Coke drum design

Issues to consider for extending the turnaround schedule of a delayed coking unit. Theory behind coke drum failure is discussed, with detailed solutions centred on drum design and support structures

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The global supply of crude is getting heavier. In response, refiners are making their refineries flexible enough to handle the changing feedstock. These crudes are cheaper than sweet crudes due to their limited processing capacity. One of the major additions and targets for upgrades are delayed coking units, which process the bottom-of-barrel material into valuable, lighter products such as gasoline and distillates. Adding a delayed coker unit to a refinery flow scheme provides a two-fold financial incentive: cheaper feedstock and a higher volume of light products.

In several parts of the world, North America being more severe, refining capacity is struggling to keep up with the demand for products. Refiners are making strong efforts to improve the reliability and availability of process units, with the ultimate goal of decreasing the frequency of turnarounds and making process units safer.

In an environment where it is very profitable to keep refinery availability as high as possible, efforts are directed toward process units and equipment that bear the most wear and tear. Also, it is financially preferable to run heavier crudes, especially when a refiner has an existing delayed coking unit. But nothing is easy: delayed coking units require more maintenance than normal process units in a refinery, and increasing the availability of this unit has a major impact on the long-term profitability of a refiner.

Delayed coking process

Delayed coking is a process in which a heavy residual feedstock is superheated and then introduced into an insulated, vertically oriented cylindrical pressure vessel, commonly known as a coke drum. Vapours are then removed to be further refined into various petroleum byproducts, leaving behind a high-density hydrocarbon residue referred to as petroleum coke. Petroleum coke is a solid coal-like substance that has been commercially manufactured for nearly 80 years and is used primarily as a fuel or for the production of anodes for the aluminum industry, electrodes for the steel industry, graphite or similar carbon-based products. This residue is then water quenched not only to allow for its removal once the vessel has been depressurised, but also to cool it to the point where it will not self-ignite when exposed to air. As part of the delayed coking process, coke drums undergo severe thermal and pressure cycling, as the vessel is filled with hot product and subsequently water quenched after coke formation.

Due to the severe heating and quenching rates of this process, the useful life of coke drums is much shorter than that of other pressure vessels operating in non-cyclic conditions. This is because the severe operational thermal cycling causes the plate and the weld to be stressed with each cycle and, due to their differential strengths, the drum may bulge and eventually crack in the vicinity of the circumferential weld seams. This leads to coke drums experiencing significant downtime throughout their useful life to make needed repairs or partial shell replacements. It is a problem that has plagued refineries for decades.

Depending on the operating parameters, type of coke produced, feedstock and other variables, the cycle time of a given unit can be from as little as 14 hours to more than 24 hours. The industry recognises that the shorter and more severe the cycle, the sooner and more pronounced the bulging and cracking will appear. To illustrate this, Figure 1 is a photo that was taken from a coke drum shell replacement project, illustrating the severity of the distortion.

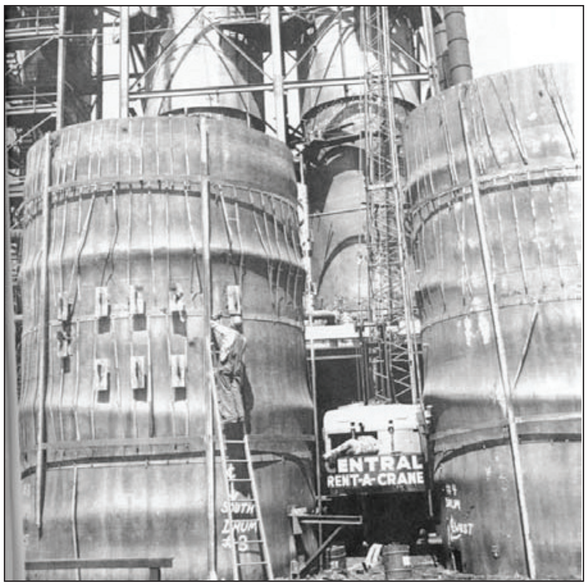

Figure 1 *Coke drum shell bulging in early 1960s*

In the last decade, the demand for delayed coking capacity has been steadily increasing. Experts attribute this trend to refineries having to process more lower-quality crudes than in the past, as previously discussed. Thus, few refinery owners have the option of increasing cycle time, as they must balance drum distortion with the desire to meet rising throughput requirements. Instead, refiners must often resort to shortening the coking cycle, adding more units or doing both.

