

Design, Fabrication, Operational Effects, Inspection, Assessment, and Repair of Coke Drums and Peripheral Components in Delayed Coking Units

API TECHNICAL REPORT 934-G
FIRST EDITION, APRIL 2016



AMERICAN PETROLEUM INSTITUTE

Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be utilized. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

Users of this Technical Report should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

All rights reserved. No part of this work may be reproduced, translated, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the Publisher, API Publishing Services, 1220 L Street, NW, Washington, DC 20005.

Copyright © 2015 American Petroleum Institute

Foreword

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, DC 20005, standards@api.org.

Contents

	Page
1 Scope	1
2 Normative References	1
3 Terms, Definitions, and Acronyms	1
3.1 Terms and Definitions	1
3.2 Acronyms	3
4 Background	3
4.1 General Information	3
4.2 API Survey of Experience	4
4.3 Degradation Mechanism(s)	8
5 Design	18
5.1 General	18
5.2 Design Approaches	18
5.3 Materials Selection Including Plate Material, Welding Consumables, and Cladding	19
5.4 Thickness Considerations	22
5.5 Fatigue Design Considerations	22
5.6 Skirt and Vessel Support Details	23
5.7 Insulation Details (including Hot Box details)	27
5.8 Tolerances for New Coke Drums	31
6 Fabrication	34
6.1 General	34
6.2 Weld Joint Design Details, Including Finishing	34
6.3 Clad Restoration Welds	35
6.4 Weld Property Requirements	35
6.5 PWHT Requirements	36
6.6 QA and QC Requirements	38
7 Effects of Operating Practices on Drum Reliability	40
7.1 General	40
7.2 Effect of Drum Cycle Time	40
7.3 Quench Portion of the Operating Cycle	40
7.4 Feed Injection Portion of the Operating Cycle	40
7.5 Drum Preheat	41
7.6 Manufacture of Fuel Grade Shot Coke	41
7.7 Analyzing the Effect of Changes in Operating Practices on Drum Reliability	41
8 Inspection and Monitoring	43
8.1 General Inspection Considerations	43
8.2 Bulging Inspection Method	43
8.3 Cracking Inspection Methods	43
8.4 Frequency of Inspection	44
8.5 Use of Strain Gages and Shell Temperature Measurements to Monitor Drum Damage	46
8.6 Monitoring for Drum Bowing or Tilting	46
9 Condition Assessment	47
10 Repairs	47
10.1 General	47
10.2 Types of Coke Drum Repairs	47

Contents

	Page
10.3 Minor Shell Replacements in Coke Drums	50
10.4 Major Replacements in Coke Drums	51
10.5 PWHT Versus Temper Bead Welding	51
11 Peripheral Equipment	52
11.1 General	52
11.2 Feed Nozzle Location/Details	53
11.3 Top and Bottom Unheading Design	53
11.4 Foundation Bolting	55
Bibliography	56

Figures

1 Typical Drum Heating and Cooling Cycle	4
2 Correlation Between Drum Shell Thickness and D/t Ratio and Time to Bulging	7
3 Overview of Coke Drum Thermal Cycling Damage	9
4 Early 1960s Photo Showing Typical Bulging Observed in Drums Used in Delayed Coking Units	11
5 Circumferential Weld Crack Between the Nickel-based Restoration Weld and 12Cr Cladding	12
6 Typical Cracking Observed at Skirt-to-Bottom Head Weld	12
7 Keyhole Skirt-to-Bottom Head Weld Cracks	13
8 Coke Drum Bottom Cone Cracks	13
9a Internal Surface Bulge Cracks	14
9b External Surface Bulge Cracks	14
10 Bowed Drum in a Delayed Coking Unit	15
11 Corrosion of 12Cr Cladding in a Coke Drum Upper Section	17
12 A Typical Sectional Plate Layout Used to Minimize Plate Strength and Thickness Mismatch	20
13 Typical Skirt-to-Shell Fillet Weld Detail Used in Earlier Drum Construction	24
14 Skirt-to-Shell Detail of a Modified Fillet Weld with an Internal Weld Crotch Radius to Reduce Stress at the Weld	24
15 Forged Skirt-to-Shell Attachment Detail Removes Welds from High Stress Areas	25
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	25
17 Typical Details for Coke Drum Skirt Keyholes	26
18 General Details for the Insulation System on Drums in Coking Units	28
19 Insulation Support System with Pins/studs Welded to the Shell, Heads, and Cones	29
20 Insulation Support System with Clips Welded to the Shell With Segmented Rings Connected to the Clips by Bolts	29
21 Insulation Support System with Clips Welded to the Shell Supporting Floating Rings	30
22 Insulation Support System with Bird Cage Type Supports with a Floating Ring	31
23 Typical "Hot Box" Insulation Details at the Shell-to-Skirt Connection	32
24 Typical Tolerances Specified for Drums in Coking Units	33
25 WRC Bulletin PWHT Heating and Insulating Details	38

