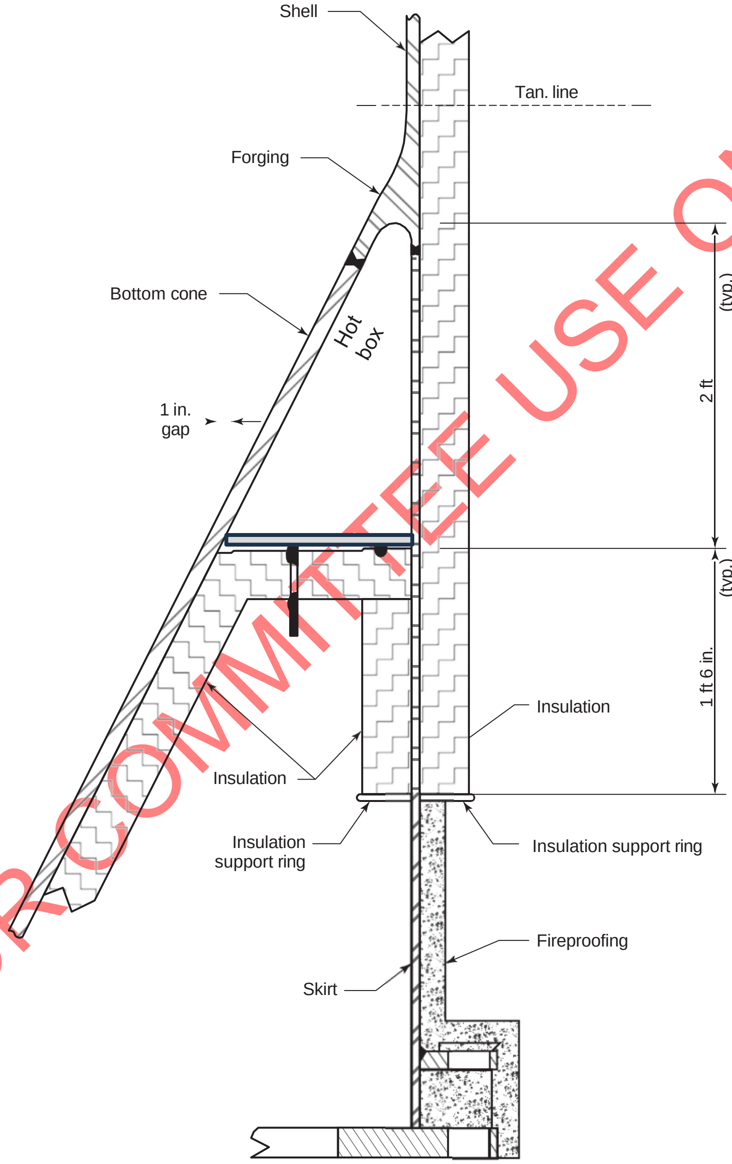

Figure 23—Typical "Hot Box" Insulation Details at the Skirt-to-Shell Connection

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5.7 Tolerances for New Coke Drums

5.7.1 General

Drums in coking units routinely experience severe thermal cycles during normal operation. As a result, it is important to maintain tight tolerances to avoid creating stress concentrations that accelerate crack initiation and propagation. The tolerances discussed in this section will include only those that have a direct impact on minimizing the potential for stress concentrations, which is particularly important for drums in coking units. Other standard tolerance requirements will not be discussed, such as nozzle placement to ensure piping flange fit-up and skirt bottom bolt hole locations to ensure foundation bolts properly fit on the skirt. Figure 24, which was provided by an engineering contractor, illustrates typical tolerances that need to be maintained during the fabrication of a coke drum. There are 17 different tolerances illustrated in this figure. Some of the more important tolerances for coke drums include the following.

5.7.2 Maximum Out of Roundness at any Cross Section

The maximum out-of-roundness at any cross section can be an important design factor in promoting longevity in coke drums. Out-of-roundness becomes especially important when a coke drum is also subject to vacuum conditions. The ASME Code limits out-of-roundness to 1% of the internal diameter, compared with the European Code which limits out-of-roundness to 0.5% of the internal diameter. Most coke drums are fabricated with an out-of-round tolerance between 0.5% to 0.75% of the internal diameter.

5.7.3 Maximum Deviation from the Vertical Applied to a Shell

The maximum deviation from the vertical applied to a shell should not exceed $^{1}/_{10}$ in. (2.5 mm) in 10 ft (3 m) or ½ in. (13 mm) in 50 ft (15 m).

5.7.4 Distortion Caused by Welding

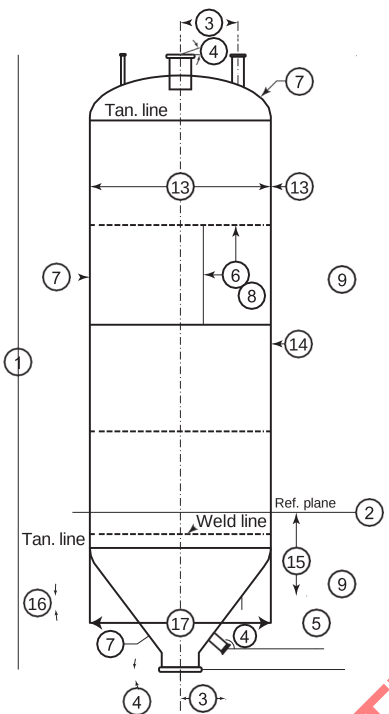
Distortion caused by welding of longitudinal and circumferential joints (weld peaking or banding) should be controlled in order to avoid a stress concentration at the weld that promotes crack initiation and shortens drum life. Typically, peaking is limited to between $^{1}/_{8}$ in. (3.2 mm) and $^{1}/_{4}$ in. (6.3 mm) in maximum depth or height in a length of 36 in. (914 mm), as measured by a sweep board contoured to the theoretical (internal or external) diameter of a coke drum. Peaking welds significantly increase the stress concentration factor at the weld, with the overall effect of reducing drum operational life.

