Delayed coking advances

New technologies and procedures for building and upgrading delayed coking facilities are enhancing health, safety and the environment while increasing economic viability

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Delayed coking remains the industry’s leading economical choice for converting heavy crude into high-value products. However, choosing the right delayed coking process goes beyond improving the bottom line. Significant technological advances are now making it possible to process heavier feedstocks while increasing throughput, improving safety, reducing environmental emissions, and enhancing the reliability, flexibility and overall economics of the delayed coking process.

Safety
The most significant recent safety improvement has been the development of a comprehensive audit methodology designed to improve personnel safety on the coke drum structure. A recent study of coker safety incidents identified several important issues. While the companies involved in these incidents often had excellent PHA systems and emergency response measures, they were not completely immune to potential hazards. Analysis of the details and findings from incident reviews showed that, regardless of the root cause, nearly all major coker accidents occurred in three key areas: at the coke drum top head, the bottom head and outlet of the drain lines.

Workers in these areas were exposed to fires, smoke inhalation, thermal steam and water burns, coke drum blowouts and coke bed cave-ins. A gap was identified in existing safety systems during the interim between a loss-of-containment event and the emergency response team arriving. These findings sparked the development of a methodology to evaluate each work location on the coke structure relative to key hazard areas. The overriding objectives were to identify the steps needed to mitigate hazards. In the process, three key principles emerged:

— Workers should be removed from hazards
— Workers should be protected from inappropriate actions
— Protect personnel by providing emergency exits.

Remote operation, as the first level of safety design, should be incorporated wherever possible in an effort to remove workers from hazards. Some examples include: the capability to remotely drill coke drums; the utilisation of remotely actuated bottom unheading systems, which can be either fully automatic or semi-manual; relocating valve actuation locations; and automating the lowering and lifting of the coke drum telescopic chutes.

When workers cannot be relocated to a safe or more protected area, it is critical to evaluate their primary and secondary paths for egress in the event of a dangerous situation. Steps must be taken to ensure that workers have quick and direct access to safe evacuation routes. Changes in procedures or operating systems should always be considered carefully. For instance, it is important to work with equipment manufacturers to understand the capabilities and limitations of new unheading devices and other safety enhancements. Only after information has been thoroughly evaluated can the most advantageous devices be incorporated into a system that provides the required levels of protection.

No matter how well a refinery designs its safety programme and trains its operators, mistakes and inappropriate actions can happen. So, the second level of safety is to design and operate systems that prevent those mistakes and protect workers from inappropriate actions. An example of this focus on improved systems is the comprehensive safety-interlock system. This system was developed by studying each step of the coke drum cycle and determining the position of all the valves for each step of the cycle. That, in turn, led to the design of an interlock system that is applicable to all cokers, regardless of their level of valve automation.

The third level of safety is to provide personnel protection and a safe route of egress in case something goes wrong on the structure. Achieving this goal requires a rigorous study of where operators will be during each step of the drum cycle, and then evaluating means of providing either protection in place or a safe way-out.

Environmental stewardship
Air quality concerns involving delayed cokers focus around stack emissions from the coker charge heater, off-gas from the blowdown system that enters the refinery flare system, and fugitive dust emissions from the coke-handling area. Designs utilising new technology can reduce heater stack emissions by operating with low excess air for maximum efficiency, by using low-NOx or ultra-low-NOx burners, and by incorporating air pre-heater systems. Flare emissions during the backwarm and drum quench can be reduced through a totally enclosed, closed blowdown system design that recovers hydrocarbon vapours and steam generated from the off-line drum.

In older delayed coking units, the main areas of air quality concern are the coker charge-furnace stack emissions and the closed blowdown system stream that ties into the refinery flare stack. During the backwarming and drum-cooling phases of the normal decoking cycle, hydrocarbon vapours pass from...
the coke drum overhead through the closed blowdown system, with the uncondensed gases going directly to the flare system. In more recent grass-roots coker designs, the off-gas stream is routed back to the main fractionator overhead accumulator for recovery. This design modification significantly reduces routine emissions to the refinery flare system from the delayed coker unit. Many existing facilities are now installing new low-pressure refinery flare-gas recovery systems downstream from the closed blowdown system to further decrease air pollution, particularly SO₂ emissions levels.

An efficient coke pit-pad design with high walls around the coke storage area helps to significantly reduce windborne dust, as does the use of overhead cranes. Eliminating wheeled equipment keeps the operators further away from the coke and reduces dust generation, while substantially improving the inherent safety of the operation.