Tables

1 Factors Used in Evaluating the Change in a Coke Drum Operating Cycle Time	42
2 Typical Onstream and Downtime Inspection Techniques and Frequencies for Coke Drums	45

Design, Fabrication, Operational Effects, Inspection, Assessment, and Repair 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 on the design, fabrication, operation, inspection, assessment and repair 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, or inspection tools, operating devices/components, repairs techniques, and/or engineering assessments offered by contractors. 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 industry and is not an API Recommended Practice for coke drums in delayed coking units.**

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 are included in the bibliography.

3 Terms, Definitions, and Acronyms

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

3.1 Terms and Definitions

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 through 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.

3.1.3

fracture ductility

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

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

where

RA is reduction in area during a tensile test.

3.1.4

Larson-Miller parameter (LMP)

Formula for evaluating the effect time at temperature has on 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 to be agreed upon by 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 to be agreed upon by 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 inspection during fabrication of the coke drum while following the quality assurance and quality control program.

3.2 Acronyms

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

ACFM	alternating current field measurement
AE	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
LPWHT	local post weld heat treatment
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

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 reheating. 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 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 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.

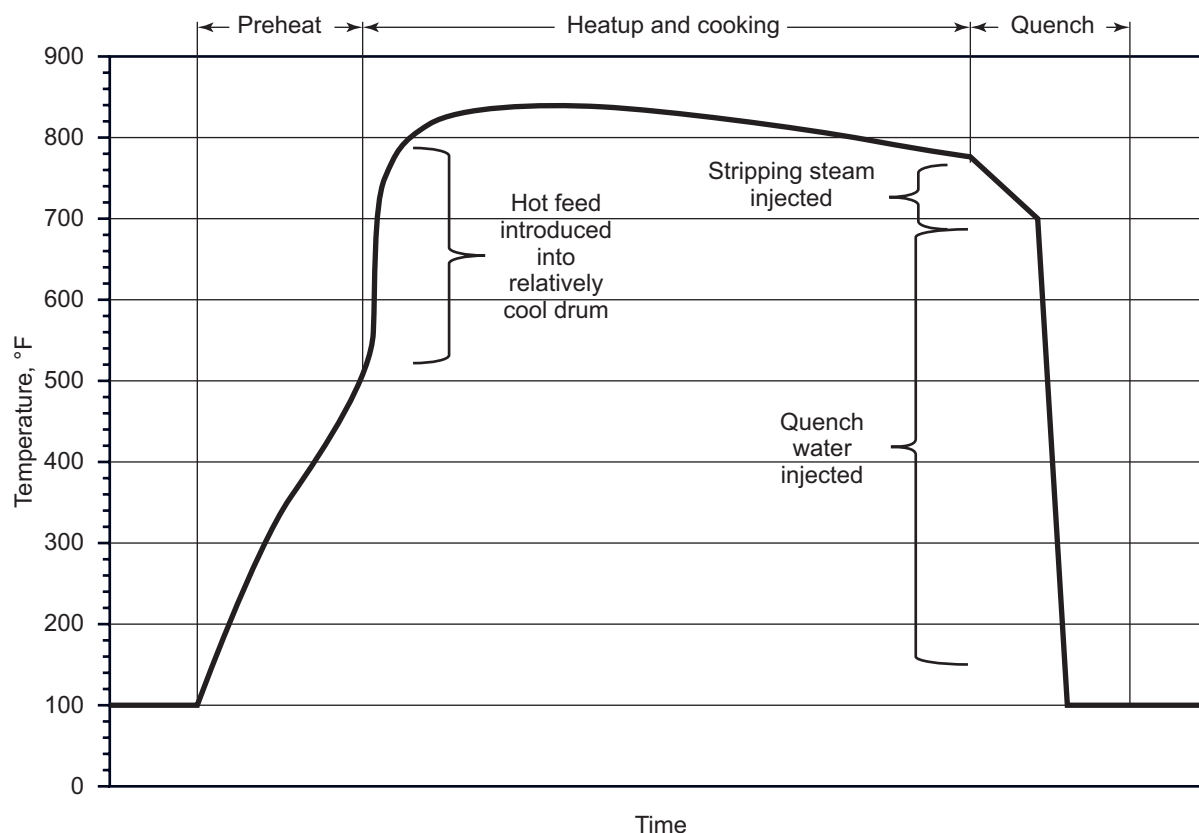


Figure 1—Typical Drum Heating and Cooling Cycle

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 a 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.

