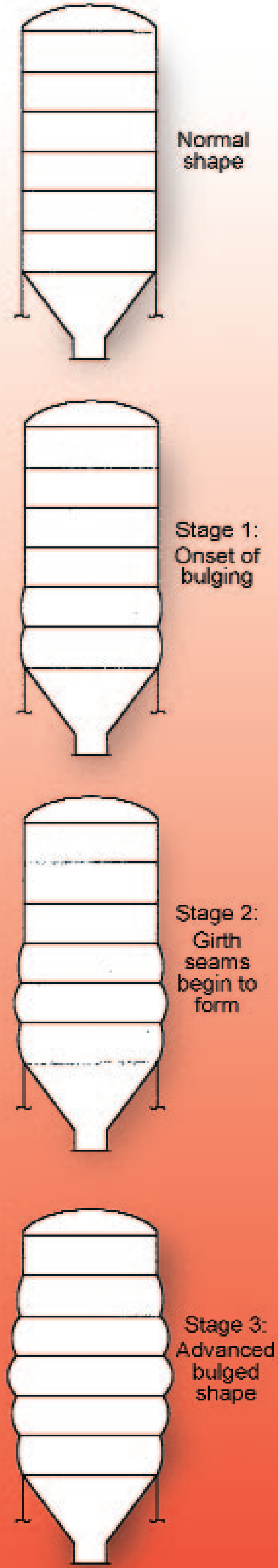

Fig. 1 — Successive stages in bulging deformation.

Vertical Plate Technology Extends the Life of Coke Drums

BY COBY STEWART

A method for eliminating circumferential welds addresses a historical problem with coke drums

The bulging and eventual cracking of coke drums in the vicinity of their circumferential weld joints create a maintenance and reliability problem that has plagued refineries for decades. This bulging phenomenon is caused by the severe operational thermal and pressure cycling process these vessels experience in the production of petroleum coke, a solid coal-like substance used primarily as a fuel for the production of anodes, electrodes, graphite, or similar carbon-based products. As the number of thermal cycles and the frequency in which they occur increase, the more pronounced the bulging and eventual cracking becomes, resulting in reduced reliability and significant downtime to make repairs or replace the drums altogether.

Various solutions have been proposed to extend the life of these units, with only a few achieving a limited amount of success. CB&I, a full-scope engineering, procurement, and construction contractor that has fabricated, erected, and repaired coke drums for more than 50 years, decided to address this challenge. The company developed an innovative solution that didn't just reduce bulging and cracking in the circumferential weld joint, but eliminated the joint altogether, leading to the production of vessels with a longer operating life and lower maintenance costs — the solution: vertical plate coke drums.

What Causes the Bulging and Cracking Phenomenon?

In the past decade, the demand for U.S. petroleum coke has been steadily increasing. Experts attribute this trend to refineries having to process more lower quality crudes than in the past, which requires longer and more severe processing techniques to obtain desirable petroleum products. When these lower quality crudes are processed, they typically produce a substantial amount of heavy residue, including petroleum coke, which in itself has become a useful petroleum product due to its versatility and availability.

Petroleum coke is produced through a delayed coking process in which heavy residual feedstocks are superheated and introduced into a vertically oriented cylindrical "coke drum," where the vapors are removed for further processing, leaving behind a high-density hydrocarbon residue. This residue, referred to as petroleum coke, is then water quenched to allow for its removal once the vessel has been depressurized, as well as to cool it to a point where it will not self-ignite when exposed to air.

It is this severe operational thermal cycling experienced in the coke drums during the delayed coking process that tends to be the primary cause of the bulging and cracking that occur over time. Studies have shown that the severe heating and quenching cycles of the process are directly responsible for shortening the useful life of coke drums, with quenching rates serving as the key driver. In addition, the industry recognizes that the shorter and more severe the cycle, the sooner and more pronounced the bulging and cracking will appear.