Bulging and cracking phenomenon

Weil and Rapasky[1] (1958) identified radial bulging as a “re-occurring difficulty” that existed in essentially all operating coke drums of the time. Through extensive research carried out on a total of 16 coke drums erected between 1938 and 1958, they identified a radial growth varying from almost negligible to as much as 0.3in per year. The rate of bulging was found to be directly attributable to the “quenching portion” of the operating cycle. They also recognised that the girth seams, due to the higher yield strength of the weld

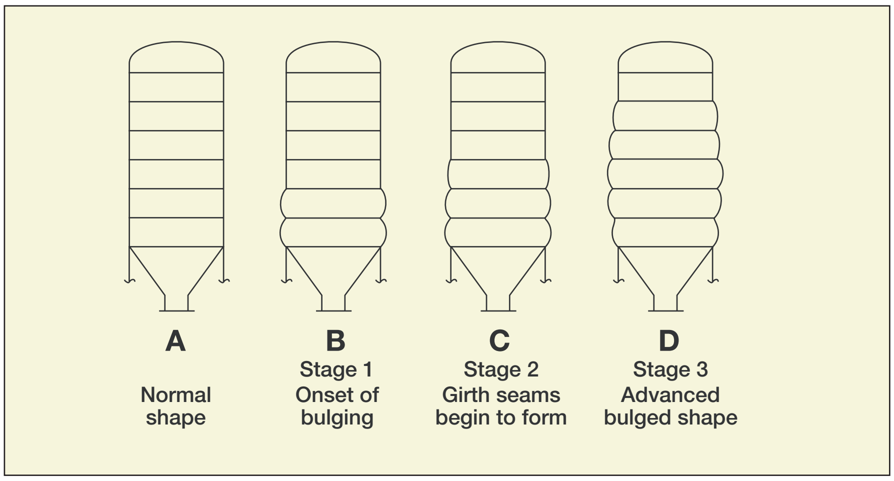

Figure 2 *Coke drums displaying constrained balloon shape due to distortion*

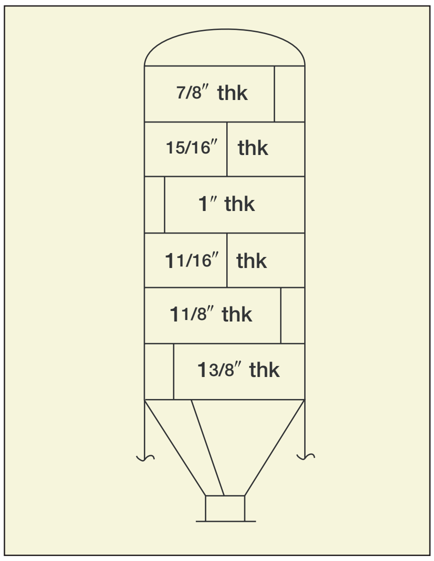

Figure 3 *Coke drum vessel step reduction in thickness*

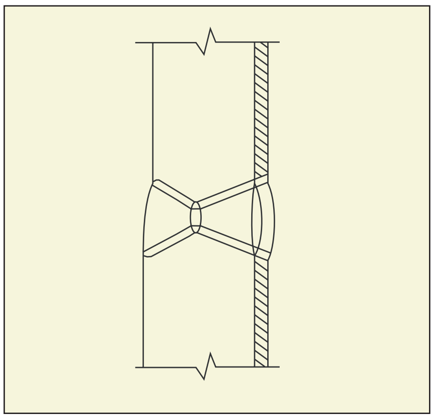

Figure 4 *Weld profile compounds stiffening effect*

metal, tended to augment the bulging, causing a "constrained balloon shape", as illustrated in Figure 2.

As a result of the restraint caused by the weld seams, the base material tends to become thin and ultimately fails via through-wall cracking. The bulging is most severe in the lower cylindrical portion of the vessel, usually 40–50ft above the cone section. This section of the vessel experiences the highest quench rates during the quench cycle and typically has four to five circumferential weld seams, depending on the width of plate used for each shell course.