In a properly designed and operated coker, the only continuous process water effluent stream during normal operations comes from the main fractionator overhead system. This stream is processed in a sour water stripper. Water discharge to the sewers from the drum-handling process can be virtually eliminated by fine-tuning coke-handling and dewatering operations. By designing an effective fines-removal system and totally recycling the drilling and quench water, it is possible to balance the amount of make-up water with the amount of water that leaves as moisture with the coke product.

Finally, an excellent way to process refinery non-biological sludges (including desalter sludge, oily water sludge and some types of tank bottoms) is by injecting the sludge into the bottom of the coke drums during the appropriate portion of the quenching process. This technology allows both wet solids and oily, wet solids to be processed. The oil is recovered within the coker process, and the solids are combined with the coke. Any water present in the sludge is also recovered and recycled.

In the US, the latest environmental issue facing the refining industry is the Consent Decree issued by the US Environmental Protection Agency, the US Department of Justice and individual state governments. Refiners must consider agreeing to implement pollution-control equipment to significantly reduce SO₂ and NOₓ emissions and enhance site-wide monitoring and fugitive emissions-control programmes. Similar types of regulations are also being implemented in other refining regions of the world to control SO₂ and NOₓ emissions.

An extensive flare-emissions minimisation study undertaken for the EPA by ConocoPhillips is the evaluation of operational best practices and design procedures to reduce delayed coker flare emissions. The results are already helping the industry reduce the environmental impact of coker operations by minimising the pass-through of gases from flare-gas recovery systems to the flare, optimising flare-gas recovery operations, and improving coker design and operations.

**Design strategies**

In grass-roots coker project development, setting the design to meet both the short- and long-term needs of the refinery is critical. Considering the future likelihood of expanding resid processing during the initial design phase can save a plant significant lost profit opportunity and equipment costs. Replacing major unit equipment, such as coke drums, the fractionator or heater, during a turnaround will result in extended downtime and increased costs. However, this strategic outlook does not mean that equipment should be deliberately oversized. Rather, it should reinforce the need to incorporate operational flexibility into the original design and make a few key equipment choices with long-term goals in mind.

In recent projects and licensing proposals, refineries are also incorporating unique long-term rationales into their designs. For example, some locations intentionally leave plot space and specify design criteria around the coker to allow for easy placement of an additional pair of coke drums with minimal debottlenecking of upstream units. This decision is based upon future plans to construct either another sour-crude train or other projects to make more coke feedstock available from existing refinery units. These units utilise the benefit of being on-line and generating earnings to help pay for the future expansion projects.

Incorporating distillate recycle in the processing scheme or at least designing the coker so that recycle technology can be added later at minimal cost is another design strategy possibility. Distillate recycle technology increases the flexibility of operating the unit. In addition to extending furnace run length and increasing liquid product yield, distillate recycle can be used to selectively increase the desired liquid products from the coker by varying the boiling range of the material circulated.

This selective product-yield maximisation allows the coker to easily adapt to fluctuations in product demands. In addition, as upstream units are expanded and additional feedstock for the coker becomes available, it is nearly always economically desirable to reduce distillate recycle and increase the fresh feed rate to the unit.

Recently, cokers have also been successfully designed and constructed to process high percentages (40-60%) of solvent deasphalted pitch in the coker feed. Utilising pitch from an existing solvent deasphalting facility can increase overall refinery economics by converting most of the pitch to more valuable transportation fuels.

Some refineries are operating and/or designing their cokers for a blocked-out type of operation. With this strategy, plants are able to process both fuel and anode-grade coke feedstocks to maximise earnings. Based on crude availability and market conditions, these coker units will process sour resid for fuel coke production for a specified time frame and then switch to run sweet resid to make anode coke. For example, when margins for running high-sulphur crudes in the refinery overwhelm the margin and net backs from anode coke production, it is more economical to operate only a fuel coking operation.

**Liquid product properties**

A well-designed coker-modelling program can produce good product property summaries that match commercial operation. Such a program helps a plant enhance the operating performance of the entire refinery by more accurately estimating the impact coker products will have on downstream units, such as catalytic crackers, hydrodearators, blending units and storage facilities.