5.7.5 Maximum Plate Offset

The maximum plate offset in a butt welded joint should not exceed $^{1}/_{8}$ in. (3.2 mm) either due to out--of-roundness of adjacent shell courses or due to differences between adjacent plate thicknesses. Such plate offsets should not be abrupt but should be feathered with deposited weld metal, tapered, and ground smooth over the width of the weld. Plates should preferably not be offset on the internal cladding side and all offsets should preferably be on the outer diameter. Plate offset due to a difference in thickness between adjoining plates can be minimized by laying out the plates used in the construction of a drum, as illustrated in Figure 12.

5.7.6 Maximum Thickness Tolerance on Plates

The maximum thickness tolerance on plates should be controlled. Typically, thickness is controlled to between –0 in. (0 mm) and +$^{1}/_{8}$ in. (3.2 mm). This is because plate mills will usually not accept tolerances less than +$^{1}/_{8}$ in. (3.2 mm), even though lesser tolerances may be specified by the purchaser. Both plate offsets and excessive thickness between adjacent plates will provide stress concentrations which have the effect of reducing drum fatigue lives. Accordingly, limiting plate offsets and thickness variations between adjacent plates is directionally the best approach. Figure 12 illustrates how the difference in plate thickness can be minimized by laying out the plates used in the construction of a drum.



Key

1. Tolerance on longitudinal dimension shall be ±$^1/_2$ in., unless noted otherwise.
2. REFERENCE PLANE Punch mark inside and out 3 in. from the root land of the bottom course.
3. Flange face nozzle from the centerline of vessel ±$^1/_8$ in.
4. The flange face of the nozzle shall be parallel with the indicated plane in any direction ±$^1/_2$ in., but not to exceed $^3/_{16}$ in.
5. Location of nozzles or TIs from reference plane ±$^1/_4$ in.
6. Distortion caused by welding of longitudinal or circumferential joints shall not exceed $^3/_{16}$ in. maximum depth in a 36 in. length of shell centered on the weld.
7. Maximum thickness tolerance shall be -0 in, +$^1/_8$ in.
8. Maximum plate offset in a butt welded joint shall be $^1/_8$ in.
9. The flange face of the top or bottom nozzle to the reference plane ±$^1/_4$ in.
10. Orientation of nozzle and other attachments shall be within ±$^1/_8$ in.
11. $^1/_8$ in. max lateral translation.
12. $^1/_{16}$ in. max rotation of flanges from the indicated position, measured as shown.
13. Max out-of-roundness at any cross-section 0.0075 x OD. Tolerance on inside shell diameter as measured by external strapping shall not vary more than $^3/_8$ in. Max out-of-roundness over a 36 in. gauge length shall be $^5/_{16}$ in.
14. Maximum deviation from straight applied to shell shall be $^1/_8$ in. in any 10 ft or $^1/_2$ in. per 50 ft of length.
15. Distance from the reference plane to base +0 in., -$^1/_4$ in.
16. Base plate out of level ±$^1/_4$ in.
17. Bolt circle diameter tolerance of ±$^1/_4$ in. and bolt holes shall be located within $^1/_4$ in. of their theoretical location.

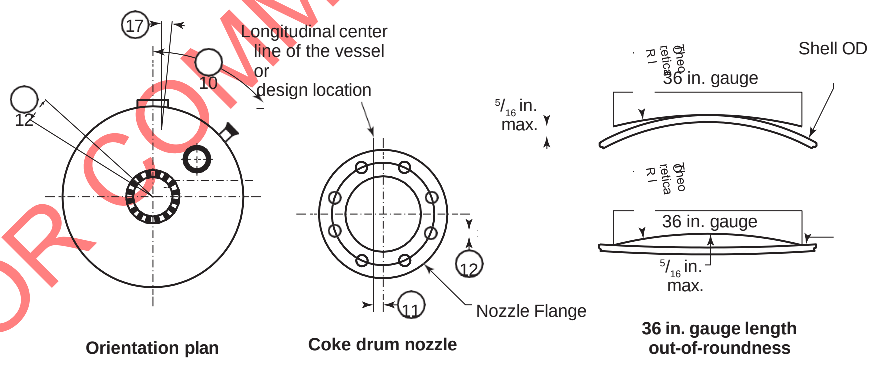


Figure 24—Typical Tolerances Specified for Drums in Coking Units

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6 Fabrication

6.1 General

In general, most owner/operators, contractors, and licensors use fabricators that have experience fabricating coke drums and are familiar with implementing the practices included in this technical report. Most of the practices discussed in this section of the report are commonly employed in the fabrication of coke drums for refinery service.

6.2 Weld Joint Design Details, Including Finishing

Weld finishing on internal and external weld surfaces of coke drums is considered important by many owner/operators in providing optimum coke drum fatigue life. For this reason, close attention has been paid to the quality of the weld finish. Some owner/operators specify that all longitudinal and circumferential welds be ground smooth and flush on both the OD and ID, including feed nozzle attachment welds. For nozzles other than feed nozzles, usually no specific surface finish for the OD is prescribed**,** however**,** weld undercutting should never be permitted.

Stress concentrations resulting from weld surface finishes or weld undercutting can have severe effects on fatigue life at the location of the stress concentrations. Thus, several owner/operators request that fabricators minimize stress concentrations by grinding welds smoothly as discussed in the previous paragraph with minimal grind marks and no undercutting. In these cases, grind marks should be oriented preferably parallel to, but no more than 20 degrees from, the longitudinal axis of the coke drum.

Shell and cone internal and external weld seam surfaces and inlet nozzle ID weld seams should also have a surface finish no coarser than 125Ra. Of course, any adjacent plate thickness transition caused by individual plate tolerances should be no greater than 1/8 in. (3.2 mm) and this transition should be smooth from one plate to another over the width of the weld.

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Commented [DC36R35]: Don's former company did.

