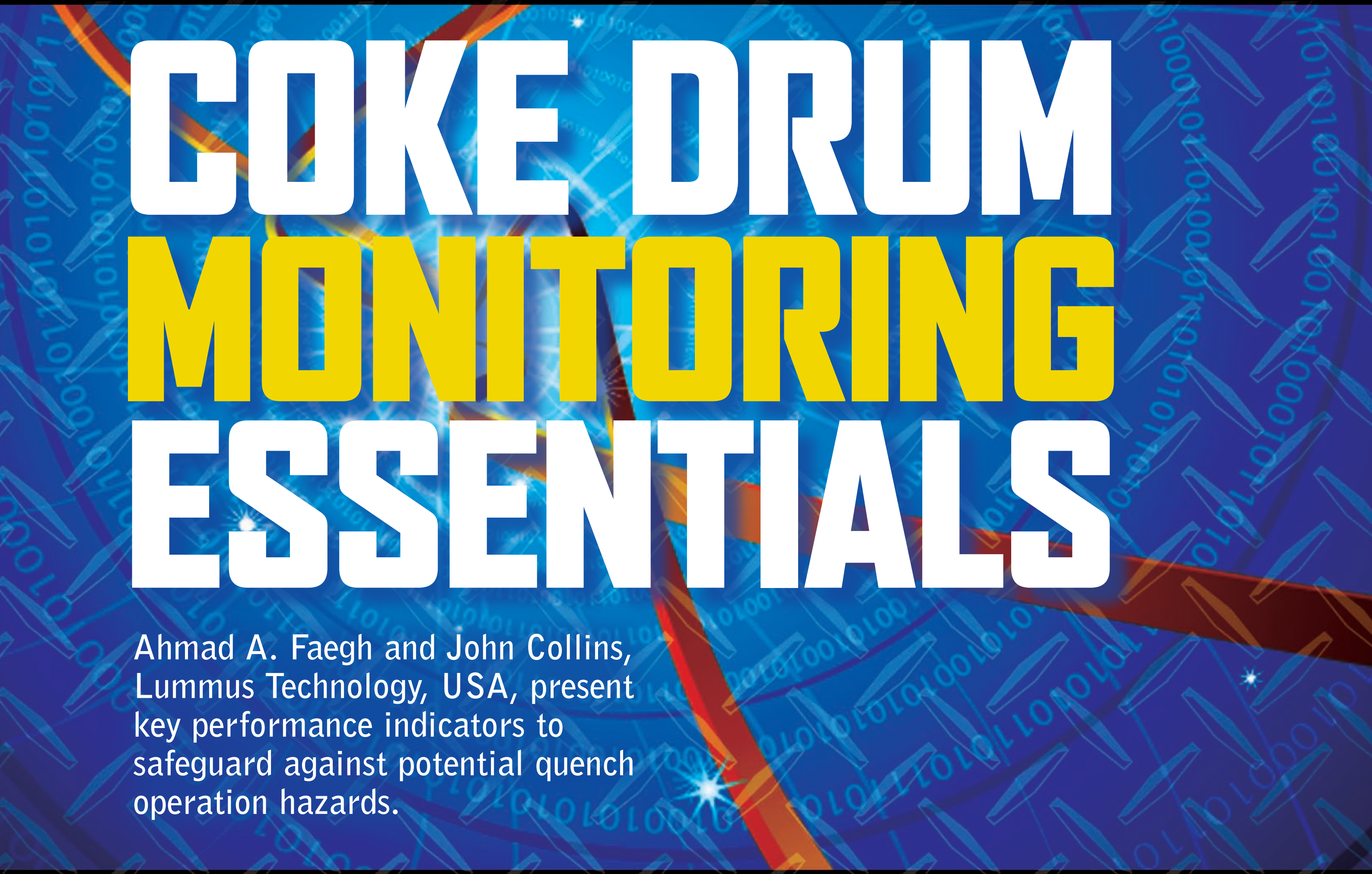

COKE DRUM MONITORING ESSENTIALS

Ahmad A. Faegh and John Collins, Lummus Technology, USA, present key performance indicators to safeguard against potential quench operation hazards.