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 has 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 interest in improving the reliability of these drums. The summaries of the survey results are in 4.2.2 through 4.2.5.

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 increasingly embrittled with 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.
- 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 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 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 this 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 2500 years of coke drum service. The results from this recent survey are as follows.

- 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.
- 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.
- Approximately 75 % of respondents reported that their drums' shell, cone and top of the skirt were fabricated from either 1Cr- $\frac{1}{2}$ Mo or 1 $\frac{1}{4}$ Cr- $\frac{1}{2}$ Mo. 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.
- An evaluation of responses related to the type of coke (shot, sponge, and needle) and coke hardness showed no relation to the tendency for cracking and/or bulging.
- 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.
- 98 % of the respondents indicated that coke drum failures do not result in a major consequence other than business interruption.
- 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.

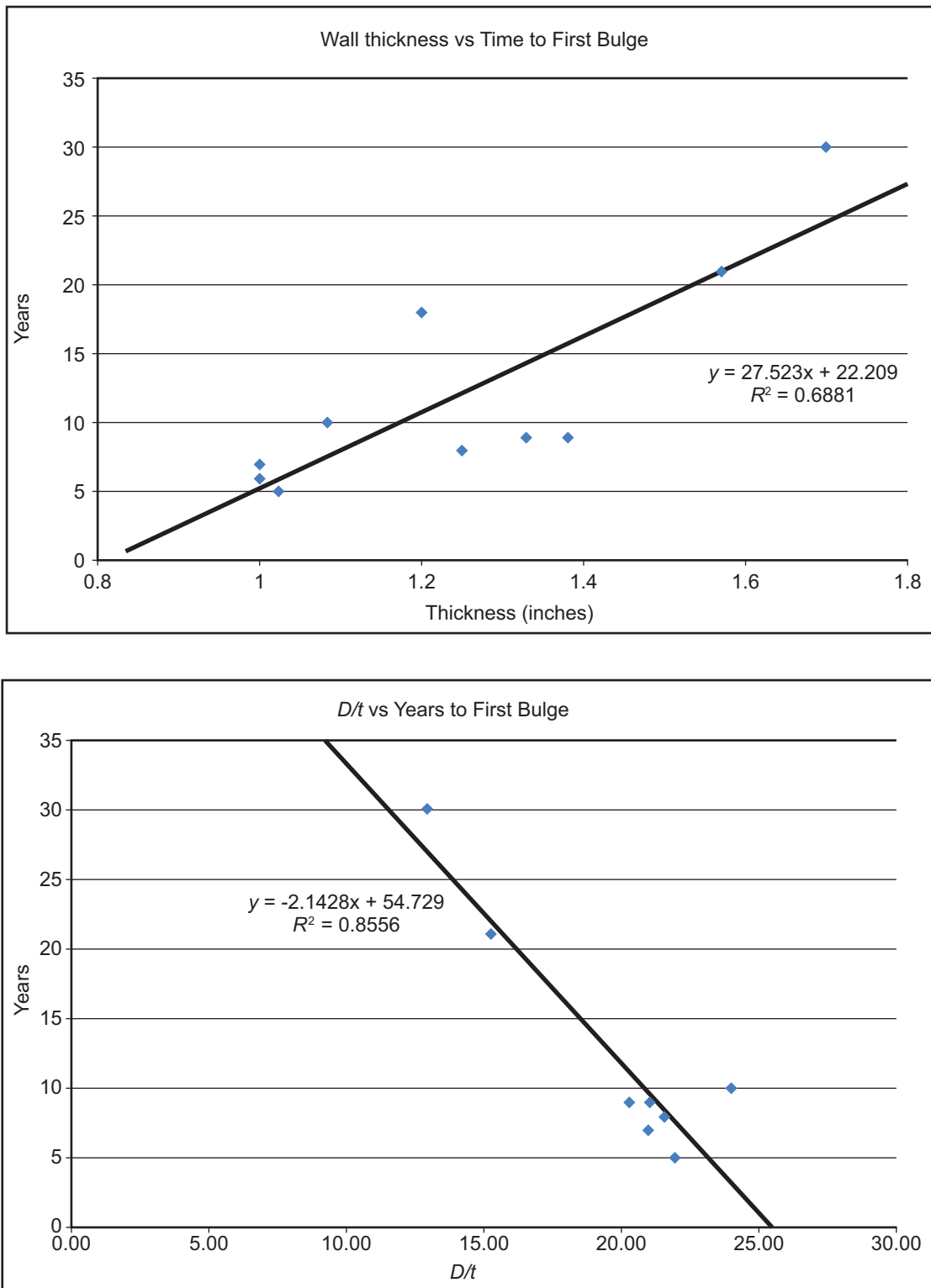


Figure 2—Correlation Between Drum Shell Thickness and *D/t* Ratio and Time to Bulging

- 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.
- 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 coarse replacement and weld overlay. Additionally, almost all reported performing these repairs with and without PWHT.
- The response to detailed questions regarding 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.
- 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 need for repairs, or to optimize operations during the cycle (such as during hot feed introduction and addition of quench water).
- Only 25 % of the respondents noticed an increase in anchor bolt problems.

4.3 Degradation Mechanism(s)

4.3.1 Commonly Observed Damage

4.3.1.1 General

Traditionally, drums in delayed coking units experience severe thermal cycling in normal operation, and as a result, incur various forms of damage. Figure 3 illustrates various forms of cracking and bulging damage due to thermally cycling encountered on drums. This “damage map” for coke drums provides general information on the nature of the damage and location on the drum where damage can be expected. Most damage observed in coke drums occurs as a result of thermo-mechanical loads experienced during each operating cycle. As illustrated in Figure 1, a coke drum