Temporary attachment welds should be made using an approved welding procedure specification (WPS). The manufacturer should strictly adhere to any material preheat and slow cooling requirements of the WPS. It is important to maintain strict preheat control when welding large lifting trunnions (which are removed before service) to a coke drum shell. Trunnions usually are quite large in diameter and are usually manually welded to the shell and it is very easy for the metal temperature to decrease below minimum preheat limits during the welding process. There have been numerous instances where welds on large trunnions on Cr-Mo vessels were found to be cracked. All temporary attachments (note that the trunnions are removed after erection) should be removed prior to the final PWHT by cutting no closer than 1/8 in. (3.2 mm) from the vessel wall. The reminder of the attachment should be ground flush with the surface to eliminate defects and surface stress concentration. Weld repairs should be performed as required to ensure no loss of minimum base metal, cladding, or weld overlay thickness. Locations where temporary attachments have been removed should be examined visually and by magnetic particle testing (MT) or dye penetrant testing (PT).

Recently some coke drum fabricators have used a “vertical plate” construction in order to minimize circumferential welds on a drum. In this construction detail, shell plates are oriented along the length of the drum resulting in a very long longitudinal weld along the length of the drum. Since most cracking appears to occur along circumferential welds on drums, it is believed this fabrication detail will mitigate cracking by reducing the number of circumferential seams on a coke drum. By the mid 2010s, this practice had been used on some 2 dozen drums, but it has not yet been determined whether it is effective in reducing cracking in coke drums.

6.3 Clad Restoration Welds

An internally 12Cr clad drum surface requires an overlay of the completed weld area on the ID surface, including where the cladding was cut back to make the weld, in order to obtain complete coverage of the ID surface with corrosion-resistant material. Typically, this is accomplished with a high nickel alloy wire deposited using a GTAW, GMAW, SMAW, FCAW, SAW, or ESW welding process. The high nickel alloy provides the best combination of weldability and thermal expansion properties for this restoration weld. The deposited high nickel alloy most commonly used for restoration welds has a similar strength compared with the 12Cr cladding and steel plate and shell weld. However, the thermal expansion properties are different enough that there is a significant likelihood of dissimilar weld cracking between the cladding and the high nickel alloy restoration weld. For this reason, it is important to make the restoration weld as thin as possible to reduce the effect of dissimilar weld cracking between the high nickel alloy weld deposit and the 12Cr cladding. The restoration weld should be limited to $^{1}/_{8}$ in. (3.2 mm) thick and the weld finishing should be per 6.2.

Type 300 stainless steel weld overlay materials (such as Type 309) are not recommended due to a high thermal coefficient of expansion compared to the base metal and the 12Cr cladding. Experience has found that welds with austenitic stainless clad restoration suffered frequent cracking.

6.4 Weld Property Requirements

In the 2000 to 2015 time frame, coke drum manufacturers and the filler metal suppliers worked together to lower the yield strength of 1¼Cr-½Mo weld metals to levels closer to that of the base metal. This addresses the stiffening effect of the higher strength welds, which may have exacerbated bulging and cracking in earlier coke drums. Filler metals are now available with deposited yield strengths that do not exceed the shell plate yield strength value by more than 10 %.

Matching weld properties with the plate is a particular challenge when using 1¼Cr-½Mo or 2¼Cr-1Mo steel for the drum. Welds typically achieve a higher hardness and strength than the base metal on welding, even after PWHT. During initial fabrication under shop-controlled conditions, it is possible to consistently match the weld deposit strength within 10 % of the plate strength after a final PWHT as long as careful attention is paid to this.

6.5 PWHT Requirements

PWHT is normally performed after all welding is completed to reduce welding residual stresses and temper hard bainitic or martensitic phases that may form during the welding process. Typically, PWHT is not performed on carbon steel for either initial fabrication or repair welds, unless dictated by Code. Maximum thickness requirements before PWHT becomes mandatory for CS is normally at thicknesses of 1½ in. (38 mm) and above. C-½Mo also possesses limited hardenability and does not require PWHT for fabrication or repair welds less than 5/8 in. (16 mm) thick. 1Cr-½Mo, 1¼Cr-½Mo and 2¼Cr-1Mo have progressively increasing hardenability compared to either carbon steel and C-½Mo and will typically require PWHT in order to control hardness in both repair and initial fabrication welds. Techniques that have been developed to perform repairs in these alloys without PWHT are discussed in API 934-J.

PWHT of new coke drums, as required by the code of construction, can occur in the fabrication shop and the field. The PWHT can take place:

a. on the whole assembly all at once in a furnace, by placing electric heating elements on the entire shell and heads, or by internal heating the vessel (while externally insulating) with gas firing from burners;

b. on the whole assembly with each half done separately in a furnace; or

c. by heat treating sub-assemblies separately and performing a final local PWHT on the closing seam.

One proven method of PWHT of new coke drums at fabrication shops is in one piece in a large PWHT furnace. This method provides a lower overall PWHT exposure time and minimizes the risk associated with sub-assemblies receiving PWHT in smaller furnaces with closure seams experiencing a local PWHT on the shop floor. The entire coke drum also can receive PWHT by wrapping it with electric heating elements or by hot gas firing the inside of the coke drum, but these options are not so frequently used.

The coke drum can also be PWHT'd by placing a little over one-half of the complete coke drum into the furnace and then PWHT the other half of the coke drum while overlapping a portion that has experienced PWHT. Typically, an insulated baffle is placed in the coke drum and insulation is placed on the portion of the coke drum nearest the oven to ensure a smooth thermal transition to the cold portion of the drum.

Commented [BDR37]: Do we really need all the details on PWHT that are provided in this section? We reference WRC 452, so shouldn't this just be clarifications of that practice? I'm all for reducing the size of this subsection and only have 'requirements' in one place (i.e., WRC 452).

Commented [BJJ38]: Comment 38 - lots of unaddressed comments

Commented [DC39]: I've never heard of PWHT'ing the entire drum in "an oven" with heating elements. The ones I've seen are in large, gas-fired "furnaces." BTW, "oven" is the wrong term for a high temperature chamber. Call it a "furnace".

Commented [DC40]: Really? I've never heard of wrapping the entire drum with heating elements.

Commented [BJJ41]: Comment 32

A facility without the ability to PWHT coke drums in one piece will typically PWHT a coke drum in halves. The two halves are then welded together with a circumferential weld which receives a local PWHT. A portion of the longitudinal weld seams that meets the final circumferential seam will receive two PWHTs, requiring longer PWHT qualifying times for construction materials, such as plate and weld wire.