In recent years, delayed coking technology has been the technology of choice for many refiners when upgrading the bottom of the barrel. The reasons behind this are predominantly the favorable margin between sweet light and sour heavy crudes and the forecast that an increasing part of the available crude slate will consist of sour heavy crude. Delayed coking can offer a significant advantage to refiners compared with other upgrading technologies due to its flexibility in processing feedstocks derived from a variety of crude oils.

Delayed coking units are unique because of the semi continuous nature of the process and operational features that include solids handling. Consistent, trouble free, and safe operation of delayed coking units can directly and significantly impact the profitability of refineries. The most economical operation of a delayed coker is not only dependent on the length of time between major turnarounds, but also hinges on the number of days the unit is onstream. Accordingly, any trouble with coking unit operations can lead to a slowdown or shutdown of the unit, which may have a ripple effect on refinery operation, eventually leading to crude rate reduction and downgrading of liquid products to cope with the problem. State of the art hardware and software alone are not sufficient to monitor and maintain highly reliable operations. The number and nature of tasks to be performed on a daily basis, along with the complex mechanical aspects associated with this technology, require keeping the key and critical performance parameters under constant surveillance. This is even more important for older delayed coking units.

Coke drum cooling is one of the tasks where effective monitoring is essential in sustaining a reliable and safe operation. At the end of a coking cycle, solid coke is stored inside the coke drum at a high temperature. Opening of the coke drum to the atmosphere is a necessary step in removing the accumulated solid coke from the drum and preparing it for the next coking cycle. Because of the risks involved in this operation, it is vital that operating personnel know in advance whether it is safe to open the coke drum. This article discusses the key indicators for monitoring coke drums during the quenching/cooling operation for the telltale signs of an at-risk drum.

Coker operating conditions

The primary objective of refiners opting for a fuel grade delayed coking unit is to convert inexpensive bottom of the barrel oil into the maximum possible yield of clean liquid products, especially distillate liquids. Fuel grade coke is an undesirable byproduct of this upgrading process that should be minimised.