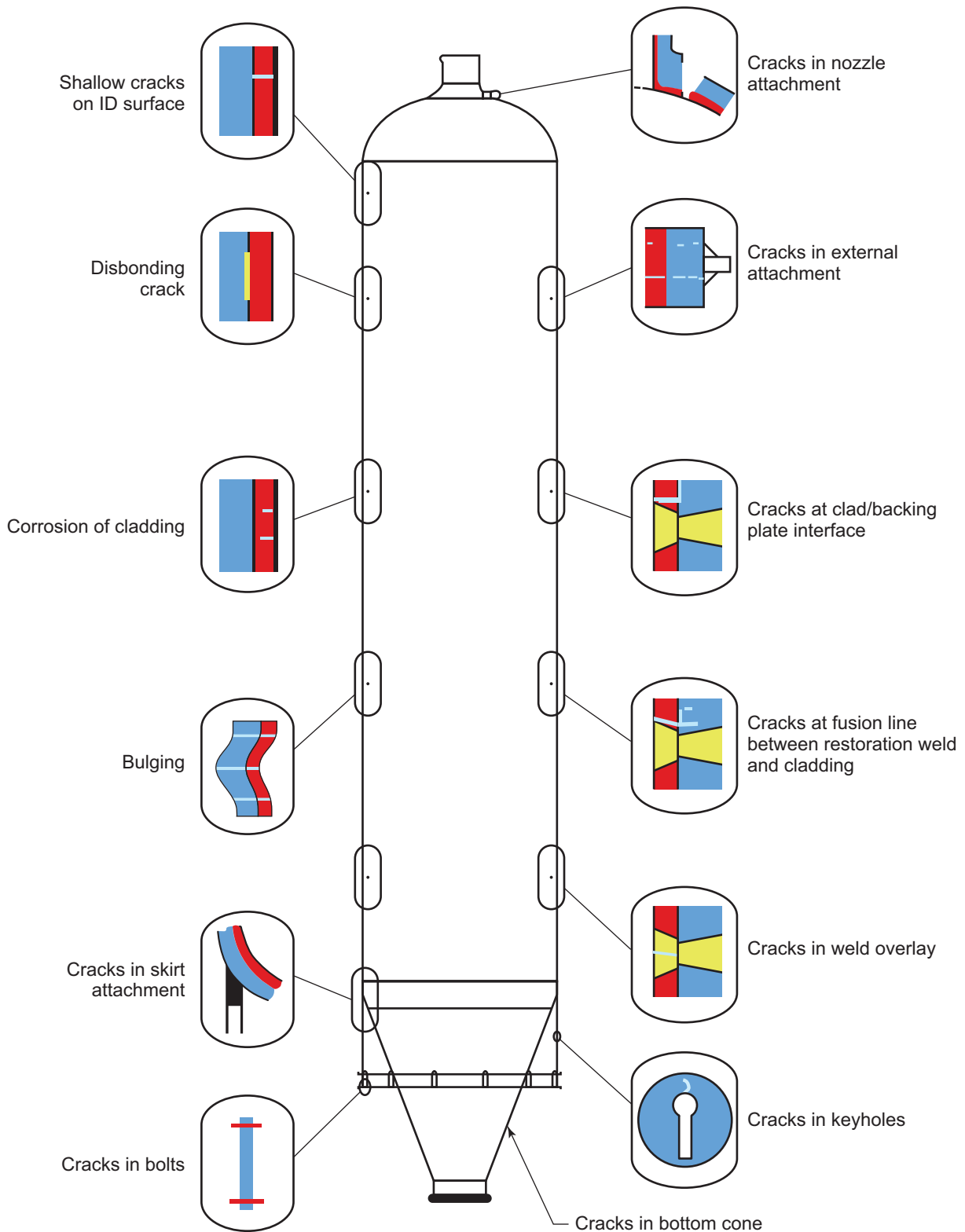


Figure 3—Overview of Coke Drum Thermal Cycling Damage

experiences a thermal load during the heating part of the cycle when hot resid is introduced into a relatively cool drum. Additionally, an even more severe thermal load can be experienced during the cooling part of the cycle when cool quench water is introduced into a relatively hot drum. Experience shows that the thermal cycles can be more or less severe depending on how the hot feed and cool water are introduced into the drum.

The repeated severe thermal stress cycles experienced by coke drums results in a phenomenon called ratcheting. Ratcheting is defined in API 579-1/ASME FFS-1 as a progressive incremental inelastic deformation or strain that can occur in a component subjected to variations of mechanical stress, thermal stress, or both (thermal stress ratcheting is partly or wholly caused by thermal stress). Drum distortion from ratcheting is a result of cyclic thermo-mechanical loads that result in through-wall bending stresses in conjunction with membrane stresses. Ratcheting is produced by a sustained load acting over the full cross section of a component, in combination with a strain controlled cyclic load or temperature distribution that is alternately applied and removed. Ratcheting causes cyclic straining of