The PWHT of field fabricated coke drums can consist of PWHT of sub-assemblies at a fabrication facility followed by local PWHT on the closing seams. Local PWHT can be performed in a shop or the field. Local PWHT is performed by wrapping the weld area being PWHT'd with electric heating elements or by hot gas firing the inside. Local PWHT also has been performed from the outside by building a short (typically 5 ft to 6 ft [2.5 m to 3 m] long) furnace box that fits over a weld joint being heat treated. The furnace box is heated with hot circulating flue gas from a gas burner outside the box. Local PWHT should be done in accordance with Welding Research Council (WRC) Bulletin 452. WRC Bulletin 452 provides guidelines for local PWHT in terms of soak bands (SB), heated bands (HB), and gradient control bands (GCB) that are necessary to avoid unacceptable thermal gradients that can result in high residual stresses. Local PWHT typically takes place in a circumferential band or as a symmetrical spot on spherical heads.

Local PWHT for new coke drums should be performed in a full circumferential (360°) band. All thermocouples should be placed on the opposite side of the shell from the heating elements. Temperature gradients need to be "softened" by employing heated and gradient bands as outlined in 1) through 3) below. Figure 25 illustrates the dimensions for the soak band, heated bands, and thermal gradient control bands for the PWHT of a drum, as provided in the guidelines of WRC Bulletin 452.

1) Soak Band. The soak band width that is exposed to the full PWHT temperature $T1$ needs to extend for a distance of at least $2t$ beyond each edge of the weld, where t is the nominal base metal thickness at the weld.

2) Heated Band. The temperature decay along the longitudinal axis of the vessel should be controlled at a distance equal to $2\sqrt{Rt}$ from the edge of the soak band, where R is the internal radius of the vessel shell and t is the nominal base metal thickness at the weld. The temperature $T2$ at this point should nominally be one-half of the actual PWHT temperature $T1$ maintained at the weld. The tolerance used for temperature $T2$ shall be +100 °F (56 °C) / –0 °F (0 °C). Additional heating elements may be required in this area to ensure that the target temperature is achieved and maintained.

3) Gradient Control Band. Thermal insulation should be applied to both the internal and external surfaces of the vessel in the areas of all heating elements to facilitate heat conservation and to control the temperature gradient along the shell. Insulation needs to extend a distance of at least $2\sqrt{Rt}$ beyond the edge of the heated band.

   a) Local PWHT bands should be located a sufficient distance away from the nozzle and manhole attachments to ensure they do not influence the smooth temperature gradient down the shell. When this is not feasible, the band widths need to be increased as necessary to fully encompass the nozzle or manhole and the attachment should be completely insulated and heated during the PWHT operation.

   b) Proposals to use heating band and insulation configurations different from those depicted in Figure 25 should be supported by an elastic-plastic stress analysis to show that the residual stress in the vessel after local PWHT and hydrostatic test does not exceed 50 % of the base material specified minimum yield strength. Refer to WRC Bulletin 452 for details.

   c) Spot (bull's-eye) PWHT should not be permitted on cylindrical shells. Spot PWHT may be performed on the spherical portion of heads only when approved by the buyer. Proposals need to be supported by sufficient analysis, as outlined in item b), above.

Gas firing or blowing of hot gas from a burner for PWHT is a low-cost option for PWHT, but this should be carried out in a carefully controlled manner. The biggest concern with internal firing for PWHT is the stratification of the heated gas. If the gas flow is left uncontrolled, hotter gases will rise vertically, causing hot spots on the drum shell. This can cause high thermal gradients and excessive residual stresses in the drum after the PWHT. In a properly designed gas fired PWHT procedure, insulation, baffles, and mechanical controls are used inside the coke drum to control the gas flow to ensure even heating.

Changes to material properties, such as tensile strength and Charpy impact toughness, occur during PWHT. Both

Commented [AB42]: Cathy's comment: "Check if this is typically done. It would require ID scaffolding."

Commented [DC43R42]: Typically, the drums are on their side to facilitate sub-arc welding. Therefore, it's not that difficult to attach TC's.

Commented [AB44]: Cathy's comment: "Per UW-40(a) this is 1 t on either side, and a max of 2". "

Commented [DC45R44]: But in WRC 452, it is indeed 2t, not 1t.

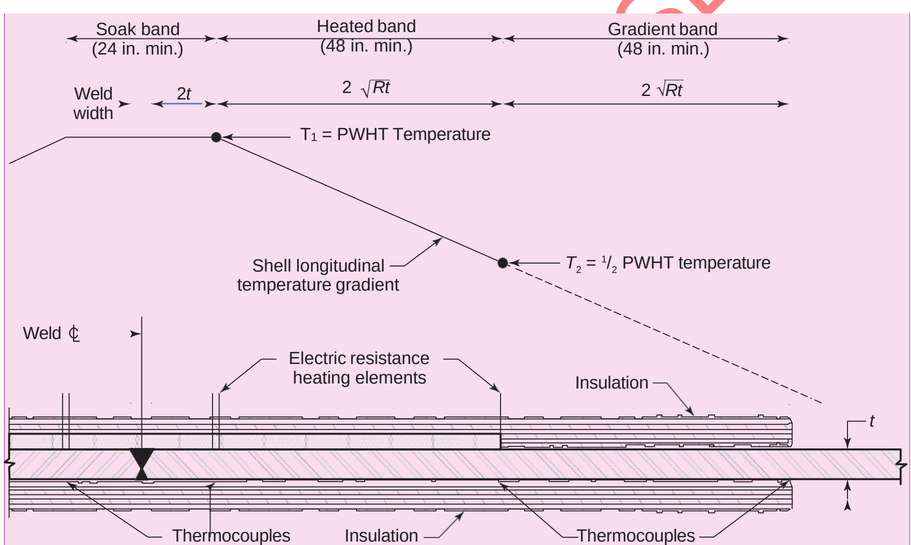
Commented [AB46]: Cathy's comment: "I could not find this in WRC 452 (the closest comment was in section 6.4). Does anyone know the history?"