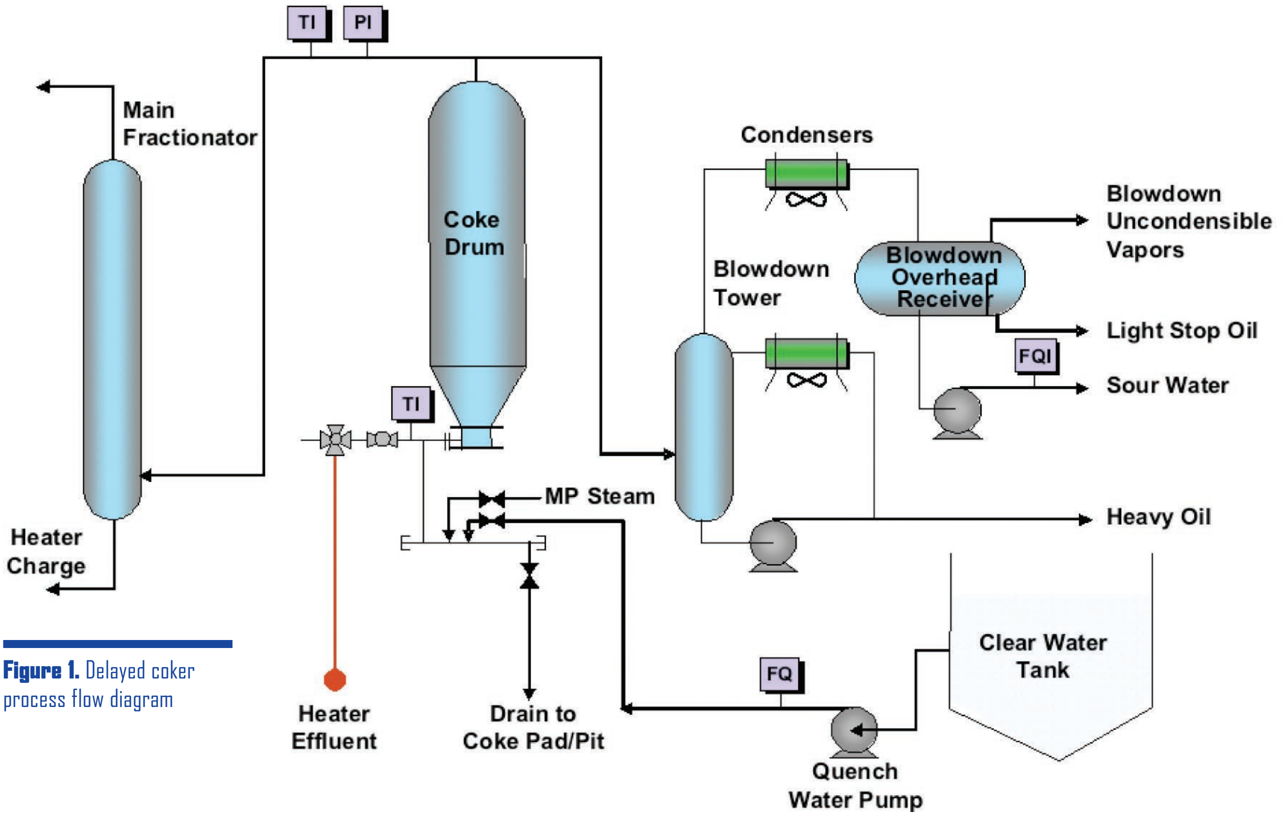

Figure 1. Delayed coker process flow diagram

Table 1. Impact of operating parameters on coker product yields

Increasing	Gas yield	C5+ liquid yield	Coke yield	HCGO quality
Pressure	↑	↓	↑	Improves
Recycle rate	↑	↓	↑	Improves
Coil temperature	↓	↑	↓	Deteriorates
Velocity medium	↓	↑	↓	Deteriorates
Cycle time	-	↑	↓	-

For maximum liquid yields, the delayed coker must be designed for low pressure and low or ultra low recycle operation. The operating parameters that influence the product yields and properties are:

- Coke drum pressure.
- Recycle rate (throughput ratio).
- Heater coil outlet temperature .
- Heater velocity medium injection rate.
- Cycle time.

Coke drum pressure and recycle rate (throughput ratio) have the greatest effects on coker yield structure and product properties: increasing coking pressure or recycle rate increases coke and gas make. As a rule of thumb, every 10 psig increase in coking pressure results in an approximately 1% loss in C5+ liquid yield.

The heater coil outlet temperature (COT) also has an appreciable impact on coking unit product yield. A higher COT results in a higher liquid product yield. However, the range of COT variations is limited in practice due to consequential operational concerns such as increased fouling of heater tubes and increased coke hardness. Increased fouling reduces the heater run length. Harder coke takes longer to cut from the drum. Unit operation at the low end of the COT operating range typically results in the production of soft coke while generating excessive coke fines.

It is important to note that there exists a minimum COT, outside of the normal operating range, beyond which the coking reaction will not fully proceed. This temperature is mainly dependent on the nature of the feedstock. Operation below this temperature for even a short time can lead to formation of solidified tar pockets inside the drum that sometimes encapsulate hot hydrocarbon vapours. This situation poses a potential risk for a flash fire when the hot flammable vapours are exposed to the air after opening the bottom head or during the cutting operation. Furthermore, cleaning the coke drum and removing this uncoked material can be time consuming, resulting in a switching schedule delay and consequently, a unit slowdown.

The impact of the remaining parameters (velocity medium and cycle time) on delayed coking product yield is not as appreciable. An increase in the injection rate of steam or boiler feedwater (BFW) into the heater (increasing tube velocities) results in a slightly greater liquid yield. Shorter cycle time, on the other hand, results in lower liquid product yield since the time required to reach steady state coking operation at the required temperature is reduced. The impact of each parameter on coker product yield is summarised in Table 1.

Coker cycle time

As mentioned, coking is a semi continuous operation. Most units consist of one pair or multiple pairs of coke drums. One coke drum is always in coking mode while the other drum is being decoked. Most of Lummus Technology's current designs utilise a 36 hour cycle (18 hours filling and 18 hours cooling/decoking). Table 2 shows a typical breakdown for a 36 hour cycle followed by a brief description of the steam out and water cooling/quenching steps.