Through their studies, Weil and Rapasky observed that high quenching rates produced thermal gradients in excess of 10°F per inch, while lower quenching rates produced smaller gradients, thus less bulging. To measure this effect, they developed a "unit quench factor" (UQF, Table 1), which is the ratio of water-quenching time in minutes to the coke yield per drum in tons. Utilising the resulting data, they theorised that when the UQF is greater than 0.5, the bulging is minimal, and when the UQF is greater than 0.8, the bulging is all but non-existent. The UQF is directly proportional to the rate of water injection during the quench cycle — the slower and more controlled the quench is, the greater the UQF, which translates into less bulging. However, as previously mentioned, fewer owners have the option of longer cycle times. To the contrary, the trend is for even shorter cycles, the result of which is a higher UQF that will ultimately reduce the overall lifespan of the vessel.

In recent years, there have been a number of studies undertaken that substantiate the conclusions of Weil and Rapasky:

— Penso *et al*[5] suggest that low cycle thermal fatigue is the most common failure mechanism of a coke drum. The authors state that thermal shock is the main mechanism for the initiation of these cracks. They further propose that additional analysis of the cooling cycle is warranted, since the cooling cycle affects the severity of thermal shock

— Livingston and Saunders[4] report that the coke drums in their survey began to through-wall crack at roughly 2400 cycles. The frequency of through-wall cracking increased

— This evidence of initial and subsequent cracking is further supported by an independent 1996 API Survey that confirms the first through-wall cracks on conventional drums typically occur in the 3000–5000 cycle range

— Antalffy *et al*[3] cite at least three additional examples of recent papers that reference the bulging phenomena. He also cites that Boswell and Ferraro[2] and others concluded that the high relative strength of the circumferential weld metal, as compared to the lower strength of the adjacent base metal, was the cause of the bulging.

As one can see, it is common industry knowledge — supported by several thermal and stress analyses of various operating units — that the higher strength of the weld metal in the circumferential seams tends to have a stiffening effect, which increases stress and leads to distortion and cracking. It should be noted that the longitudinal weld seams required to make the shell courses were reported to be unaffected by the thermal cycling, except where these seams intersected the circumferential ones. In the bulge areas near the circumferential seams, the longitudinal weld seams were also affected by the thinning effect and would be prone to crack given enough thermal cycles.

Coke drum metallurgy and shell thickness

To extend the useful life and reduce the downtime of coke drums, several modifications have been made to standard coke drum design metallurgy. Coke drums that were once constructed from mild steel have in recent years been constructed from low-alloy clad

Comparison of quenching methods and growth on various coking

Unit no.	Water quenching time, min	Coke capacity, tons	Unit quenching factor, min	Relative severity of bulging distortion
9	90	380	0.24	Severe
8	100	370	0.27	Severe
7	90	310	0.29	Severe
1	140	180	0.78	Negligible
5	135	170	0.80	Negligible
2	150	170	0.88	Absent
6	180	180	1.00	Absent

$$\text{UQF} = \frac{\text{water – quenching time (minutes)}}{\text{coke capacity (tons)}}$$

Table 1

materials such as Carbon-1/2 Moly and 11/4 Chrome-1/2 Moly, as well as 21/4 Chrome-1 Moly and other higher alloys, typically with 410SS cladding. With the exception of 21/4 Chrome-1 Moly and other higher alloyed coke drums, those manufactured with low-Chrome alloy materials have all failed in time.

The drums manufactured from 21/4 Chrome-1 Moly and other higher alloy materials have been in service for only a few years and have not yet endured enough cycles to demonstrate improved reliability. The normal method of designing the shell courses of coke drums is to base the thickness of the material on the specified design pressure. Typically, the pressure is specified as varying linearly from a minimum value at the top of the vessel to a maximum at the bottom flange. Since overall vessel cost is a function of weight and thickness, the tendency is to design each shell course for the design pressure specified at the bottom of the course. As a result, there are typically step reductions in thickness from one shell course to the next, as shown in Figure 3. However, the resulting weld profile compounds the stiffening effect already present due to the higher yield strength of the weld metal, as shown in Figure 4.

Increasing vessel life

Further effort to improving the reliability and lifespan of coke drums has focused on developing or proposing measures to mitigate the stiffening effect of the weld seams. Most of these measures, several of which have been incorporated into numerous procurement specifications, were aimed at reducing the discontinuity effect at the circumferential weld seam. The most common of these specifications were as follows:

— Decreasing the weld metal yield strength to be within a close percentage of base metal yield (ie, 0%, +10%)

— Blend grinding the weld profile

— Specifying higher alloy materials (ie, 21/4 Chrome-1 Moly and higher)

— Requiring more non-destructive examinations (NDE) and using more restrictive NDE acceptance criteria than the construction code requires

— Maintaining a uniform shell thickness throughout the vessel

— Specifying materials greater than 2in in thickness.