Depending on the type of coke produced, feedstock, and other variables, the cycle time of a given coke drum can last anywhere from 12 to 36 hours. Recognizing that shorter, more severe cycle times increase the distortion rate leading to an earlier occurrence of cracking, it would

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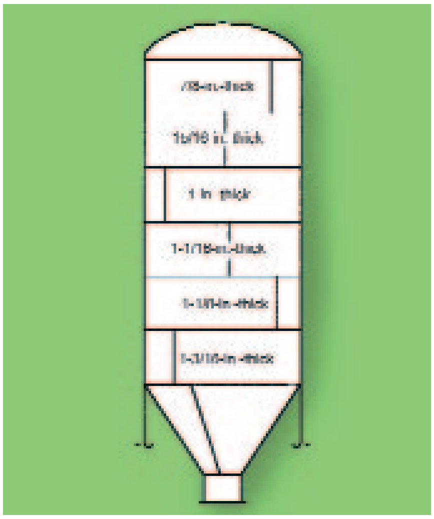

Fig. 2 — Typical shell thickness reduction.

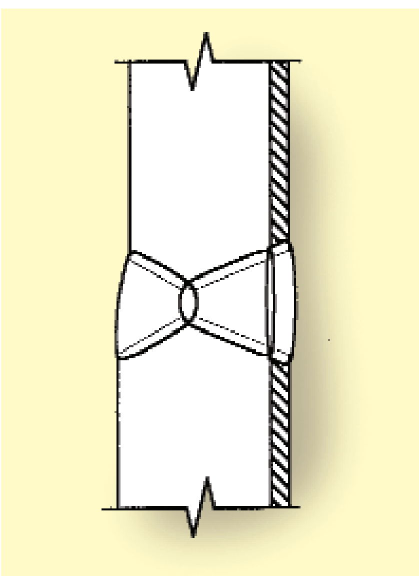

Fig. 3 — Weld profile.

stand to reason that refinery owners would decelerate the thermal cycling process. However, refiners must balance that action with the desire to meet rising throughput requirements, leaving few refinery owners with the option of increasing cycle times. Rather, refiners must often resort to either shortening the coking cycle, adding more units or doing both.

Coke Drum Design and Construction Methodology

Since reducing cycle time is not a viable solution, other measures have been developed or proposed to extend the useful life of coke drums, including constructing units from low-alloy materials such as Carbon-½ Moly and 1¼ Chrome-½ Moly, as well as higher alloy materials such as 2¼ Chrome-1 Moly. In spite of these efforts, the coke drums manufactured with these low-alloy materials still failed over time, while the units built from the higher alloy materials have yet to endure enough cycles to demonstrate improved reliability. It is generally accepted that the problem relates to the higher-strength weld metal in the circumferential girth welds, which, according to several analyses, does not yield at the same rate as the base material. The resulting stiffening effect causes a "constrained balloon shape" as illustrated in Fig. 1. Because of this restraint, the base materials begin to weaken and ultimately fail due to cracking.

This bulging is most severe in the lower cylindrical portion of the coke drum — usually 40 to 50 ft above the cone section — where four to five circumferential weld joints are typically located. It is in this section where the shell is thickest, since the design pressure is greatest at the bottom of the vessel. Because the thickness of each shell course is determined by the vessel's specified design pressure, which varies linearly with a minimum value at the top of the drum to a maximum value at the bottom flange, there are typically stepped reductions in thickness from one shell course to the next, as seen in Fig. 2. While this thickness reduction design is utilized because overall vessel cost is a function of weight and thickness, the resulting weld profile compounds the stiffening effect already present — Fig. 3.

Solutions Intended to Increase Vessel Life

Some of the most common approaches developed to mitigate the stiffening effect of the weld joints have been to decrease the weld metal yield strength to be within a closer percentage of the base metal yield, maintain a uniform shell thickness throughout the vessel, specify materials greater than two inches in thickness, and "blend grind" the weld profile. While most of these requirements have some technical merit, their results may only be incremental and not necessarily practical.

For instance, attempting to narrow the yield strength mismatch between the base metal and the weld metal is difficult due to the many variables involved — not to mention the expense. By that same token, specifying very thick and uniform shell courses throughout the vessel, although shown to somewhat reduce the peak stresses caused by the thermal cycles, does not reduce the stiffening effect of the circumferential welds and is also costly.

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 be cost effective if properly specified and managed; however, eventual repairs to the weld joint are inevitable. While the stress caused by thermal cycling may be temporarily curtailed by implementing one of these solutions, none of them have been effective in preventing coke drum distortion completely.