At the end of the coking period, the coking heater effluent is switched to the empty drum of the pair. Steam is injected into the base of the coke filled drum with the overhead line routed to the main fractionating column (Figure 1). Coke drum steam out continues for a longer period after its overhead is lined up to the closed blowdown system. The function of the closed blowdown system is to condense the steam/oil vapour mixture from the coke drum during the coke drum steaming and water quenching/cooling operation. In the blowdown tower, these vapours are cooled and washed with a recirculating oil quench to remove heavy hydrocarbons. The overhead vapour from the blowdown tower is condensed in the blowdown overhead condenser.

Prior to completing the steam out, water is slowly injected into the coke filled drum to cool the coke bed. Cooling water is introduced slowly at first to avoid excessive thermal stresses in the coke drum shell. The cooling water rate is increased in stages until the entire coke bed is soaked with water. Water is vapourised during this cooling operation and, along with any stripped oil, is sent to the blowdown system. After water cooling, the drum is drained and the top and bottom heads are opened.

Slops produced from the blowdown system are recycled back into the unit. Condensed steam is collected in the blowdown overhead drum and subsequently sent to sour water disposal. Vent gas is recovered by routing it to the suction of the wet gas compressor.

Table 2. Typical coking 36 hour cycle

Operation	Hours
Coking	18.0
Switch drums	0.5
Steam out to coker fractionator	0.5
Steam out to closed blowdown system	1.0
Slow water quenching/cooling	1.0
Fast water quenching/cooling	3.0
Drain coke drum	2.0
Remove top and bottom heads	0.5
Hydraulic coke boring/cutting	4.0
Reheading/pressure testing	1.0
Drum warm up	4.5

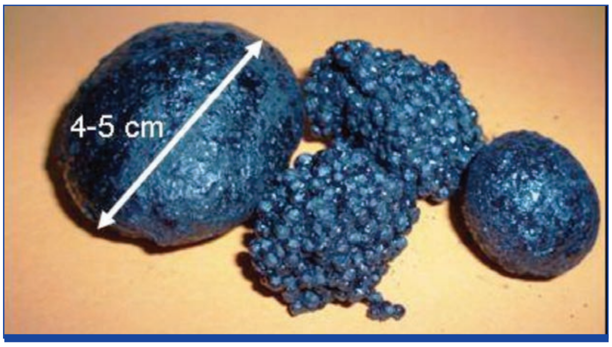

Figure 2. Beads of shot coke.

Figure 3. Dumped shot coke.

The industry has been moving toward larger diameter and fewer pairs of coke drums combined with shorter cycle times. Revamped units are typically operated with shorter cycle times, with some pushing the limits and targeting 24 hour cycles (12 hours filling and 12 hours decoking). Most of the reduction in cycle time is accomplished by decreasing the time dedicated to cooling, cutting, and warm up operations as they take up most of the decoking time. In some cases, the reduction in cycle time is carried out without an appropriate level of scrutiny to preserve the longevity of the coke drums. Reducing cycle time below 16 hours leaves no room for error: any operational problem that is not detected and corrected may have undesirable consequences.

Operational challenges

Designing a fuel grade coking unit to maximise liquid yield while processing heavy feedstocks has been the primary engineering challenge of the past decade. Lummus Technology's improvements to its delayed coker designs resulted in new units with longer heater run length, increased operational reliability, and improved safety. However, economical and safe operation of these units in actual operation is not automatically guaranteed solely on the basis of a good design with state of the art features. Variations in the feedstock and the semi continuous nature of the process make every cycle different. The mechanical features associated with delayed cokers and the unique habits of each operating crew introduce another level of complexity to the daily operation of these units. Timely identification of any developing issue during each cycle can prevent slowdown and possible unit shutdown. Critical and key performance indicators must be developed for each unit and monitored daily by unit operating personnel in order to fulfill this objective.

Operating conditions maximising liquid yield and reducing coke make, together with processing heavy feedstocks, contribute to a number of operational issues in fuel grade cokers. Heavy and extra heavy oil are typically high in asphaltene content, which, based on experience, is believed to be responsible for shot coke formation. As shown in Figure 2, shot coke is in the form of variously sized solid amorphous beads, either loosely arranged or fused together, and sometimes held in a matrix of sponge coke. This form of coke is hard and non-porous.