While most of these requirements have technical merit, the resulting improvement may only be incremental and not necessarily practical. For example, attempting to narrow the yield strength mismatch between the weld metal and base metal is difficult at best due to the many variables involved. The actual yield strength of the base metals when compared to commercially available weld metals is typically more than 10% lower (Table 2). In addition, the yield strength of base metals and weld metals varies with temperature, which may make the yield strength differential greater than 10% at elevated temperatures. Also, controlling weld metal yield strengths to a specific minimum/maximum in relation to the as-supplied base metal typically requires the use of weld processes that are not necessarily productive or cost-effective.

Blend grinding the weld profiles, which reduces the geometric stress raiser effects near the weld joint, can extend the service life of the weld joint and can be cost-effective if properly specified and managed. However, eventual repairs to the weld joint are inevitable.

The use of uniform shell thickness throughout the critical area of the vessel has an added material and labour cost. But, as previously mentioned, not keeping a uniform thickness will increase the stiffening effect of the metal used for welding the circumferential weld joints. And while the specification of very thick and uniform shells will reduce the peak stresses caused by the thermal cycles somewhat, it will not reduce the effects of the circumferential seams acting as stiffeners during the quench cycle.

Higher alloys such as 21/4 Chrome-1 Moly are thought to be able to resist the thermal cycling better because of their higher yield and better creep and creep-fatigue resistance. While these higher alloys may increase the useful life of the vessels and slow down bulging, most of the newer drums manufactured from this alloy have not yet seen enough coke production cycles to determine if this is a major improvement. Plus, using these alloys translates into increased costs.

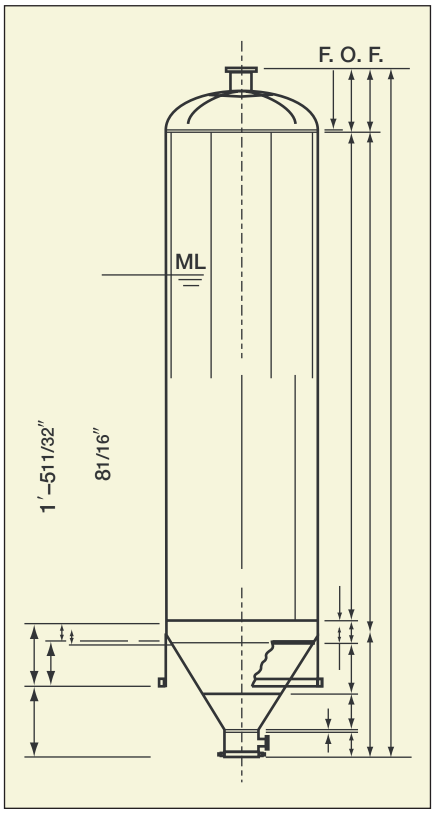

Figure 5 Cylindrical shell sections of up to 46ft help eliminate several circumferential weld seams, increasing endurance under the most severe thermal cycles.

Some specifications are requiring increased NDE testing to be performed and the acceptable flaw size reduced in an attempt to get more uniform weld joint properties. This increases costs without having any effect on the basic problem of the circumferential welds acting as stiffeners. There is also some evidence that excessive repairs during manufacturing may, in fact, reduce service life by causing premature failures.

Elimination of circumferential weld seams

When CB&I first approached the girth weld distortion and cracking problem, two observations were pivotal in the analysis. One was the well-known fact that the higher strength of the weld metal in the circumferential seams tends to have a stiffening effect that increases

Typical plate and weld metal properties[6]