The ConocoPhillips (COP) coker model provides estimates of the butane and lighter product yields and composition. Pentane and heavier liquid yields are segregated into the required number of fractions, allowing exact liquid cuts to be tailored to the specific boiling-point ranges of the products for the coking unit. Providing linkage to a liquid-cut, pseudo-component generation program is another key COP coker model design feature. This linkage enables the liquid products to be expanded into 50 boiling-range components for assimilation into the proprietary Hysys and other standard modelling programs. Recent research and development efforts have also focused on improving the modelling of the flash zone area of the
coker fractionator. This focus has proven essential in providing users with a useful tool for defining fractionation capacities within the coker and evaluating advanced process control schemes.

**Furnace design**
The recommended design for new coker furnaces is a double-fired, horizontal-cabin configuration with air preheat. Either fuel gas or natural gas is the preferred fuel type, and the double-fired design is preferred over single-fired because of the better flux pattern and shorter in-tube residence times, which helps to improve furnace run lengths when processing heavy feedstocks. Either high-pressure steam or boiler-feed water is injected into each of the furnace coils to help maintain the optimum velocity and residence time in the furnace tubes. High velocity aids in suppressing coke formation in the tubes.

A sophisticated computer program for modelling the process side conditions throughout the heater has been developed. This can accurately calculate the amount of cracking and evaporation at any tube in the coker furnace, as well as assist with other critical design factors. The program has been successfully used in conjunction with commercial operating data to design new furnaces, debottleneck existing furnaces, and evaluate the effects of feed and operating changes on the coking process. Process side knowledge is coupled with other critical mechanical design features to ensure the refinery-selected furnace vendor/contractor will construct the most efficient and most reliable coker furnace available.

The furnace modelling tool also helps quantify the benefits from distillate recycle for furnace operations. The distillate recycle stream promotes vapourisation during the coking process. In the heater, the increased vapourisation raises the tube velocity, which, in turn, decreases the total residence time inside the furnace during the period it is above the cracking temperature of the feed. Reducing the total time in the furnace above this temperature helps to limit coke lay-down inside the tubes, thereby extending the furnace run length.

**Coke drums and fractionation**
The furnace effluent flows to the on-line coke drum, where time, temperature and pressure conditions impact the conversion of the feed into coke and hydrocarbon vapours. Recent coke drum designs generally operate at 15–25psig and 820–845°F drum overhead temperature. Operating at low drum overhead pressures decreases the coke yield for a given feedstock. Operating at high coke drum temperatures further decreases coke yield. Distillate recycle technology is available to substantially enhance operating performance, allowing refiners to run higher coke drum overhead temperatures at a lower furnace outlet temperature. The coke drum vapour stream is quenched with cooled heavy coker gas oil (HCGO) to stop the reaction and retard coke build-up in the overhead line. A good post-quench target temperature range is 790–810°F. The quenched vapour-line feed enters the fractionator above the section’s flash zone gas oil (FZGO) draw tray. HCGO is sprayed into the top of the flash zone area to help cool and condense the heaviest hydrocarbons and knock down any entrained coke fines and heavy liquid from the upward-flowing vapours.

The specially designed and patented FZGO draw tray collects the heaviest portion of the gas oil, which is condensed in the flash zone of the fractionator. A significant advantage of the FZGO draw system is that it eliminates coke accumulation in the bottom of the tower. Conventionalokers allow fines from the coke drum overhead vapour to accumulate in the bottom of the fractionator. The bottom fines level continuously increases and eventually starts interrupting flow to the unit charge pumps. The coker then requires a shutdown to physically clean out the column and bring the furnace back on-line. Whereas conventional cokers may require downtime for cleaning the fractionator every one or two years, cokers using the FZGO draw system have demonstrated six years of operation without significant coke accumulation in the fractionator. A second advantage of the FZGO draw system is the ability to improve liquid yields. Conventional coker designs use this flash zone gas oil, or natural recycle, to provide operability in the furnace. However, recycling this heavy liquid increases coke production and decreases more valuable liquid coker yields. With current distillate recycle technology, it may not be necessary to utilise natural recycle for furnace operability.

**Coke drum design**
The coke drums serve two primary purposes. They provide time to allow coking reactions to go to completion, and they collect the subsequent solid coke. This coke accumulates in the drum, forming a densely packed coke bed. At a predetermined drum level, the furnace effluent is directed through a switch valve from the full drum into the other pre-warmed drum. While one coke drum is being filled for a fixed cycle time, the other undergoes the cooling, cutting and drum preparation steps.

Coke is hydraulically removed from the drum via the jet water pump, which produces a high-pressure (2500–4500psig) and high-volumetric flow (900–1300gpm) water stream. Most current cokers use a combination tool bit that first drills the pilot hole before switching modes to cut the remainder of the coke from the drum. The cutting water and coke flows from the bottom of the drum onto the sloped wall and into the pit.

