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Managing the life cycle of coke drums

Coke drums have finite lives. Understanding where they are in their life cycle is key to managing spending on repair or replacement

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Becht

Coke drums are fatigue machines. Fatigue damage accumulates with every cycle and cannot be reversed. Fatigue damage is not easily measured like corrosion, and will manifest in cracking over time, occurring first at the highest stress areas. The location and rate at which this fatigue damage occurs is different for every coker and is dependent upon numerous factors such as the design and operation of the drums (see **Figure 1**). Understanding how much fatigue damage has accumulated along with how quickly it will continue to accumulate and when to take action is critical to managing the life cycle of coke drums.

As fatigue accumulates in coke drums, more frequent inspection and repairs are needed. There is no true 'end of life' for coke drums, instead there is a turning point when outages for inspection and repair or unplanned downtime with reactive repairs outweigh the cost of replacing the drums. Predicting the point when these costs will increase allows time to weigh the economic benefits of the repair and/or the replacement options. Without this forward looking assessment, many sites have found themselves having to react by making very costly repairs, not necessarily because they are the best option but to buy time to plan for drum replacement.

For these reasons, it is critical to know where in the life cycle coke drums are, although this step is easier said than done. Coke drums fall outside of programmes that are used for other pressure vessels, tanks, and piping, such as risk based inspection. Recognising this gap, Becht developed a coke drum reliability assessment tool, BechtCokers, and associated work process to save clients the time and expense of other methods of analysis to understand the current phase of life of their drums (see **Figure 2**). As part of this assessment, a life cycle view is created for the coke drum from the day that it is placed in service. That allows proactive optimisation of the economic trade-off between coke drum fatigue life and operating costs and the margin value realised.

Figure 1 Two drum coker unit

Since this approach directly links design, condition, and operation of the drums, Becht's team includes process, mechanical, materials, inspection, and reliability subject matter experts. The work process also facilitates multi-disciplinary discussions between site personnel. Reliable operation of coke drums requires good communication across disciplines to understand the impact of operational changes to the life cycle of the drums and the resulting changes that need to be made to the inspection and maintenance plans.

Becht's approach uses a ranking of critical factors to benchmark drums at a single site or across several sites' drums versus the historical performance of other drums in industry. This benchmarking allows us to establish the phase of life and the estimated life fraction consumed to date as a percentage. This approach also provides a predictive model for estimated remaining life in number

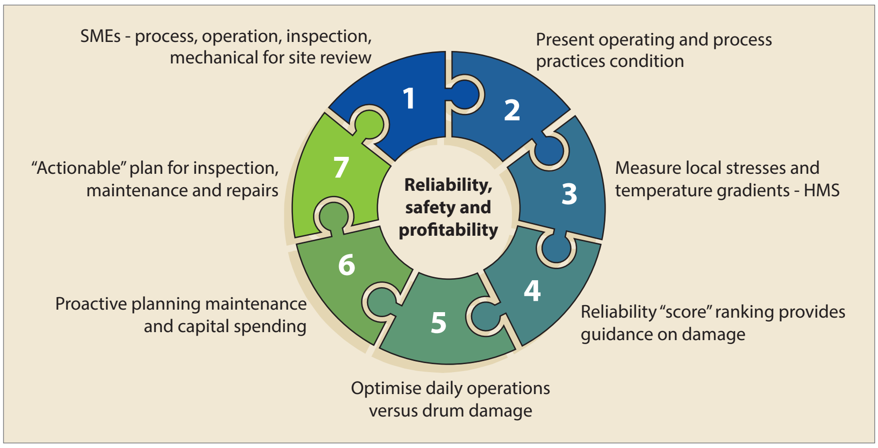

Figure 2 Becht's coke drum reliability assessment work process

However, historically a large number of drums had been built with thickness transitions, sometimes several of these. In this case, the thickness transitions from thicker material at the bottom of the shell to thinner sections nearer the top of the drum. This was done to minimise materials manufacturing cost and to reduce the weight of the drums, reducing structural steel costs. The stress risers due to the thickness changes results in a greater propensity for cracking than in drums of consistent thickness.

of cycles and years, depending upon current and future operations.