Base metal	Type	Tensile ksi	Yield min. (typ) ksi	Typical weld metal selection	Tensile ksi	Yield min. (typ) ksi
A516-70	Carbon steel	70–90	38 (46)	EM12K	70–95	58 (61)
A204 C	Carbon-1/2 Moly	75–95	43 (52)	EA2	70–95	58 (61)
A387-11, CL2	11/4 Cr-1/2 Moly	75–100	45 (58)	EB2	80–100	68 (75)
A387-12, CL2	1 Cr-1/2 Moly	65–85	40 (50)	EB2	80–100	68 (75)
A387-22, CL2	21/4-1 Moly	75–100	45 (58)	EB3	90–110	67 (80)
405 (clad)	13 Cr	60–90	25 (36)	ERNiCr-3	80–95	40 (52)
410S (clad)	12 Cr	60–90	30 (36)	ERNiCr-3	80–95	40 (52)

All weld metal and base metal in typical PWHT condition for material combinations. All weld metal data is from the SAW (submerged arc welding) process

Table 2

Figure 6 *Plate-by-plate replacement method in progress*

stresses and leads to distortion and cracking. The other, based on previous research, was that the longitudinal welds required to make the shell courses were seemingly unaffected by the thermal cycling, except in the areas where those welds intersected the circumferential ones.

After extensive research and analysis, CB&I concluded that the best solution to the problem of girth seam distortion and cracking was to eliminate the circumferential weld seams in the area of concern. A method was developed for successfully fabricating shell plates with the long side oriented vertically. This process allows fabrication of cylindrical shell sections of up to 46ft without a circumferential weld seam. The steel mill manufacturing capability only limits plate size. Currently, the largest plates available are in the range of 46ft, depending on the specified thickness and alloy. Depending on plate size limitations, up to five circumferential weld seams can be eliminated, resulting in a cylindrical shell section that can endure the most severe thermal cycles (Figure 5).

In late 1997, CB&I launched an extensive investigation into the feasibility of designing, fabricating and erecting a vertical plate coke drum. The resulting conclusion was that such a vessel could be economically produced, providing a uniform thickness throughout the cylindrical portion of the vessel. This method is applicable to new construction (shop-built or field-erected) projects, as well as retrofit applications where the lower cone and top head sections of the vessels are reused.

Vertical plate coke drums

Since 2000, CB&I has completed four retrofit projects with the proprietary vertical plate coke drum technology, all of which were finished at an equal or lower cost to the refiner than traditional repair methods, and were much less expensive than a full-vessel replacement.

The first successful installation of two drums took place at a refinery on the US West Coast in 2000. The refiner had originally planned to replace two 20ft-plus sections of distorted and cracked shell on two of its coke drums, which would still have left circumferential seams in the section of the drum where the bulging and cracking was most pronounced. However, after reviewing the vertical plate concept, the refiner decided to modify its plan and replaced all but the upper 9ft of shell with two vertical plate courses reaching heights of 23.5ft and 40ft respectively.

For this project, CB&I performed all of the turnaround activities itself, including forming and welding the plates at one of its fabrication shops, mobilising the crane and all of the on-site materials, and erecting the vessels. To execute the actual shell replacement, CB&I cut the old circumferential sections and then removed them using a customised rail system attached to the structure. From there, the new vertical plate sections were set in place. The project included replacing a large nozzle in the top head and sections of the skirt support, along with post-weld heat treating and hydrostatic testing, all within a span of 28 days. This vertical plate solution was so successful that the refiner subsequently contracted to replace the shells on an additional four coke drums.

In 2001, CB&I replaced the shell courses on four coke drums for another refiner that were originally fabricated and installed by the company in 1968–69. These vessels had reached the end of their useful life, and the coker structure required major modifications to meet current building codes. CB&I recommended replacing the existing can sections on the coke drums with vertical plates. Total shell replacement was approximately 65ft 8in in height.

A lower shell course 46ft in height and an upper shell course 18ft 8in in height were fabricated. These courses comprised eight shell plates, all of which were formed in one of CB&I's fabrication shops and then welded into two-plate assemblies. The assemblies were then shipped to the refinery, where the on-site project team would first erect the lower and upper shell courses and then set one on top of the other to complete the can section. In addition to replacing the shell plates, braces were added to the stairwell and the drum was insulated. Working on a plant-wide, non-critical turnaround basis, the can sections on all four drums were replaced in 37 days.

The most recent vertical plate project, which involved the replacement of a 35ft vertical section on a ten-year-old coke drum, was completed on a turnaround basis in 16 days. For this project, CB&I utilised its can section replacement method. This particular vessel had experienced excessive bulging and cracking in 60% of its circumferential welds. Its shell courses were replaced with new 35ft-long plates arranged vertically in four sections. Braces were also added to the vessel stairwell and the drum was insulated.