the material, which can result in failure by fatigue cracking and at the same time may produce cyclic incremental growth of a drum, which frequently leads to the formation of permanent bulges or other forms of deformation on a drum. When load controlled mechanisms dominate, coke drums constructed from lower strength materials are more likely to experience ratcheting and subsequent bulging than those constructed from higher strength materials.

Each of the forms of observed damage in coke drums are discussed in greater detail below.

4.3.1.2 Bulges in the Drum Shell

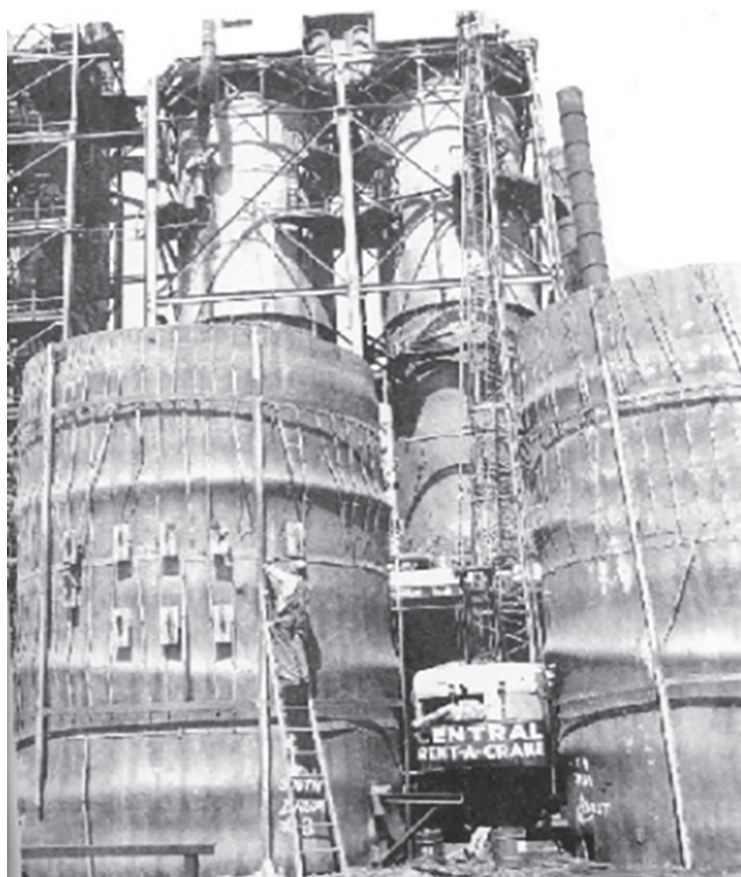
Many drums, especially ones fabricated from carbon and C- $\frac{1}{2}$ Mo steels display bulges after years in service. Figure 4 shows bulging that has been experienced in drums. Experience indicates the most pronounced bulging occurs in the lower to middle shell courses of a drum. This observed bulging has been attributed to large differences in the shell metal temperature from one area in the drum to another. These local differences in the shell temperature appear to be greatest during operating cycles when either hot or cooler liquids enter the drum. This includes the initial filling of the drum with hot feed and when injecting water into the drum during the quenching operation near the end of the operating cycle.