Commented [BJJ47]: Comment 32

Commented [DC48R47]: I don't see a reason to delete gas firing.

base material and weld material are qualified for a specified PWHT time and temperature. Typically, the weld procedure qualification will include both a minimum and maximum PWHT combination of time at temperature. The minimum PWHT condition will reflect a minimum temperature for a minimum amount of time, while a maximum PWHT condition will reflect a maximum amount of time at the maximum temperature not only for one PWHT cycle during fabrication, but also a PWHT cycle after a repair during initial fabrication and several additional repairs during the life of the drum. The vendor will determine the amount of maximum PWHT time at the temperature required for material qualification based on the purchaser's specified number of repair cycles. Larson-Miller Parameter (LMP) calculations should be used to account for the time at temperature for all temperatures above 900°F (480°C) during a PWHT cycle. Material property tests are conducted for the minimum and maximum PWHT conditions.

The coke drum must be analyzed for the PWHT conditions to ensure the drum will not buckle, deform or induce damaging residual stresses during PWHT or local PWHT. Typically, these analyses are performed using a thermo-mechanical finite element analysis (FEA). The analysis needs to use the material properties of the steel at PWHT temperatures. Selecting the correct material properties for the analysis of structural integrity during PWHT is critical. The analysis needs to include the effects of time-dependent creep and high thermo-mechanical stresses created by temperature gradients and geometric discontinuities. This type of analysis should also identify locations for support spiders that are placed on the inside of the drum. Additionally, the number, size, and angle for support saddles on the outside of the drum can be determined from this analysis.



NOTE This drawing only shows one side of the heated bands and the thermal gradient bands.

Figure 25—WRC Bulletin PWHT Heating and Insulating Details

6.6 QA and QC Requirements

6.6.1 General

Coke drums are normally manufactured in accordance with the requirements of the applicable design code and additional requirements specified by the owner/operator. To ensure these requirements are met, manufacturers should comply with their written QA/QC program, which typically is reviewed with the purchaser and sometimes

Commented [BJJ49]: Comment 34, 35 and 36

Commented [AB50]: Cathy's comment:

"Why is the SB 24" minimum? Thinner walls would have a much narrower band. Also, why is the HB 48 in min? and instead of 2.5* sr. rt Rt text has 2*. Also, Sec. VIII requires 1t on each side of weld for SB not 2t, and it is not clear in WRC 452 that they intend to exceed Code on the SB."

Commented [AB51]: Cathy's comment:

"The symbology is unclear, and the arrows may not point to the right spots for the insulation. Why are there so many little items along the shell? Why does the outside of the insulation have uneven bands? Much of this figure is great for showing the concepts, we just need to get it to be clearer. I'll contact Superheat if we don't know the source and the proper corrections."

modified as needed and as agreed with the purchaser for the specific purposes of the coke drum fabrication. This program should clearly define the responsibilities of the manufacturer, purchaser, purchaser's QA and QC authority, and shop inspector(s).

6.6.2 Manufacturer's Responsibilities

Responsibilities of the manufacturer typically include:

a. obtaining and reviewing all fabrication requirements and related documentation, and following them during the manufacturing of the coke drum to ensure requirements are met;

b. notifying the purchaser of any known deficiencies, non-conformances, or other deviations to the coke drum design/fabrication requirements;

c. complying with company quality assurance requirements;

d. cooperating with the shop inspector by permitting access to all areas used for the manufacturing of the purchaser's equipment; and,

e. providing copies of all documentation relating to quality control to the purchaser or purchaser's representative, e.g. shop inspector, on request.

The manufacturer should have and maintain a documented QA and QC Control System and a Quality Assurance Manual that establishes all code requirements, including materials of construction, design and fabrication details, and inspection requirements for vessels and vessel parts.

6.6.3 Purchaser's Responsibilities

The purchaser typically has the following responsibilities (in addition to the other responsibilities listed in API RP 588x):

a. To provide information in all bid and purchase order drawings and documents to adequately describe the Purchaser's design and manufacturing requirements (i.e. those not already specified by the ASME Code) necessary to properly fabricate the coke drum so that it will fulfill its intended use safely and reliably.

b. To determine the amount and intensity of inspection to ensure that the manufacturer has met the requirements of the purchase order.

c. To review any problems associated with the coke drum manufacture and ensure that all problems are resolved by the manufacturer or otherwise to the satisfaction of the Purchaser before commissioning the drum.

6.6.4 Shop Inspector's Responsibilities

The shop inspector is typically responsible for the following (in addition to the other responsibilities listed in API RP 588):

a. providing inspection at the manufacturer's site by auditing, reviewing, witnessing, and inspecting selected elements of the manufacturing process, as specified in the purchaser's inspection checklists and other appropriate documents;

b. remaining alert to all items of manufacturing which may impact the quality of the coke drum;

c. notifying the purchaser of any deficiencies and non-conformances observed during these inspections;

d. documenting all inspections on appropriate forms which will become part of the owner's/operator's permanent coke drum file.

6.6.5 Inspection and Nondestructive Examination Activities of the QA and QC Program

Quality assurance and quality control programs typically include an inspection and test plan (ITP) which includes a list of nondestructive examination (NDE) activities that provides the basis of a shop inspector's verifications when visiting the manufacturer. The suggested content of ITPs is given in API RP 588. The manufacturer's ITP is used by the Purchaser and Shop Inspector to develop a plan for the Owner's inspection program which typically may include the frequency of the Shop Inspector visits, the level of inspection, and the extent of inspection to be performed. All activities of the shop inspector during the manufacturing phase are normally documented to serve as a permanent record of the quality assurance performed. This documentation may also serve as elements and verification of the communication between the purchaser, owner/operator, his or her QA and QC authority, manufacturer, and shop

Commented [AB52]: Cathy's comment:

"This section is inconsistent on capitalization of Purchaser and other similar entities."

Commented [SAJ53]: See suggestion in Section 8, about: 1) adding some wording on how important is to conduct baseline inspections; 2) for in-service inspection/monitoring should be per API TR 934J)

Commented [BDR54R53]: This is covered in a new section and rewrite as requested (below in Section 7).

Commented [BJJ55]: Comment 39

inspector.