Eliminating the Circumferential Welds

When the girth weld distortion and cracking problem was approached, two precepts came to the forefront of the analysis. One was the well-known fact that the stiffening effect resulting from the circumferential welds leads to distortion and cracking, which had already been the focus of many proposed solutions. The other, based on previous research, was the knowledge that the longitudinal welds required to make the shell courses were seemingly unaffected by the thermal cycling, except where those welds intersected the circumferential ones. While this finding had not been extensively investigated to see if any innovative solution could be developed, it became the focus of CB&I's investigation.

By incorporating this knowledge about the longitudinal welds with the company's technical expertise and experience from other applications, a method for successfully fabricating shell plates with the long side oriented vertically, reaching lengths of up to 46 ft without a circumferential weld, was developed — Fig. 4.

Depending on plate size limitations, up to five circumferential welds can be eliminated from the vessel, resulting in a cylindrical shell section that can endure the most severe thermal cycles. The concept is applicable not only to new construction (shop-built or field-erected) projects, but also to retrofit applications, where the lower cone and top head sec-

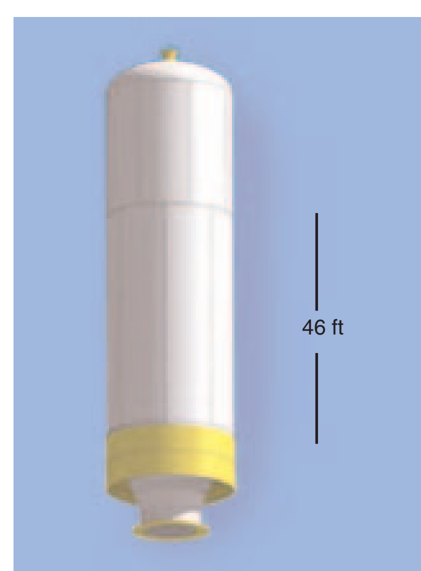

Fig. 4 — Elimination of circumferential weld joints.

Fig. 5 — Replacement of a vertical section of a coke drum.

tions are reused. Vertical Plate Coke Drum technology is patented in the United States, and patent coverage is currently pending in several other countries.

Application

Since 2000, four Vertical Plate Coke Drum retrofit projects have been completed, all at an equal or lower cost to the customer than traditional repair methods, and were much less expensive than full-vessel replacement. The first successful installation took place at a West Coast refinery in 2000.

The client had originally planned to replace two 20-ft-plus sections of distorted and cracked shell on two of its coke drums, which would still have left circumferential welds in the section of the drum where the bulging and cracking was most pronounced. However, after reviewing the vertical plate concept, the client decided to modify its plan and replaced all but the upper nine feet of shell with two vertical plate courses reaching heights of 23.5 ft and 40 ft, respectively.

For this project CB&I self-performed all of the turnaround activities, including forming and welding the plates at its fabrication shop in Texas, mobilizing the crane and all of the on-site materials, and erecting the vessels. To execute the actual shell replacement, the old circumferential sections were cut and then removed using a customized rail system attached to the structure. From there, the new vertical plate sections were set in place. A large nozzle in the top head and sections of the skirt support were also replaced, as well as postweld heat treating and hydrostatic testing, within a span of 28 days. The vertical plate solution was so successful, the client subsequently contracted CB&I to replace the shells on an additional four coke drums.

The most recent vertical plate project performed, which involved the replacement of a 35-ft vertical section on a 10-year-old coke drum, was completed on a turnaround basis in 16 days — Fig. 5. For this project, CB&I utilized 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 35-ft-long plates arranged vertically in four sections. Braces were also added to the vessel stairwell and the drum was insulated.

Working in a Limited Area

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

Overall, four vertical plate projects have been completed, bringing the 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 to 73 ft, as well as new lower knuckle and skirt assemblies.

Currently, additional projects are being pursued, several of which require a full coke drum replacement to add to a refinery's existing coke drum production. To replace an entire vessel, the entire derrick on top of the structure is removed with one lift. A crane is then used to remove the damaged coke drum and set the new Vertical Plate Coke Drum into place. Once the new coke drum is set, the derrick is replaced at the top of the structure. It is a unique process that requires extensive planning and coordination.

Future Repairs

As feedstocks become heavier and the need for increased coking capacity continues to rise, refiners will need more than ever to have coke drums that provide greater reliability than traditional methods. CB&I has developed an innovative, cost-effective solution to meet those needs. Whether it is a retrofit application or a full vessel replacement, Vertical Plate Coke Drums will be able to endure the most severe thermal cycles and outlast conventionally designed vessels. ◆