4.3.1.3 Cracks at Circumferential Weld Seams

Drums frequently display cracking at circumferential weld seams, occurring in drums with and without noticeable bulging. In general, carbon and C- $\frac{1}{2}$ Mo steel drums display both bulges and cracks, while Cr-Mo drums typically display cracks and less bulging. Figure 5 shows a cross-sectional view of a circumferential weld with a crack initiating on the inside surface of the drum along the fusion line between the nickel-based restoration weld and the 12Cr cladding. It appears that this cracking is typical for a dissimilar weld made with a nickel-based welding consumable. Cracks initiating at the inside surface of a drum at the back cladding weld are most commonly observed; however, cracks initiating on the outside surface at circumferential welds also have been reported. Cracking has been attributed to the same thermal loads that cause bulging.

4.3.1.4 Cracks at the Skirt-to-Bottom Head Attachment

As indicated in the survey results (see 4.2.5), cracking in coke drums typically is first observed in the weld connecting the skirt-to-bottom head. Figure 6 shows typical cracking observed at the circumferential skirt-to-bottom head weld. Cracking at this weld is attributed to the severe thermal gradients that exist between the shell and skirt. The skirt acts as a fin that enhances the thermal gradient that exists at the shell-to-skirt junction of a drum during a typical operating cycle. During the drum heating cycle the relatively cooler skirt tends to restrain the shell/head expansion while during the quench cycle the relatively hotter skirt tends to restrain the shell/head from shrinking back to its cool position. In each case, significant bending stresses of opposite signs (between heat up and cool down) occur around the skirt-to-shell, joint from the thermal cycling. Usually, the more severe the temperature gradient between the shell/head and the skirt the more severe are the bending stresses generated in the skirt attachment weld. More recently, some owner/users have installed drums with an integrally forged connection between the bottom head and skirt as illustrated in Figure 16 and have employed designs where the skirt is non-welded, all in an effort to increase the time it takes for cracks to form in this area.



Courtesy of CB&I

Figure 4—Early 1960s Photo Showing Typical Bulging Observed in Drums Used in Delayed Coking Units

4.3.1.5 Cracks at Keyholes in the Skirt

Keyholes frequently are placed in the skirt close to the shell-to-skirt weld in order to improve the skirt flexibility and act as a preferred site for initial cracking as opposed to the skirt-to-shell weld (see Figure 17 for keyhole details). Figure 7 shows cracking that initiates in the keyhole and runs up to the shell-to-skirt weld where the crack turns and runs along the shell-to-skirt weld.

4.3.1.6 Cracks in the Bottom Cone

Figure 8 shows severe cracking that has been experienced at the bottom cone on a coke drum. In general, this cracking was attributed to thermal stresses that have been introduced during the fill and water quench portions of the operating cycle. Additionally, cracking in the weld between the bottom cone and the drum shell has been attributed, in part, to weld misalignment.