Equipped with this knowledge, an owner can plan inspection and maintenance activities that will help ensure reliable operation of the drums by reducing the likelihood of through wall cracks, and structural skirt damage. As the end of life approaches, economic analysis can be applied to the factors that affect the life of the drum, such as operational changes, skirt replacements, structural weld overlay, and drum replacement to make the best financial decisions. In some cases, owners have found they can defer significant coke drum replacement capital investment with the right strategies.

Life cycle analysis

When projecting the life of coke drums, we evaluate individually three parts of the drum: shell girth seams, cone, and skirt. This helps identify the limiting component and customise the mitigation plans for different life profiles. The evaluation includes classifying the drums into one of the following three phases of life:

- **Phase 1: Minor problems**
  - Proactive minor maintenance
  - Baseline and routine inspection, as justified
- **Phase 2: Predictable crack growth**
  - Increased inspection
  - Planned repairs
  - Optimised repairs during planned shutdowns
- **Phase 3: Maintenance intensive**
  - More frequent shutdowns
  - Higher risk of unplanned outages
  - Repair vs replace economic evaluation

For the purposes of this article, we will focus on the critical factors used to evaluate the shell girth seams. The two major categories of factors that affect the life of girth seams are the design and operation of the drums. The design is a fixed condition, so let us first examine the critical factors of design that have the greatest impact on drum life.

Material of construction

The most common materials for the shell and cone of coke drums are 1 Cr – ½ Mo and 1-1/4 Cr – ½ Mo, with almost all drums being constructed in low chrome alloys. The vast majority of drums in industry have a 410 SS lining. The BechtCokers tool is calibrated for those materials as well as carbon steel, C – ½ Mo and 2.25 Cr, although they are less common in industry. For materials outside this envelope, materials engineers are consulted for additional calibration as necessary to determine the effects on the fatigue life of the drums.

Effects of drum thickness and changes in thickness

In simplistic terms, the thicker the shell is the longer the fatigue life the drums will have. This is due to a number of factors but can be summed up by saying that once cracks are initiated they will take longer to propagate through a wall. The BechtCokers tool gives credit for thicker shells and reduces the number of estimated cycles in life for thinner wall drums.

Some drums have a constant thickness which is the case for most recently constructed drums.

Feed inlet design

Traditionally, the feed entered a coke drum at the bottom of the cone. This configuration is referred to as true centre feed. This design was typical for coke drums in the 1940's to 1970's, since sponge coke was produced and there was very little safety risk of coke fallouts or incomplete drains. As the industry shifted to shot coke production, the risk of injury during bottom head removal increased.

To reduce the risk to operators, slide valve technology was introduced, which eliminated significant safety risks during opening of the coke drum. This technology requires that feed come in from the side, above the slide valve. There are now three typical feed entry arrangements: single side entry, dual side entry, or centre feed.

The centre feed configuration results in the most uniform filling, heating, and cooling of the drum, thus minimising thermal gradients that cause high localised stresses. Symmetric dual-opposed designs can produce similar results. Single side entry configurations generate preferential asymmetric flows into the drum. Depending upon coke morphology, this can result in high thermal stresses and what is called the 'banana effect', when drums will bow to one side during operation. Localised high thermal stresses also commonly cause localised bulging.

Asymmetric flow entry can result in preferential flow channels in shot coke beds. When this happens, there is a higher probability of cold quench water contacting hot metal, creating high thermal stress which reduces the fatigue life of the drum.

The BechtCokers tool accounts for the configuration of feed inlet nozzle and adjusts the projected cycle life accordingly. The largest debit to life is for single side entry; the next largest is for dual side entry, and the least is for centre feed (see **Figure 3**).