Plate-by-plate replacement

In many refineries, the area surrounding the coking unit does not permit the use of a large-capacity crane to lift out the entire can section. To replace the shells on the four coke drums at the West Coast refinery, for instance, the damaged can sections had to be cut into smaller vertical pieces, which were then removed plate by plate. Likewise, the new vertical plates had to be lifted into place piece by piece, as shown in Figure 6. While not as fast as replacing the entire can section, the plate-by-plate replacement method is still a safe, low-cost solution.

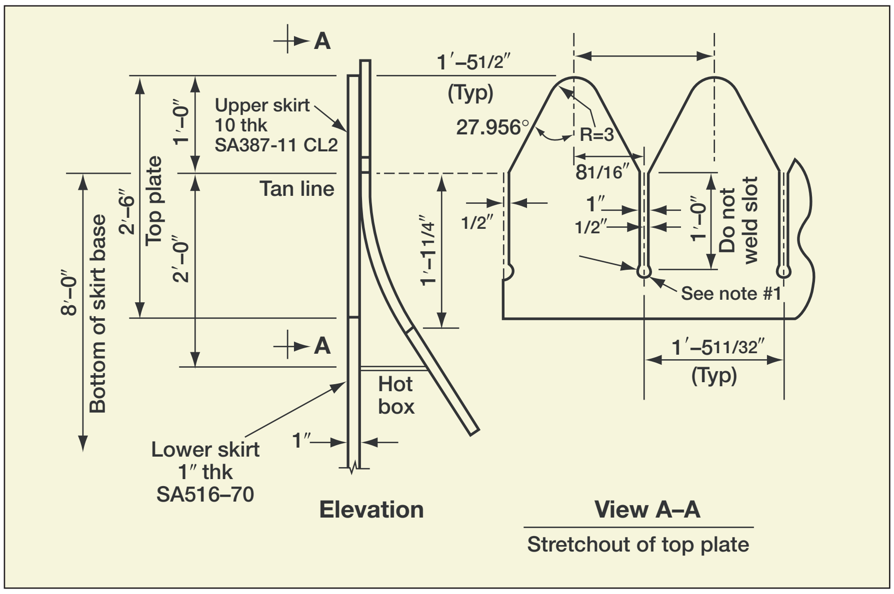

Figure 7 *T-Rex skirt design*

Innovations in skirt design

Another potential area of failure in coke drums is the skirt-to-shell weld attachment. Since most coke drums have a knuckle transition from their cylinder top to a conical bottom, a skirt assembly is used to support the vessel at its lower tangent line and provide uniformity of support stresses in the structure. Since thermal cycling is most severe near the bottom of the coke drum, where temperatures can reach up to 1000°F, the skirt and other attachment welds are just as prone to cracking and premature structural failure as the vessel wall.

Several alternative skirt designs have been developed to counter these failures. One such design is the T-Rex skirt (Figure 7), which is a culmination of best practices and lessons learned from years of fabricating and repairing coke drums. In service since the 1970s, this design has proven to be one of the most reliable skirts currently around.

Recently, a finite element analysis (FEA) was performed on the T-Rex design, the results of which were compared to those for the conventional design configuration. This is a transient thermal analysis to establish the model temperature profile over the load cycle time history. The results of the thermal load tests show that the T-Rex configuration has lower stress levels at all locations for the critical charge and quench thermal cycles. This appears to be due to the longer hot-box length, which results in a more gradual thermal gradient and also moves the gradient lower on the skirt away from the welded connection. As such, the FEA evaluation shows that the T-Rex has substantially reduced stresses as compared to other skirts currently in operation. Some of the features of the T-Rex design include sloped attachment welds that help reduce stress-related failures and an attachment that covers the tangent weld (unless an elongated straight flange is utilised). The T-Rex design reduces initial application costs and improves long-term reliability over other designs that have been evaluated.

Another design recently developed is the Wrapper skirt (patent pending). This employs a fabricated wrapper-type skirt that conforms to the geometry of the upper cone, knuckle transition and lower cylinder to support the drum primarily by bearing and frictional forces rather than load bearing weld attachments (Figure 8). This detail provides a more flexible connection between the skirt and vessel than traditional methods, which improves the fatigue resistance of the structure. In addition, the extended contact between the drum and skirt lessens thermally induced stresses in both components by ensuring a uniform temperature gradient between the two. Finally, the elimination of the weld attachment substantially reduces large pre-stresses from weld shrinkage, weld-induced heat-affected zones and high local stresses in the structure, which likewise improves the overall fatigue resistance of the structure and supporting skirt.