The inspection and NDE list of activities varies with specific owner/operators, but it should contain summaries of at least the following planned activities:

a. inspection of base material before manufacturing,
b. positive material identification (PMI),
c. visual inspection (VT),
d. dye penetrant examination (PT),
e. magnetic particle examination (MT),
f. radiographic examination (RT),
g. ultrasonic examination (UT),
h. QA and QC considerations for repairs during fabrication,
i. other inspection and NDE considerations during fabrication,
j. QA and QC program considerations for the hydrostatic test,
k. QA and QC program considerations for PWHT.

7 Initial Inspection and Monitoring

7.1 General Inspection Considerations

Coke drum inspections are performed to find and measure the extent of damage that occurs over time. As this document (API TR 934G) is concerned with the fabrication and installation of a new coke drum, service-related inspections are not addressed. Please refer to:

1) For source inspection, QA/QC of fabrication, see Section 6 of this document.
2) For inspection, after the coke drum has been placed into service, see Section 5 of API TR 934-J.

Coke drums are prone to the accumulation of wear, fatigue, and other physically damaging effects. (See API TR 934-J for examples.) Some of these effects may be due to flaws induced by fabrication or original material issues therefore, it is important to have a thorough inspection of the new drum prior to putting it into service. For example, during observations at future inspections, the degree of cracking at welds will depend on the vessel design and fabrication (e.g., whether or not the welds were ground flush during fabrication). Additionally, other damage may occur and will also depend on vessel design and fabrication, as well as operation (e.g., bulging, thinning, cladding damage, etc.). Thus, a baseline inspection is typically performed to measure critical areas so that the original condition may be compared to the future observed condition.

In general, new drums do not require an initial internal inspection until after the first 4 to 6 years of service. However, external inspections should occur regularly and can be tied into observations from operator rounds. These regular inspections can help plan for the remediation of observed damage. (See API TR 934J for further information on in-service inspections.)

7.2 Baseline Inspection Considerations

Baseline inspections may encompass several different methods and techniques. However, these are generally constrained to VT and UT. It has been noted that some operators are using laser scanning (i.e., laser mapping) on new drums to create a baseline of the shell section before placing drums in service. These baseline scans may reveal the existence of initial bulges formed by the fabrication process and can be accounted for in future inspections. Additionally, a visual record (e.g., video, photographs) can be used as part of a baseline record.

The owner-operator may select the baseline inspection methods needed for their situation, and use industry-accepted procedures, processes, etc. to complete, evaluate, and document as needed. A baseline inspection checklist may include: a representative thickness of each plate of each shell course (including the cone and heads); a laser scan of the ID; a review of the weld profiles; check for vertical alignment (tilting should be zero); and visual inspection of the skirt, keyholes, and peripheral attachments.

7.3 Initial Placement of Strain Gages and Thermocouples to Monitor Drum Damage

Strain gages (SG) and thermocouples (TC) provide the backbone of a health monitoring system (HMS) for a coke drum. An HMS can be specified and put in place when a new coke drum is installed. Gathering this type of data from the moment the operation starts can help one understand where the operation needs modifications to improve coke drum life. The SG/TC locations are typically initially placed at predicted areas of concern. Note, the predicted areas of concern are usually determined from historical data (both from industry and the owner-operator) on similarly sized and similarly operated coke drums. Also, a review of the previous API surveys may provide guidance on such areas to use in the initial monitoring. However, as the coke drum ages, these locations may need to be moved or added based on observed damage. (See API TR 934-J for further information.) There is no specific suggestion for the initial number of SG/TC locations, but there should be enough to gather information for process improvements and life cycle management.

Typical baseline locations for SG/TC instrumentation include the shell-to-cone weld area, locations to track quench effects, high-stress areas in the middle shell course welds, and areas where the feed stream may impact the pressure boundary.

At the time of design, consideration for connectivity to a data warehouse needs to be discussed. The question of what one would do with the data collected by the SG/TC locations needs to be answered. The analysis and use of the data also need to be considered and planned. HMS data can be beneficial in analyzing the operation of the coke drum (e.g., quench cycle analysis and modification) with regard to life cycle planning, but only if proper planning is implemented.

Commented [BJJ56]: Comment 40

Commented [DC57R56]: I did a bit of modification, but overall it doesn't seem choppy to me. If Cathy wants to propose alternate wording, that would be fine.

8 Peripheral Equipment

8.1 General

This section discusses peripheral equipment associated with the coke drum and generally not associated with the drum pressure boundary. For this document, the peripheral equipment includes the feed nozzle(s), unheading valves, and foundation bolting. Other equipment, such as overhead piping and feed transfer lines, are not included, even though there is experience that suggests these piping circuits do have problems. In general, problems associated with these piping circuits have been attributed to designs that lack adequate support and/or flexibility. A thorough piping flexibility analysis normally can identify problems in these piping circuits and provide guidance on how best to mitigate them.

8.2 Feed Nozzle Location/Details

Side entry feed nozzles in the conical section of coke drums have been used for some time, with many installed in the 1960s. Since unheading valves have been installed on the bottom of coke drums, the use of side entry nozzles has been increasing because unheading valves require an alternate location for the feed lines, which in the past were normally located in the center of the bottom cover.

When unheading valves are utilized, a common design employs feed entry through a single nozzle located below the bottom conical knuckle or within a conical transition. In other cases, the entry has been a single nozzle in the drum cone. Some designs have included inlet nozzle upsweeps to direct the flow upwards and into the drum, while others used horizontal nozzles and nozzles in drum cones.

Some designs in new or replacement coke drums where un-heading valves are used, employ dual entry nozzles with diametrically opposed inlet nozzles. Dual entry nozzles are sometimes installed in existing coke drums when un-heading valves are to be retrofitted.

The purpose of a dual inlet is to better achieve fluid upflow from the center of the bottom. A positive attribute of this flow pattern is a reduction in the impingement of hot feed on the opposite side cone or cylindrical shell wall. Impingement of hot fluid can promote "hot spots" and/or "cold spots" on the vessel wall during feed or quench cycles, which, in turn, can generate large local stresses. These stresses can significantly reduce the fatigue lives of coke drums.

It appears that dual-entry nozzles have worked well in certain coke drums, while in other drums dual entry nozzles appear to not have operated as well. Currently, more data and operating experience are necessary to objectively assess the effects of these designs on the drum coking process and coke drum fatigue life.

