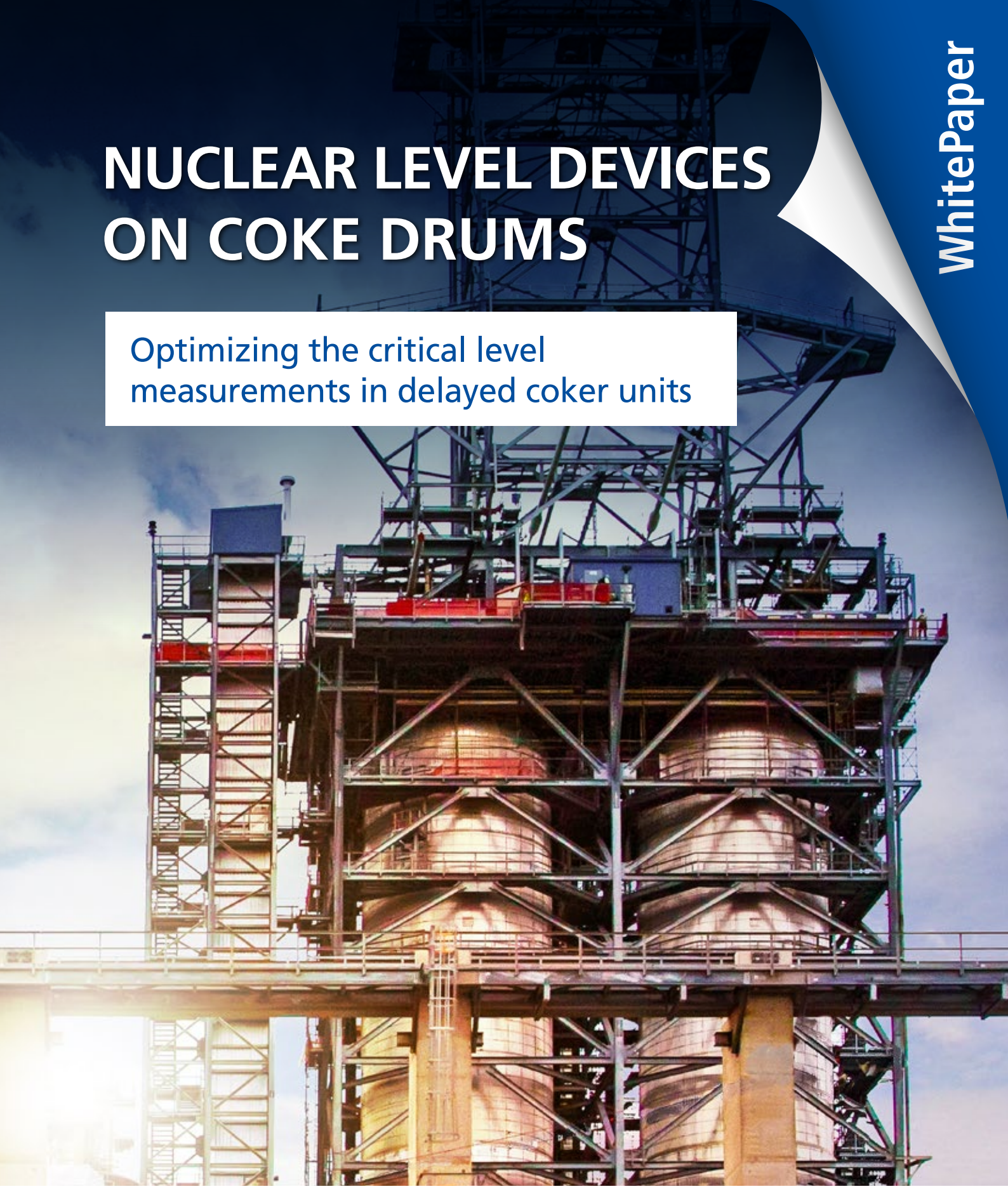
WhitePaper

NUCLEAR LEVEL DEVICES ON COKE DRUMS

Optimizing the critical level measurements in delayed coker units



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Introduction

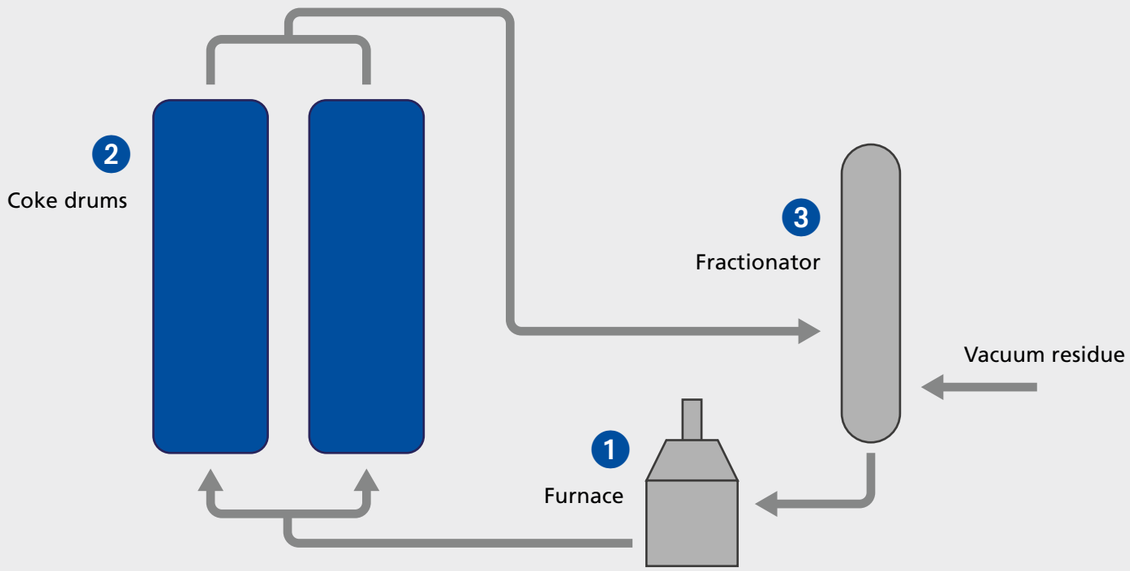
Global refiners are always seeking new techniques to optimize their refinery assets with the purpose of maximizing their profitability. Most refiners look for methods to convert lower value residual into higher value products. In other words, refiners are searching for bottom of the barrel conversion technologies such as visbreaking, delayed coking and resid hydrocracking, either ebullated bed or slurry hydrocrackers (Sawarkar et al, 2007). Since delayed coking is one of the most profitable units in the refinery and it has a lower initial cost than some of the other heavy oil conversion technologies, many refiners are turning to this proven conversion technology (Jaguste, 2016). The coking process dates back as far as the later 1920s, around 1929 when Standard Oil in Whiting, IL started the first delayed coker unit.

Delayed coking – an overview

The heart of the delayed coking unit is the drums where the actual cracking of the hydrocarbons takes place. The unit is the only semi-continuous batch process in the refinery, which means that feed is continuously switched between two, or sometimes more than two, drums in a time-based cycle, typically 12 hours (Jaguste, 2016).

In the simplified view, fresh feed, usually from the vacuum tower bottoms, is fed to the bottom of the coker fractionation tower (Figure 1, item 3) to help pre-heat the feed and is mixed with the bottom hydrocarbons (product that was not fractionated out) of the fractionator tower. This mixed resid is then fed to the furnace (Figure 1, item 1), where the resid has enough energy applied to thermally crack the large hydrocarbon chains. Since the required time for this cracking is 30–45 minutes (hence the name delayed coking unit), the resid is fed into the coke drums (Figure 1, item 2) where it remains until it is thermally cracked (Sawarkar et al, 2007). After the resid is cracked the resultant hydrocarbons are vaporized and leave the drums to be cooled and fractionated into

Fig. 1 Schematic flowchart of a delayed coker unit



different side streams in the coker fractionator (Figure 1, item 3). Some of the vapors are not fractionated into the side streams and therefore mix with fresh incoming feed to be recycled back to the furnace where they are further cracked. This is referred to as recycle ratio – the recycle feed compared to the fresh feed (Motaghi et al, 2010).