Delayed coker operations

Cycle time

The coking cycle time is the time during which the feed is filling up the coke drum. Coke drums operate in pairs, with one drum being filled at a time, while the coke in the other drum is being quenched, cut, and emptied from the drum. The coking cycle is roughly half the time of the complete operation. Cycle times vary from 12 hours to over 24 hours.

The difference in the cycle time is accounted for in BechtCokers, with faster cycle times resulting in a shortened life, and the longer the cycles the longer the life. In the absence of stress data, the model uses a correlative approach to relate fatigue life to cycle time (see **Figure 4**).

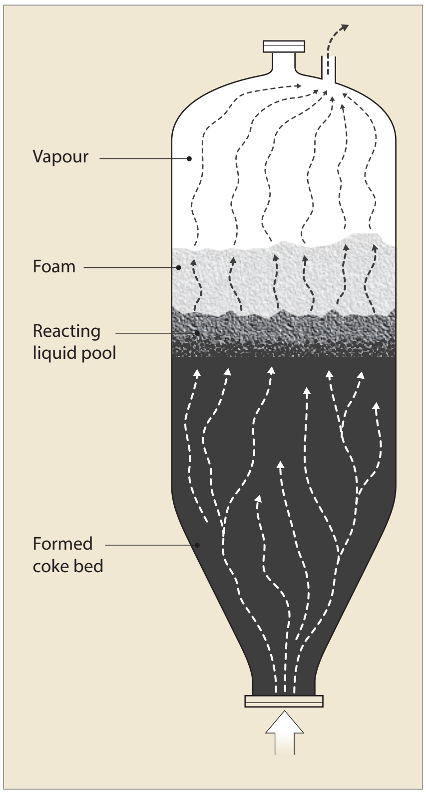

Figure 3 Coke drum with centre feed

The feed nozzle configuration and type of coke produced can greatly affect the amount of stress seen in the drum during the quench. Directionally, the higher the initial quench rate is, the higher the stresses will be, resulting in a shorter projected drum life. Reducing the initial quench rate either by lengthening the quench duration or maximising the flow rates later in the quench, depending upon the operational constraints, is beneficial for prolonging the life of the drum.

Initial quench rates vary from <50 gpm to >300 gpm for up to an hour, with rates increasing to the maximum output of the pumps towards the end of quenching. Most quenches are automated to ensure consistent flows and duration for the quench portion of the cycle. Becht benchmarks quench rate data by comparing the rates to over 50 other coking units worldwide (see **Figure 5**). As we will discuss later on, quantifying the stress levels in the drum during the quench significantly improves the accuracy of the life estimate significantly and enables a more accurate understanding of how the changes in operation can affect the drum life rather than

Operations and current condition

Quench

Quench is when water is introduced to the drum through the feed nozzle, and sometimes above the coke bed, in order to cool the coke. There are two key areas where stress manifests itself:

- Skirt-to-shell weld area
- Coke drum shell circumferential welds

The skirt-to-shell weld area is the most responsive and sensitive area, since it achieves the lowest warm-up temperature and can rapidly see the effects of early quench water flow rate. The drum shell life is most greatly affected by quench water stresses and secondarily by extent of warm-up in the coke drum cylinder. Stresses during quench can be as high as twice the yield stress of the material. The initial rate at which the water is introduced plays an important role in the accumulation of damage, especially in the cone, lower drum, and skirt. The overall rate of quench water flow increase is also very significant, and primarily affects cylinder life.