IIn the approximate 2015 – 2016 time frame, a center feed nozzle was introduced… For a particular set of mass flow rates and process fluid properties (e.g. momentum), it appears a central entry nozzle can be tuned to reduce thermal stresses due to the impingement of hot feed and quench water on the coke drum shell. At the time of this publication, only a few coke drums (one coker unit) have been fitted with a central entry nozzle. After 1 year of service, it appears that compared to a single side entry nozzle, the use of a single central entry nozzle has reduced thermal loads, resulting in less coke drum movement, vibration, and bowing. No comparison has been provided for center single entry and dual entry conditions.

8.3 Top and Bottom Unheading Design

In early designs, coke drum bottom heads were hinged and a pair of hydraulic cylinders held the heads in place while un-heading operators removed flange studs manually. After stud removal, these hydraulic cylinders were actuated to lower the head, swing it out of the way, and permit a discharge chute to be raised and mated with the coke drum flange. Operators were still required to be in the vicinity of an open drum to raise the deck chute.

Un-heading systems were developed and first installed in 1988. While the new unheading system was a significant improvement, operators still had to work in proximity to the open drum to raise the discharge chutes. This early system was further improved by the addition of automated discharge chutes that were hydraulically raised from the deck and automatically locked to the coke drum head. However, operators still had to undo the head studs, clean the drum cover flange, and reinstall and tighten the studs, causing the operator to be in an unsafe location as the heads were lowered and the chutes were raised. Ultimately, a completely automated top and bottom head system was developed that relied on a series of tapered rollers riding on ramps to provide the motive force to provide positive closure.

Commented [RBD58]: More information will be provided for this section. Per discussions with other vendors, and will not be commercial. Primarily about center feed devices.

Subdivide this into:
1)Single feed
2)Dual feed
3)Center feed

Flange strength needs to be addressed at a high level. Fit-for-purpose.

<Antoinio Volunteers HERE!>

Commented [BJJ59]: Comment 47

Commented [DC60R59]: I don't know when side entry nozzles were first used, and if they were used well before unheading devices.

Commented [BJJ61]: Comment 45

Commented [BJJ62]: More valves installed by now - Comment 44

Commented [BJJ63]: Comment 46 (2016)

Commented [BJJ64]: Comment 51

Commented [BJJ65]: Comment 48

Commented [DC66R65]: I revised the wording to what I think the original writer of this paragraph meant. Check it out.

While the next unheading system design also included hinged heads that swung out of the way and automated discharge chutes, this system's head studs were automatically tightened/untightened, obviating the need for unheading operators to be in proximity of the coke drums.

The most recent coke drum unheading design utilizes a bottom valve, eliminating the need for operators to be present on the switch deck during the unheading process.

The first fully automated system was removed for a thorough inspection after 5 years of operation to determine whether wear or degradation had taken place. While the slide valve showed some wear (grooves) and the springs were coked (lost steam), the design showed merit.

The fully automated system contains both top and bottom unheading valves. The bottom device [available in 54 in. (1.372 m) and 60 in. (1.52 m) sizes] is a flanged slide valve separating the coke drum from the discharge duct. The top automated un-heading systems are typically available in 30 in. (0.762 m), 36 in. (0.914 m), and 42 in. (1.07 m) sizes. These systems are now in widespread use and many existing units have been retrofitted with these designs.

Slide valves are hydraulically operated. A single hydraulic cylinder moves the gate horizontally between the upper seat (dynamic) and the lower (static) seat. The system is purged with steam to mitigate the flow of resid in the drum and into the unheading valve body. This automated bottom un-heading valve system can be fully opened or closed in approximately three minutes, depending on the hydraulic system.

Slide valves are normally supported by spring cans and trolleys mounted to overhead beams, permitting valve installation and removal during maintenance, if needed. Installation of this automated un-heading system on existing coke drums requires rework of the feed nozzle and associated feed piping, as the feed nozzle is required to be located either in the drum cone or in the drum cylindrical section immediately above the drum bottom flange. The original system also required cooling water to keep hydraulic cylinder rods cool. A more recent design eliminates the need for hydraulic system cooling water and provides a larger live-loaded (steam + springs) seat design.

The unheading system also requires steam to provide a positive pressure differential between the drum and the valve body so that any leakage across the gate seats occurs into the drum and not into the valve body. Steam also cools the upper part of the valve body, maintaining the valve body at a relatively constant temperature. The steam purge system also requires an associated condensate drain system that can cope effectively with contaminants. Continuous monitoring of purge steam consumption provides a good tool for determining gate and seat wear trends.

During engineering design, it is prudent to verify compliance with NACE MR0103, where necessary, and that the coking unit sour water system can handle the additional sour water generated by un-heading valve purge steam leaking into the coke drums.

Recent automated unheading valve designs permit upper and lower valve components to be disengaged from each other for maintenance and or inspection.

Both automated unheading systems include a drill stem guide/cutting tool enclosure to complement a top head cutting system. It also has a feature that permits an automated change in the cutting tool that switches from pilot mode to side cutting mode, triggered by a change in the cutting water pressure.

A second supplier of automated unheading systems provides valves with two independent floating discs with a triple seal system for each disc. This design was originally developed as an isolation valve for ethylene service but was later modified for coke drum unheading service. The bottom unheading valves are supplied in a nominal 60 in. (1.52 m) size, while the top is typically 30 in. (0.762 m) or 36 in. (0.914 m). The valves have double block and purge features. The required force to seat the discs against the seals is provided by a wedge system that increases the force as the stroke advances to a full stop. Sealing is also facilitated by purge steam pressure. In the mid-stroke and open positions, the upper dynamic seal provides tightness to the valve body and additional loading in the closed position.

This valve design does not require cooling water but does require that the drum feed line be modified for entry into the drum above the un-heading valve installation, either in the drum cone or in the cylindrical section below the cone. Like its competitor, this valve requires steam purge and condensate drain systems and may require steam relief systems to protect the valves against excessive steam pressure. These valves require a hydraulic power unit (HPU) to provide the requisite motive force to dual hydraulic actuators.