Packaging these skirt designs with the previously discussed vertical plate proprietary technology provides a comprehensive vessel solution that not only improves the lifespan of a refinery's delayed coking vessels, but also saves the owner significant repair and replacement costs. These designs can be used during retrofit projects such as coke drum repair or replacement, as well as for incorporation into new unit designs.

Economics of vertical plate coke drums

While the installation of vertical plate technology will reduce the capital refinery owners will need for repairing and replacing their vessels, it is too early to quantify the actual observed benefit, since the existing vertical plate coke drums in service have not seen enough coke production cycles. However, the cost and benefits associated with the technology can be demonstrated using a lifecycle value assessment (LCVA) methodology, which establishes a true cost of ownership. This tool, which was developed by the Pembina Institute, is a value assessment model that allows owners to combine initial Capex and 20 years' Opex for both conventional drums and the vertical plate coke drums. The methodology also considers the direct financial losses arising from unplanned outages of the drums, and also applies net present value (NPV) principles to further assess the expected cost savings. A rigorous NPV calculation can demonstrate the excellent value of these innovations. However, for the purposes of this discussion, a simplified LCVA model is utilised as follows:

Conventionally designed drums

Capex The initial Capex outlays for four vertical plate coke drums are assumed to be $26.1 million. In this example, the drums come at an initial Capex premium of $2.175 million compared to conventional drum designs. Thus, Capex for conventional drums is assumed to be $23.9 million.

Opex At an average of 14 hours per unit cycles, each conventional drum in operation will go through 313 cycles per year, which translates into 6260 cycles over a 20-year period. As previously mentioned, Livingston and Saunders reported that the coke drums in their survey began to through-wall crack at roughly 2400 cycles, while an independent 1996 API Survey confirmed that the first through-wall cracks on conventional drums typically occur in the 3000–5000 cycle range (Figure 3). Based on these findings, no fewer than 11 cracks per drum may reasonably be predicted during the 20-year period.

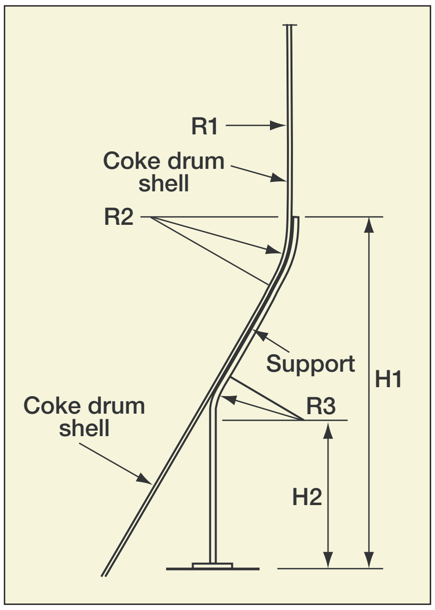

Figure 8 *Wrapper design*

For simplicity, it is assumed that planned outages deal with 30% of the cracks that will appear (three cracks), so the remaining eight cracks will significantly dictate more expensive unplanned refinery stoppages of the coke drums, which is where the Opex cost is greatest. In this example, costs are determined for a planned turnaround, and then a 30% uplift is applied for unplanned events. It is assumed that each stream-to-stream unplanned outage will last an average of six days. Thus, to remedy a through-wall crack, it will cost (in 2005 dollars):

— *Costs of a single crack repair* (20 workers * six days * two 10-hour shifts * $85 per hour) + (materials, scaffolding/equipment, insulation, repairs and so on) = minimum $225 000

— *Costs of crack repairs over a 20-year period* Three planned events * ($225 000) + eight unplanned events * ($225 000 * 1.3) = $3 million in repair costs for each drum, or $12.1 million for all four drums.

Direct financial losses The greatest impact occurs when one considers the lost revenues caused by the aforementioned cracking events. In addition, there are hazardous plant risks that can accompany the cracking. For the eight unplanned refinery stoppages that will occur over the 20-year period, if the example drum pair has a capacity of 25 000bbl/day and the product is valued at 85% of the WTI value (an average of $50 per bbl):

— *Direct financial losses over a 20-year period* Eight unplanned events/drum pair * six days for each event * 25 000 bbl/day * (0.85 * $50) = $51 million in lost revenues for each drum pair, or $102 million for all four drums.