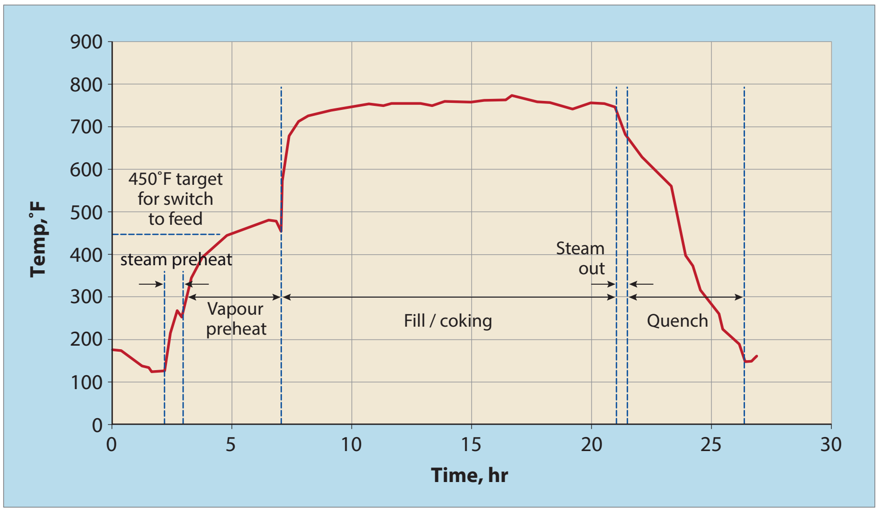

Figure 4 Example of a coker cycle (14 hours)

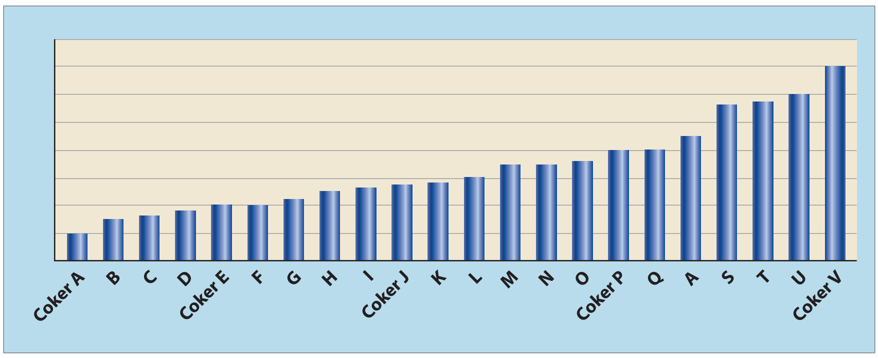

Figure 5 Benchmarking initial quench rate

providing a directionally 'good' or 'bad' assessment.

Switch temperature

Switch temperature is the target temperature at which the drum is heated before introducing hot feed into the drum. The higher the switch temperature, the lower the thermal stresses will be when introducing the feed. The impact of switch temperature is greatest at the skirt-to-shell junction. Optimisation of switch temperature is often intended to mitigate cracking in the skirt to shell; however, when cycle times need to be reduced, there is often a trade-off between the time allotted to warm-up and to quench.

Coke morphology

The two most commonly produced types of coke are shot and sponge. Sponge coke is a porous material and shot coke resembles small pebbles. Shot cokers in industry typically have at least a ~20% shorter life than sponge cokers. This is most commonly attributed to the porous nature of the sponge coke that results in an even distribution of quench water, allowing steam to more likely contact the metal before water, which reduces the stress, when water arrives (see **Figure 6**). Metal temperatures in the drum will cool more evenly than in shot cokers, reducing the thermal gradients that produce high stresses and rapid accumulation of fatigue damage.

Figure 6 Sponge coke

Shot coke beds can result in what is called 'channeling'. The number of flow paths is greatly reduced in comparison to sponge coke. This results in quench water either flowing preferentially to certain areas of the coke drum or in cold water contacting hot metal. This results in either a higher frequency of high stress in preferential areas or rapid quenching of metal throughout the circumference with large temperature gradients and high stresses.

The cycle life of delayed coke drums in industry varies between 4000 and 14 000 cycles. Shot cokers have an average life of 8000 cycles, while a sponge coker's average life is 10 000 cycles.