4.3.1.7 Cracks at Bulges

Cracking initiating from both internal and external surfaces is observed at bulges. Figure 9a shows typical cracking observed initiating from the internal surface. This includes a major crack at the toe of the restoration weld in the internal cladding plus an array of cracks commonly referred to as “elephant skin” cracking. This is a typical cracking pattern observed in cases where relatively cool water splashes on a hot metal surface. Figure 9b shows cracking at a bulge that initiates on the outside surface. This array of many cracks at a bulge generally is associated with thermal fatigue which occurs as the shell plate accumulates a large amount of plastic deformation from the repeated thermal loads experienced during each operating cycle.

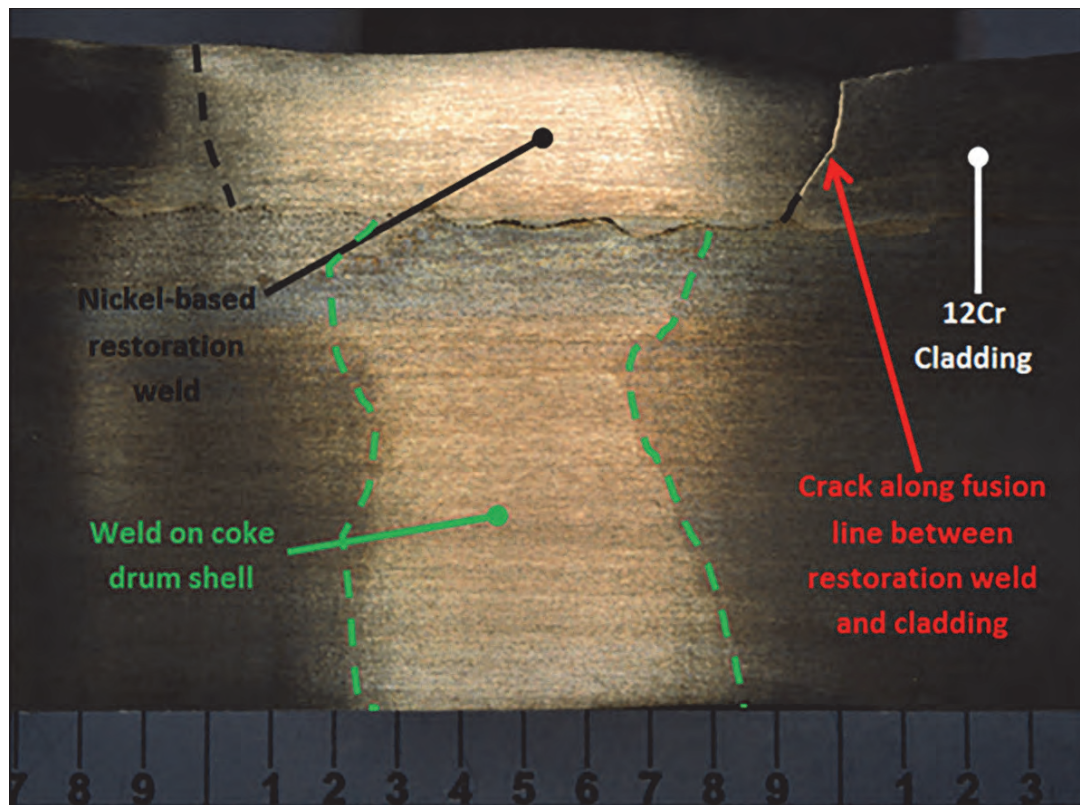


Figure 5—Circumferential Weld Crack Between the Nickel-based Restoration Weld and 12Cr Cladding