At the end of the approx. 12h cycle the coke drum is filled with a solid residuum of coke. To remove this coke, a high-pressure water drilling system is used to cut the coke block into chunks, that can be then removed.

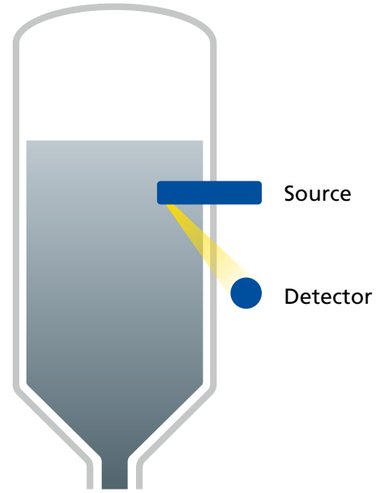
Level measurements to control the process

One of the most critical measurements in the delayed coking unit is the level measurement inside the coking drums. Due to the conditions inside of the drums this measurement is a challenging application. As the heavy hydrocarbons are thermally cracked, the resulting hydrocarbons are then converted into a vapor as a result of the high temperature. As the vapors escape the viscous liquid, they tend to create a foam layer. This foam layer can vary depending on several parameters such as the operating temperature, pressure of the drum, type of crude or charging rate. To increase throughput of the unit, one of the most important objectives is to fill the drum higher safely and reliably (Sawarkar et al, 2007). For this reason, it is necessary to reliably measure the foam front in the drum to ensure that it does not go over into the overhead lines and/or fractionator tower, in other words, a so-called foam-over should be avoided. A foam-over in a delayed coker unit is a costly event, not only due to the loss of production but also the manual labor required to clean the coke out of the overhead lines and fractionation tower. This cleaning can take up to two or three weeks depending on the severity of the foam-over. In the meantime, many different types of technologies have been tried and tested to measure this level. Among them are differential pressure (DP), radar and nuclear. Due to the extreme process conditions inside the drums, DP and radar units tend to either fail or turn out to be extremely unreliable. Thus, almost all coke drum level measurements are some type of nuclear measurement devices.

Different types of measurement devices

The first type of nuclear gauge that was tried was a gamma switch. This consisted of an internal source and an externally mounted detector (Figure 2). The internal source was required because of the large diameter of the drum and the substantial wall thickness. Furthermore the detector technology at the time was not sensitive enough to measure the lower radiation fields as is possible today.

Fig. 2 Sketch of the first type of a nuclear measurement



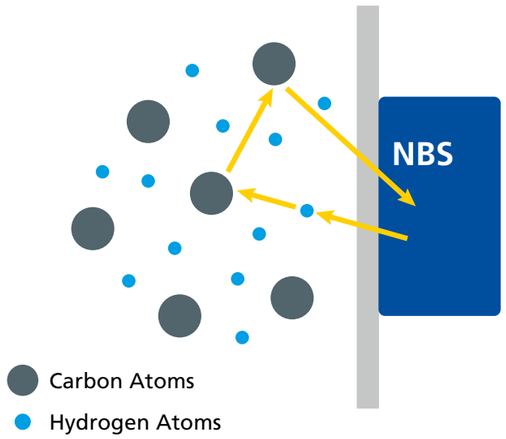
This type of measurement did not last long due to the complications posed by the internal source well and drilling of the drum. Customers did not want to take the risk of losing a source during cutting of the drum. The shift in the industry was initially towards a neutron backscatter measurement (NBS) since both the source and detector are located outside the drum in the same housing. Consequently the mounting of the device was much easier.