Condition assessment

With a wide range of cycle lives in industry, our estimate takes into account the current known condition of the drums to determine if the rate that damage is occurring is faster or slower than the norm. The inspection history of the drums is reviewed to determine if cracking or bulging has occurred and, if so, to what extent. If damage has been found, what repairs have been made and what is the quality of those repairs?

Common inspection techniques on coke drums include laser scans and high definition video on the internal diameter of the drum. These scans document the size and depth of any bulges and will document the rate at which the bulges are progressing, if the inspections are done regularly.

Visual and other types of NDT are used, including advanced ultrasonics to identify and size cracks at welds. Depending upon the rate and extent of damage, the team will adjust the cycle life estimate accordingly to ensure as accurate an estimate as possible.

If little or no inspection is done, the band of uncertainty around the estimated cycle life increases. The higher the number of cycles without collecting inspection data, the greater the band of uncertainty.

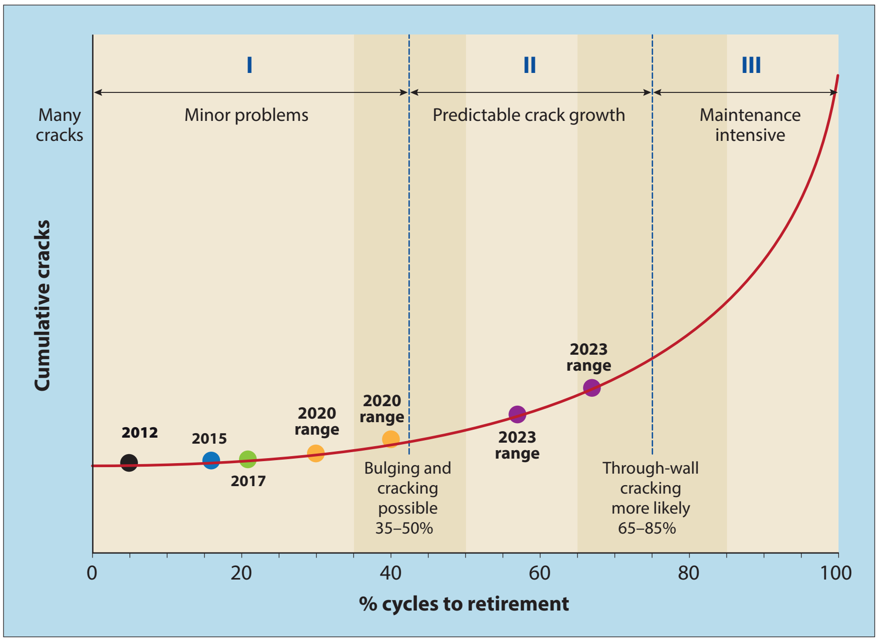

Figure 7 Coke drum life curve

Operational changes

It is common in industry to change the operational parameters of a coker unit. These changes can include almost any variable, from the type of coke produced, the length of the cycle, the switch temperature, to the initial quench rate. These changes can have a significant impact on the cycle life of drums. BechtCokers takes this into account by reviewing the historical changes and bucketing the cycles into different periods of operation. This enables accounting for periods of time when more or less damage has accrued. The output of the tool shows the life fraction consumed for each of the periods of operation, and projects behaviour into the future, allowing planning for upcoming major events, typically the next two turnarounds (see **Figure 7**).

Some coker units have been in service for many years. As a result, a site's historian may not have operational data for the whole life of the drums. This is one of the important reasons for engaging with experienced operators on the unit. They can provide valuable input on the history of operations and repairs to the drums.

Mitigation of risk and life extension

Understanding where the drums are in life is the stepping stone to mitigating the risks of through wall cracks and unplanned outages, as well as steps that can be taken to extend the life of the drums if this is economically justified.