Both of these automated unheading system suppliers typically provide programmable logic controllers to sequence operations. They also provide electrically-powered actuators in lieu of hydraulic actuators.

8.4 Foundation Bolting

Experience shows that foundation bolting can crack as a result of movement, including rotation of the base plate on the drum support skirt. Skirt movement promotes high shear and tensile loads on the bolting that eventually can lead to bolt cracking. In most cases, movement of the base plate can be accommodated by slotting the bolt holes to reduce the shear loads imposed on the bolting.

Commented [BJJ67]: Comment 52

Commented [DC68R67]: To answer Cathy's question, I'd think this recommendation would be beneficial for new designs, not just retrofit or repairs.

Bibliography

[1] API 510, *Pressure Vessel Inspection Code: In-Service Inspection, Rating, Repair, and Alterations*

[2] API Recommended Practice 582, *Welding Guidelines for the Chemical, Oil, and Gas Industries*

[3] API Recommended Practice 934-C, *Materials & Fabrication of 1-1/4Cr-1/2Mo Steel Heavy Wall Pressure Vessels for High-Pressure Hydrogen Service Operating at or Below 825 °F (441 °C)*

[4] API Recommended Practice 934-E, *Recommended Practice for Materials and Fabrication of 1-1/4 Cr- 1/2Mo Steel Pressure Vessels for Service above 825 °F (440 °C)*

[5] API Proceedings of 1958, Volume 38, Weil N. A. and Rapasky F. S., *Experience of Vessels of Delayed Coking Units*

[6] API Proceeding of 1980, Pressure and Tanks Developments, Tomas, J. W., *API Survey of Coke Drums Cracking Experience*

[7] API Final Report, *1996 API Coke Drum Survey*

[8] API Standard 579-1/ASME FFS -1, *Fitness-For-Service*

[9] ASME *Boiler and Pressure Vessel Code* [1], Section II–*Materials;* Part A–*Ferrous Material Specifications;* Part C, *Specification for Welding Rods, Electrodes, and Filler Metals;* Part D–*Properties*

[10] ASME B16.5, *Pipe Flanges, and Flanged Fittings*

[11] ASME B16.20, *Ring-Joint Gaskets and Grooves for Steel Pipe Flanges*

[12] ASME B16.47, *Large Diameter Flanges*

[13] ASME *Boiler and Pressure Vessel Code,* Section V–*Nondestructive Examination*

[14] ASME *Boiler and Pressure Vessel Code,* Section VIII–*Rules for Construction of Pressure Vessels,* Division 1

[15] ASME *Boiler and Pressure Vessel Code,* Section VIII–*Rules for Construction of Pressure Vessels,* Division 2

[16] ASME *Boiler and Pressure Vessel Code,* Section IX–*Welding and Brazing Qualifications*

[17] ASME *Post Construction Code PCC-2, Repair of Pressure Vessel Equipment and Piping*

[18] ASME SA-20, *Specification for General Requirements for Steel Plates for Pressure Vessels*

[19] ASME SA-182, *Specification for Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service*

[20] ASME SA-193, *Specification for Alloy-Steel and Stainless Steel Bolting Materials for High Temperature or High-Pressure Service and Other Special Purpose Applications Specification for Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service*

[21] ASME SA-194, *Specification for Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service*

[1] ASME International, 2 Park Avenue, New York, New York 10016-5990, www.asme.org.

[22] ASME SA-263, *Standard Specification for Corrosion-Resisting Chromium Steel-Clad Plate, Sheet, and Strip*

[23] ASME SA-264, *Standard Specification for Stainless Chromium-Nickel Steel-Clad, Sheet and Strip*

[24] ASME SA-335, *Standard Specification for Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service*

[25] ASME SA-336, *Standard Specification for Alloy Steel Forgings for Pressure and High-Temperature Parts*

[26] ASME SA-369, *Carbon and Ferritic Alloy Steel Forged and Bored Pipe for High-Temperature Service*

[27] ASME SA-387, *Standard Specification for Pressure Vessel Plates, Alloy Steel, Chromium-Molybdenum*

[28] ASME SA-435, *Standard Specification for Straight-Beam Ultrasonic Examination of Steel Plates*

[29] ASME SA-516, *Specification for Pressure Vessel Plates, Carbon Steel, for Moderates- and Lower-Temperature Service*

[30] ASME SA-578, *Standard Specification for Straight-Beam Ultrasonic Examination of Rolled Steel Plated for Special Applications*

[31] ASNT RP SNT-TC-1A [2], *Personnel Qualification and Certification in Nondestructive Testing*

[32] ASTM A263 [3], *Standard Specification for Stainless Chromium Steel-Clad Plate*

[33] ASTM A380, *Standard Practice for Cleaning and Descaling Stainless Steel Parts, Equipment, and Systems*

[34] ASTM G146, *Standard Practice for Evaluation of Disbonding of Bimetallic Stainless Alloy/Steel Plate for Use in High-Pressure, High-Temperature Refinery Hydrogen Service*

[35] AWS A4.2 [4], *Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Austenitic-Ferritic Stainless Steel Weld Metal*

[36] AWS A4.3, *Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding*

[37] NB, National Board Inspection Code (NBIC) Part 3 [5], *Repairs and Alterations*

[38] SSPC-SP-10 [6], *Near-White Blast Cleaning*

[39] WRC Bulletin 342 [7], *Stainless Steel Weld Metal: Prediction of Ferrite Content*

[40] WRC Bulletin 452, *Recommended Practices for Local Heating of Welds in Pressure Vessels*

[41] S.S. Manson, *Experimental Mechanics*, Volume 5 (Number 7), 1965, page 1932

[2] American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, Ohio 43228, www.asnt.org.
[3] ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.
[4] American Welding Society, 8669 NW 36 Street, #130, Miami, Florida 33166-6672, www.aws.org.
[5] The National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Avenue, Columbus, Ohio 43229, www.nationalboard.org.
[6] The Society for Protective Coatings (previously the Steel Structures Painting Council), 40 24th Street, 6th Floor, Pittsburgh, Pennsylvania 15222, www.sspc.org.
[7] The Welding Research Council, P.O. Box 201547, Shaker Heights, Ohio 44122, www.forengineers.org.

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