The operation of the NBS also has some limitations due to the principle of measurement. While the NBS is used to measure level in the delayed coke drums, in reality it measures the concentration of hydrogen of the material inside the drum. As water has more hydrogen than resid, resid has more hydrogen than the foam, and the foam has more hydrogen than the hydrocarbon vapor, the device is used as an indirect measurement of the level. The NBS emits neutron radiation in all directions because it is very difficult to collimate neutron radiation.

To measure the level inside the coke drum with the NBS, two things must be given (see Figure 3):

1. The neutrons must be scattered back to the detector, since the source and detector are in the same housing.
2. Secondly the neutrons must be thermalized or slowed down by the process material. If the neutrons are not thermalized, they have too much energy to be detected by the sensor and travel through the device undetected (Hart, 2014).

Fig. 3 Principle of a neutron backscatter measurement



One of the most effective means of thermalizing neutrons is using hydrogen as a moderator. Hydrogen is very effective in thermalizing or slowing neutrons down since they are physically the same size. To illustrate: consider billiard balls, if the cue ball hits another ball, half the energy of the cue ball is transferred to the other ball (comparable to a neutron colliding with hydrogen nuclei). If we now assume that a cue ball hits a bowling ball, the cue ball bounces off basically at the same speed, as very little energy is transferred to the bowling ball. This is comparable to the collision of a neutron with a carbon nucleus. The distance a neutron can travel after being thermalized is very limited, therefore the NBS measures approximately 450mm into the drums. Thus, the area a NBS can measure is a sphere with a radius of 450mm. As the hydrogen content increases in front of the detector, more neutrons are thermalized and scattered back to the detector. As already mentioned before, the hydrogen content of the different phases inside the coke drum are different. So, in principle NBS measures the amount of hydrogen in front of the device. By monitoring the output changes in the detector, an operator can ascertain the level inside the coke drum. This relationship between the amount of radiation sensed and the level is a direct proportionate relationship – less radiation detected equals less hydrogen or lower level, more radiation detected equals more hydrogen or higher level.

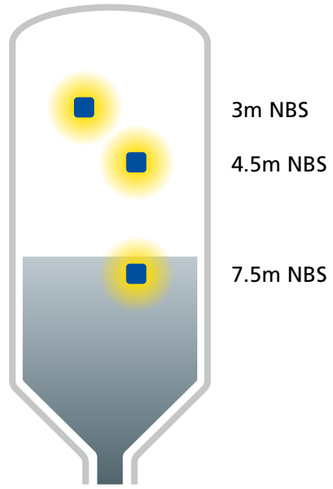
Typical coke drum arrangements

A typical coke drum will have either three or four NBS located at different elevations on the drum (Figure 4). These elevations are normally 3m, 4.5m and 7.5m down from the top tangent. The 7.5m is used to start anti-foam injection, 4.5m is typically the maximum coke bed density and the 3m is basically a high-level switch. Operators would use the NBS like switches on the side of the drums to inform them if the level has reached a certain elevation. The output of the NBS is supposed to inform the operator if the material at the elevation is hydrocarbon vapor, low density foam, high density foam, coke, or water. Theoretically this is possible since the hydrogen content is different in each of these materials. The main issue with this assumption is that the NBS measures over a range of approximately 800–900mm (400–450mm up and down) and the NBS output assumes that the range is covered by a single material, which is not necessarily the case. For instance, if in one case the range was covered by 20% coke and the rest was hydrocarbon vapor (no foam), you might get a reading of approximately 40%. At the same time, if the range of the NBS is covered with 70% high density foam and 30% low density foam, you might also get a reading of approximately 40%. This is due to the total amount of hydrogen measured over the entire range.