Vertical plate coke drums

Capex As previously mentioned, the initial Capex outlays for four vertical plate coke drums is assumed to be $26.1 million.

Opex The vertical plate technology is expected to defer cracking substantially. Since 75% of the critical circumferential weld seam footage has been eliminated, we can assume there will be 75% fewer cracks. Thus, the Opex for shell cracking on a vertical plate coke drum may be 11 * 0.25 = three events over the 20-year period, of which 30%, or one, of the events will be planned and the remaining two events will be unplanned. Using the same analysis as with the conventionally designed coke drums over the same 20-year period:

— *Costs of crack repairs over a 20-year period* One planned event * ($225 000) + two unplanned events * ($225 000 * 1.3) = $810 000 in repair costs for each drum, or $3.2 million for all four drums.

Direct financial losses In terms of lost revenues caused by cracking, the same assumptions apply from above, but for only two unplanned events. Thus:

— *Direct financial losses over a 20-year period* Two unplanned events/drum pair * six days for each event * 25 000bbl/day * (0.85 * $50) = $12.7 million in lost revenues for each drum pair, or $25.5 million for all four drums.

Based on the LCVA, it can be seen that the lifecycle Opex and lost revenue costs over a 20-year period for four conventionally designed coke drums total about $114 million, compared with about $29 million for coke drums using vertical plate technology. Thus, vertical plate coke drums can save refinery owners approximately $85 million over the 20-year period, not to mention the added advantages of greater plant safety. Note that these calculations are conservative, as downtime in a delayed coker unit, as in any key processing unit, affects the overall throughput of the refinery. Also, without a rigorous inspection and maintenance schedule, failures can occur at inopportune times such as the summer driving season when product values are at their peak. Hence, the direct financial losses due to outages are likely to be greater than described in this discussion, and the corresponding benefits of vertical plate technology are likely to be that much higher.

Future outlook

Since 2000, CB&I has completed four vertical plate projects, bringing its total number of vertical plate coke drums in service to 11. These projects have included the full circumferential can section replacement of shells ranging from 35–73ft, as well as new lower knuckle and skirt assemblies. As far as improving the reliability and lifespan of coke drums go, as previously mentioned none of the vessels have been in service long enough to allow quantification of the actual improvement. However, the vertical plate coke drums installed at the West Coast refinery in 2000 have seen about six years of service and are approaching 2000-plus cycles with no evidence of any unusual distortion.

Currently, four more drums are under contract. The first project is for a Canadian refiner and includes two new drums of slightly larger dimensions to be installed during a turnaround later this year. This project is unique in that the drums are being fabricated in three segments. The segments are then to be transported to the site and installed through the side of the structure during the outage while seams are being welded in place. The second project is for two drums being erected on site and installed on the "table top" for final assembly.

As feedstocks become heavier and the need for coking capacity continues to rise, refiners will need more than ever to have coke drums that provide greater reliability than traditionally possible. Whether it is a retrofit application, a full vessel replacement or part of a new process unit, vertical plate coke drums will be able to endure the most severe thermal cycles and outlast any conventionally designed vessel. Implementing a T-Rex or wrapper design for the support is expected to further improve the life of these vessels.

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References

1 Weil N A, Rapasky F S, Experience with vessels of delayed — coking units, API 23rd Midyear Meeting, 1958.
2 Boswell R S, Ferraro T, Remaining life evaluation of coke drums, Plant Engineering, Design and Responsibility Symposium, Energy Engineering Conference, 1997.
3 Antalffy L P, Malek D W, Pfeifer J A, Stewart C W, Grimsley B, Shockley R, Innovations in delayed coking coke drum design, ASME, 1999.
4 Livingston B, Saunders K L, Coke drums failure prediction evaluation using probabilistic techniques, ASME, 1998.
5 Penso J A, Lattarulo Y M, Seijas A J, Torres J, Howden D, Tsai C L, Understanding failure mechanisms to improve reliability of coke drums, ASME, 1999.
6 ASME Section II parts A & C, plus Plate and Electrode Manufacturers brochures and CB&I data.

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