Typically, fuel and anode cokers have a 14- to 18-hour fill cycle. However, some experienced coking facilities are able to operate at sustained ten-hour fill cycles on both two- and four-drum units. Reducing cycle time enables higher feed rates to delayed cokers and increases overall unit profitability. Reducing cycle time also exposes the drum to more severe stress. A thorough understanding of the stresses must be incorporated in any decision to reduce cycle time, or premature drum failure (cracking or bulging) may occur.

Grass-roots cokers are often designed with larger-sized coke drums than those found in older coking facilities. Coke drums are now up to 30ft in diameter and 96ft tall, tangent-to-tangent length. In addition to capacity, longevity of coke drum life is crucial in creating an optimal coker design. To meet this need, a proprietary coke drum mechanical design and skirt attachment rationale has been developed to allow coker drums to better withstand the extreme stresses during the routine quenching and backwarming cycle steps. These improved design standards, coupled with strict adherence to operating and maintenance practices, have allowed cokers to operate longer between drum replacements and run more cycles per year than conventional cokers.

**Coke handling**
There are several arrangements for coke-handling systems (Figure 1), depending upon design preferences and whether the coke is going to be sent to market by ship, truck or train, or is being directly conveyed to a calcining unit. In no instance should the coke-handling system limit the delayed coker’s operation. For grass-roots designs, a pit-cushion-type arrangement generally
works best, providing a lower overall capital and maintenance cost than is available from most of the other coke-handling systems available on the market.

A successful design should also be flexible enough to incorporate the client-preferred method of unheading. Due to the hazards associated with unheading coke drums, many operating companies install automated systems. There are several remotely operated unheading systems available on the market that offer a variety of other benefits. Since the unheading device is part of the coke drum system, it makes sense to evaluate the unheading devices as part of the overall coke drum and coke-handling system.

**Closed blowdown system**

The closed blowdown system’s primary functions are to maximise hydrocarbon and water recovery, to provide cooling for the coke drums and to minimise air pollution under normal operations (Figure 2). During the first step of the coke drum cooling process, steam is injected into the drum full of coke to strip residual hydrocarbon vapours from the coke bed and into the coker fractionation tower. After a specified time period, steam and hydrocarbon vapours from the coke drum are routed to the quench tower in the blowdown system. After steaming the coke drums, water is injected to cool the coke prior to it being drilled out of the drums. The blowdown quench tower also receives hydrocarbon vapour from the coke drums during the backwarming stage of the normal drum cycle and in emergency relief scenarios.

In the quench tower, hot hydrocarbon vapours are sprayed with oil recycled from the quench tower to condense out the heaviest portion, called heavy slop oil. Portions of the heavy-slop stream are recycled back to the quench tower inlet and to the tower overhead spray header, while the remaining portion is further processed in the coker fractionator or other downstream units. The uncondensed vapour portion exits overhead of the quench tower for further cooling in the overhead condensers.

Water and any light hydrocarbons condensed in the overhead fan-fans are separated in the blowdown settling drum. The wet gas product stream is generally routed to a vapour-recovery system to reclaim the hydrocarbons. New designs usually tie the overhead settling drum line back to the coker fractionator overhead receiver. The light slop oil is normally recycled to the blowdown tower. The water product flows either into the quench water storage tank or is sent to the sour water-stripping unit.

Fresh water is added to the recycled water stream to sufficiently fill the water storage tank. This tank provides water during the quenching phase of the coke-drum cycle, supplies decoking water for the jet water pump to cut and clean the coke drums, and sends water to the dry coke piles for dust-control purposes, as necessary.

**Operations and maintenance**

Coking facilities typically aim for runs of five years or longer between major turnarounds. Limiting coke build-up in piping and equipment, other than the coke drums, is crucial to achieving these increased unit runs. Limiting coke formation in the furnace tubes and coke accumulation in the fractionator tower has already been discussed. Another area where coke build-up causes operational problems is in the furnace transfer-line piping, which is located between the furnace outlet and the coke drum inlet, and in the overhead vapour line, which runs from the top of the coke drum to the fractionator inlet.

The plot plan should be evaluated early in the design process to help minimise total transfer-line length and to establish the proper geometry to reduce coking tendencies. Transfer lines should be designed for easy clean-out when needed. In the coke drum overhead transfer line, a quench oil stream can be injected into the vapour line to stop the coking reactions from occurring in the overhead system. Operating with an after-quench temperature of 790–810°F usually prevents any significant coke formation in this line.