Figure 6—Typical Cracking Observed at Skirt-to-Bottom Head Weld



Figure 7—Keyhole Skirt-to-Bottom Head Weld Cracks

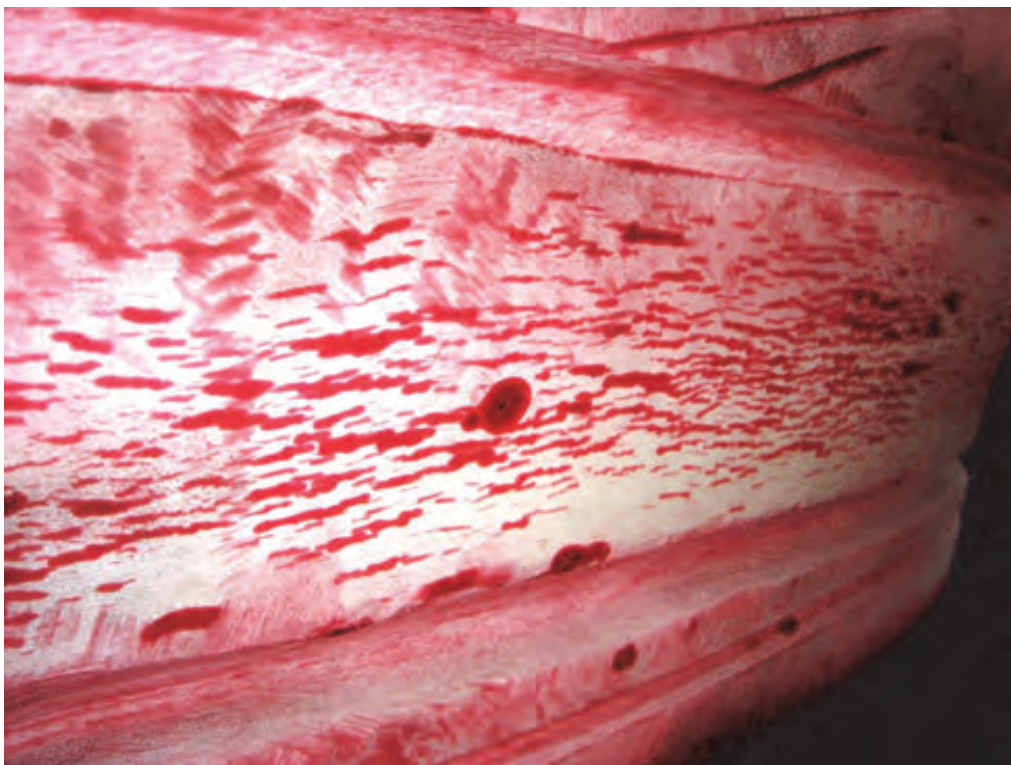


Figure 8—Coke Drum Bottom Cone Cracks

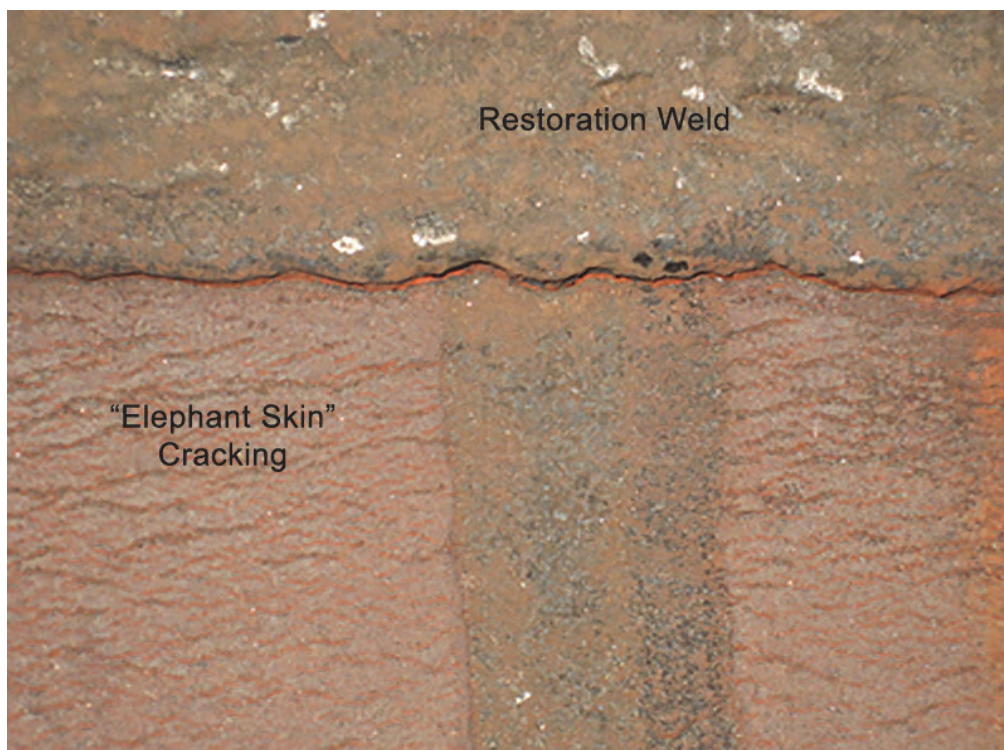


Figure 9a—Internal Surface Bulge Cracks



Figure 9b—External Surface Bulge Cracks