The formation of shot coke poses several important safety and operational concerns. It leads to abnormal channeling inside the coke drum, which prevents uniform cooling of the coke bed with water during the cooling or quenching operation. This uneven cooling leads to regions inside the coke bed with extremely high temperatures, known as 'hot spots.' Hot spots erupt violently when they come into contact with water during the coke cutting operation and pose a serious safety issue for units not equipped with a totally enclosed unheading system. Operating personnel can be exposed to high speed projectiles escaping from the open flange at the top of the coke drum.

Moreover, uncontrolled dumping of shot coke (Figure 3) can cause safety and operability issues. This occurs when loosely bound shot coke inside the coke drum empties instantly once the bottom head or slide valve is opened. The coke cutting operation can be risky for units that make significant quantities of shot coke. Before starting the cutting operation, a small hole of approximately 4 – 6 ft in diameter, known as the pilot hole, is cut through the bed. Shot coke can cave in and bury the drill stem when drilling the lower portions of the pilot hole. Recovering the drill stem can put the coker operation behind schedule, causing a slowdown.

Lower pressure and reduced recycle coking, together with higher drum temperatures, contribute to a higher in drum vapour velocity, which in turn causes a highly turbulent environment that promotes shot formation. In addition, the increase in vapour velocity lifts larger quantities of coke fines and tar like material from the reaction front inside the drum into the overhead lines and the main fractionating column. For those units that are revamped far beyond their original nameplate capacity and operated at reduced cycle time and drum outage, this condition poses a greater risk of coke drum foam over into the fractionator. Two good indicators of high carryover are the coke drum overhead line pressure drop and the frequency of strainer cleanout on the fractionator bottoms recirculation system.

There are other operational challenges, such as the incompatibility of certain feedstocks that lead to excessive foaming, foam over, or an increased tendency for heater fouling. However, these issues are beyond the scope of this article.

Adequacy of cooling operation

Solid coke, stored inside the drum at the end of the coking cycle, is at high temperature. It is imperative to reduce the temperature to a safe level before opening the coke drum to the atmosphere. This operation is inherently risky and can precipitate hazardous conditions with undesired consequences including, but not limited to, equipment damage and adverse environmental impact.

Because of the risks involved, it is important that plant personnel closely monitor the key performance indicators (KPIs) for each coke drum during the coking and quenching/cooling part of the cycle for telltale signs of an at-risk drum. Process data collected during these operations by the typical refinery data acquisition system can be used to help the operations' personnel identify an at-risk drum and adopt appropriate measures prior to opening the drum to atmosphere. Lummus Technology, based on its commercial unit experience, has developed a list of KPIs that is general in

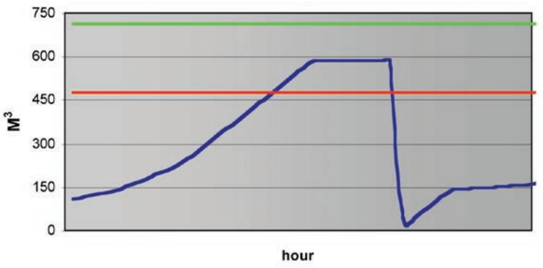

Figure 4. Cumulative quench/cooling water.

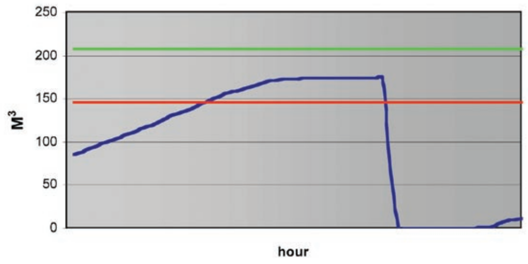

Figure 5. Cumulative sour water production.

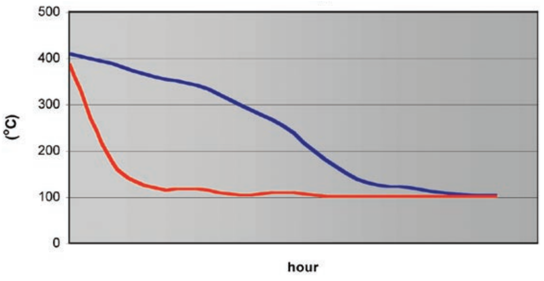

Figure 6. Drum overhead (outlet) temperature.

nature and applicable to almost all coking units. This list may be expanded based on each delayed coker operator's specific experience and includes the following:

- Total quench/cooling water flow.
- Total sour water production.
- Coke drum overhead pressure.
- Coke drum outlet temperature.