A coke drum foam-over is another...
way coke can form in the overhead vapour line. Foam-overs occur when the coke drum is either improperly operated or overfilled, pushing the reacting liquid and/or coke into and through the overhead vapour line and into the fractionator. The liquid phase then solidifies in the line and portions of the fractionator, resulting in a costly and time-intensive clean-up process. To help eliminate this hazard, many refiners have installed continuous-level indicators on the upper portion of their coke drums. Using these indicators helps operators to better control carryover by determining the height of the layer of foam. Periodically reviewing anti-foam vendor and additive types to optimise chemical addition rates and to limit downstream unit silicon contamination is also recommended.

On-line spalling
The generally preferred method of decoking coker furnaces is with on-line spalling. This process removes coke and carbon build-up from the inside of the furnace tubes, while maintaining a process flow through the non-spalled gases. It uses steam velocity and tube temperatures to provide the energy to remove coke from inside the furnace tubes. The greatest advantage of the on-line spalling technique is that it enables the coker to operate at a reduced rate while decoking. Although an effective decoking method, spalling will not remove hard, inorganic scale material, such as iron sulphide, from the tubes. Non-organic fouling is typically removed using the pigging process. If the unit must be down for steam-air decoking or pigging, it is important to clean transfer lines and to inspect exchangers or other pieces of equipment within the unit during this downtime period.

A critical factor in on-line spalling design and operating procedure development is the overall coil geometry and radiant sections. A detailed furnace geometry and tube design review will help to determine the overall feasibility of on-line spalling, as well as general spalling velocity requirements, velocity limits and operating guidelines. If not properly managed, excessive steam velocity during spalling can quickly erode furnace tubes and return bends. In addition, spalling the furnace tubes too quickly or not monitoring and controlling the critical process variables can cause serious plugging in the furnace tubes due to large slugs of coke fines being generated too quickly.

Shot coke production
Many refineries prefer to avoid shot coke production, because it increases coke-cutting difficulties. However, feedstocks with higher asphaltene and aromatic content tend to produce shot coke over sponge coke, and operations using higher temperatures and lower pressures also tend to lean toward shot coke production. In fuel-grade units, it is typically more economical to operate at conditions that produce shot coke, because of greater liquid yields and better margins for advantaged crude slates, as well as increased throughput due to faster coke drum turnaround times. Experience shows that shot coke production can be efficiently and safely handled by adopting operating and coke-handling system best practices. Strictly adhering to operating and drum-cutting procedures can prevent the likelihood of coke drum blowouts and excessive bed dumps or coke falls that are typically associated with shot coke production.

Better planning
Involving maintenance and reliability personnel early in the planning and design stages is becoming increasingly important as a way to improve unit performance. An example of these benefits includes specifying coke-handling cranes with adequate catch-up capacity for daily preventative maintenance and reliability activities. Another example is effectively designed coke drums that have long life cycles. Having to replace coke drums prematurely is a significant capital expenditure and requires a one-to-two-
month unit shutdown for installation. Providing EPC contractors with detailed drum fabrication guidelines based upon finite element analysis from extensive operating data can also make a difference. At some coking facilities, the following on-line techniques are now being used to monitor crack propagation, help reduce stresses from normal cycle operations and to determine the remaining life expectancy of coke drums:

— Acoustic emissions to locate cracks and monitor growth
— Strain gauges to evaluate thermal and pressure effects of unit operations on coke drum stress
— Internal laser scans, performed in between the clean-out and back-warming drum steps, to identify drum bulges and weak spots
— Coke drum skin temperature monitoring to help track thermal stresses on the drums during the complete coking cycle.

Advanced process controls (APC) are also useful and typically implemented as model-based multi-variable controls using one of the several commercially available tools (such as RMPCT or DMCP). Along with model-based controls, the APC strategy on a coker unit consists of custom calculations and programs, such as drum status prediction. These applications use models obtained from testing at the actual plant to predict, control and optimise the unit. Benefits from using APC on delayed cokers include increased furnace run lengths, better coke drum outage control, minimised impact of drum switches on the fractionator and pumparound systems, improved product property control, the ability to operate equipment closer to process constraints, and increased unit capacity.

Extensive operator training programmes are another developing norm. This training should be tailored to meet both the experience level of trainee operators and the needs of owners. Whenever possible, the training should be hands-on and include: coker management and technical programs for operations supervisors and technical personnel; development of operating procedures; and maintenance awareness training.

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