Phase I drums

For drums that are in phase I of their lives, there is ample opportunity for developing proactive inspection and maintenance plans and applying life extension actions. The earlier that life extension steps are taken the more successful they will be. For example, optimising the warm-up and quench steps utilising data gathered from a health monitoring system (HMS) that includes strain gauges and thermocouples installed on the drum can easily extend the life of drums for two turnaround cycles if it is applied early and the data is utilised. If HMS is applied during phase III, the goal is more likely to be reliable operation up to the next opportunity for drum replacement and helping with the design and operation of new drums, rather than life extension. Optimisation of the cycle includes gathering data for base case operations and for adjusted cases to quantify the reduction (or increase) in stress levels and to minimise fatigue damage. Often, these optimisations can be made within the normal cycle time without affecting the throughput of the unit.

Common inspection activities in phase I include laser scanning, which can be done between cycles, visual inspections of the skirt, and NDT of common areas of failure such as thickness transitions.

Phase II drums

Phase II is when inspection activities increase, with the progression of tracking of bulges over time and follow-up inspection on the more severe bulged areas. Laser scanning in advance of turnarounds can be used to develop inspection scope and repair estimates to minimise discovery work. Phase I is also when proactive inspection of weld seams is recommended to identify cracks. Developing repair criteria before cracks are found is a useful way to manage discovery work during turnarounds. Once cracks are identified, they can be sized using NDT, allowing a proper repair rather than a monitoring decision to be made.

Optimising operations during phase II can still make a significant impact on extending the life of the drums, and data from HMS can inform the timing and extent of inspection. There is an economic trade-off for changes in operation. As an example, when cycles are shortened to increase throughput, this should be expected to shorten the life of the drum. Understanding the impact on drum life versus economic gains is critical to the decision making process, and again data from HMS can be used to directly measure the effect on drum life.

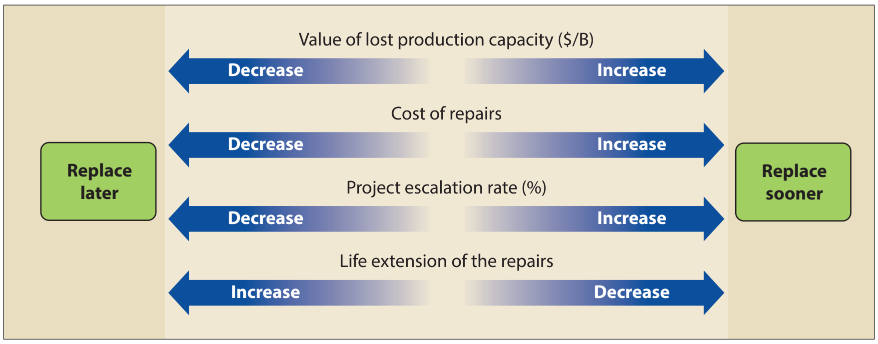

Figure 8 Sensitivities on repair vs replace

Phase III drums

As drums progress into phase III of life, which is the maintenance intensive phase, inspection and repair activities should be expected to increase. Aggressive inspection plans and proactive repairs will be required to prevent unplanned shutdowns from through wall cracks. This phase of life is about managing end of life. Economic analysis is a powerful tool to inform repair versus replace decisions (see **Figure 8**).

Conclusion

It is not a question of will your coke drums crack, but when. The life cycle of any drum depends on the design, operation, inspection, and maintenance of the drum and requires a multi-disciplinary approach to reliability.

Understanding the fatigue life of coke drums and where they are in the life cycle is the key to optimising the cost and margin trade-offs. Without this knowledge you are essentially flying blind and are risking costly unplanned downtime and repairs. Proactively assessing the life cycle of drums enables planning for the most cost effective scope and timing for inspection, repairs, and replacement. The reliability assessment using BechtCokers and a work process implemented with subject matter experts accomplishes this through industry benchmarking and analysis of site specific factors.

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