Key performance indicators (KPIs)

Total quench/cooling water

During the coking cycle, the fired heater continuously supplies energy to the coke drum's incoming fluid. A significant portion of this supplied energy is stored inside the coke bed that remains in the drum at the end of coking cycle. As mentioned earlier, water is used as the cooling medium to lower the average temperature of the bed before opening the drum for boring and cutting. The volume of water required for adequate quench is typically constant within an expected range depending primarily on coke drum outage and, to a lesser extent, on feedstock characteristics and operating conditions. The total quantity of water required can be determined initially by a simple heat balance and later fine tuned based on experience.

The total volume of water required for cooling/quenching the coke bed for a coke drum with an 8.4 m diameter and 25.9 m tangent to tangent height is calculated to be 757 m^3. Plant data for the same operation shows a consistent 715 - 757 m^3 of water used for quenching (Figure 4). Experience shows that inadequate quenching occurs when the total volume of water delivered to the coke drum is two thirds of the normal consumption. This is usually indicative of inadequate quenching of significant sections of the coke bed. The cutoff for adequate, fair, and inadequate cooling of a coke drum must be determined by each operator.

Total sour water production

Another important indicator of the quality of quench is the total sour water generated during steamout and cooling of the coke drum. Sour water production for the same 8.4 m diameter coke drum is estimated to be 208 m^3 based on the heat balance discussed earlier (Figure 5). This water is predominantly recovered by condensing the steam generated during the quenching/cooling operation. A significant reduction (below 70%) in the typical sour water production is a key indicator of poor quench. The simultaneous reduction in total water volume used for quenching a coke drum and lower sour water production should be a cause for serious concern. This typically signifies that the stored coke has not been adequately cooled and moreover, for units that process shot forming feedstocks, that hot spots may have been formed inside the bed.

Coke drum overhead pressure

Unusual pressure spikes during quenching/cooling and soaking parts of the cycle may be an indicator of hot spots coming into contact with water and causing sudden pressure surges. In many units, the overhead drum pressure is one of the interlock permissive signals that allows opening of the top head of a coke drum. If this pressure stays high, it is very likely that hot spots may be present deep inside the coke bed. Most units are designed with an emergency top quench/cooling water line, which is sometimes used to reduce the overhead pressure in order to satisfy the interlock requirement and thus stay on schedule. This procedure should be used with caution as it may be masking the root cause of the high pressure.

Coke drum outlet temperature

Drum overhead temperature decreases gradually as the quenching/cooling operation progresses. A sharp exponential like decrease in the temperature can be an indication of channeling and water bypassing significant sections of the coke bed. Each unit must develop the distinction in the rate of temperature drop for an adequate and insufficient quenching/cooling operation.

The set of KPIs presented here is not an all inclusive list as there are other parameters that can be monitored. One of these indicators is the flow of steam while steaming out the coke bed during and after the drum switch. Adequate steam out of a coke drum keeps the internal coke bed passages open, allowing even and well distributed flow of quench/cooling water. Another indicator is the heater COT, which provides valuable information about the content of a coke filled drum. Reduction in COT below a certain limit anytime during the coking part of the cycle should be taken seriously. Such an event, even for a short time, can lead to the formation of tar pockets encapsulating flammable vapours, with the potential for a flash fire as discussed previously. Using the list of KPIs, each unit must carefully define a monitoring programme in line with their past experience and specific needs.

Conclusion

In most delayed coking units, instrumentation is available to collect data related to key performance indicators. The challenge for unit supervision is to get the right information to the right people at the right time. This information should be presented in a manner that empowers the unit operators and drillers to recognise the potential risks and adopt the appropriate measures for a coke drum ready to be opened and drilled.

Data collection can be accomplished using the plant data acquisition system. This data can be organised and arranged in a manner that will enable operators to monitor and recognise an at-risk coke drum. Risk ranking tools can be developed based on the KPIs and each unit's specific experience. Such a tool enables unit operators to evaluate each coke drum at the end of the quenching/cooling operation before attempts are made to open the drum to atmosphere. Recognising potential hazards in advance allows for appropriate precautionary measures to be taken, preventing undesired consequences.