All in all there are some issues with the use of NBS:

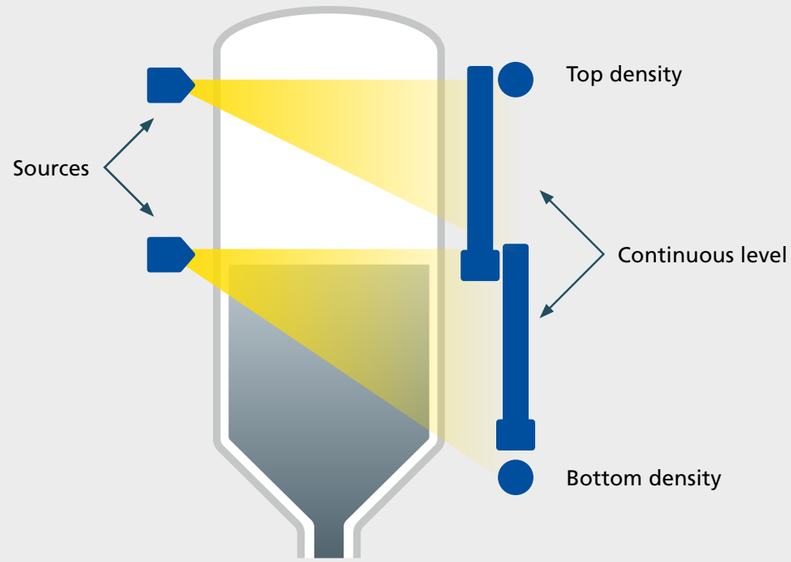
- must be mounted to the drum
- affected greatly by water (rain or water running down the outside of drum)
- measures limited ranges at specific localized locations and allows misinterpretations of the readings.

Fig. 4 Coke drum with NBS



With the advancement of gamma scintillation technology, it is nowadays possible to use fully external continuous level measurements on the drums instead of having just localized point level detection. This advancement allows operators to continuously monitor the level throughout the cycle. It provides additional information such as anti-foam effectiveness, rate changes, foam-ups, etc. As shown in Figure 5, a gamma continuous levels system consists of sources mounted externally on the vessel and one or more continuous level detectors mounted on the opposite side of the drum. Typically, such a measurement starts near the top tangent and continues 10–14m down the drum or in some cases the entire length of the drum (tangent to tangent). A continuous gamma level system works by directing gamma radiation from collimated source holders or shields through the middle of the drums. The detectors mounted on the opposite side of the drum measure the amount of radiation received (Williams, 2017). When the vessel is empty, the detectors receive the most radiation. As the level increases in the drum, the process attenuates the radiation, therefore less radiation is received by the detectors. When the level reaches 100%, no radiation from the source is sensed by the detectors. The relationship between the amount of radiation and the level is inversely proportionate – more radiation equals lower level, and less radiation equals higher level. As discussed earlier with the NBS, this relationship is opposite when compared to the NBS.

Fig. 5 Coke drum with gamma level



DCU process control with continuous gamma level measurement

During normal operation of the delayed coker, vapor can vary greatly as seen in Figure 6. This trend graph is from a nuclear density point located at the top tangent where only the density of the vapor in the drum is measured. At point 1 in the graph, the vapor density is close to zero since the drum is cold and empty. Between point 1 and 2, some of the overhead vapor from the online drum is directed to the standby drum to preheat it. This helps to prevent thermal stress on the vessel when it is time to add hot resid feed to the drum (Jaguste, 2016). At point 2, the switch valve is aligned to allow the hot resid feed to the standby drum, causing a sudden increase in vapor density. Between point 2 and point 3 is the normal charging of the drum. At point 3, feed is then shifted from the online drum back to the other drum to start its charging cycle. Between point 3 and 4 the steam quench and water quench are located which are used to cool the coke and drum for deheading and decoking (removal of the coke from the drum by means of high-pressure water). The drilling portion of the cycle is located from point 5. Consequently, the density reading is high and varies greatly since the drill stem inside the drum attenuates some of the radiation causing the readings to fluctuate.

To provide an accurate level output, the radiation detector must be able to detect the change in radiation that is only caused by the change in level and not by the change of the density in the vapor space above the level. By using the output from the density point that is mounted at or near the top tangent of the coke drum, the output of the gamma continuous level detectors can be automatically compensated. By measuring the change of radiation in the vapor space, an advanced algorithm can be used to calculate the change that is only caused by the change in level (Williams, 2019).

Most modern delayed coker are operated at a lower pressure to increase the gas oil yield (Motaghi, 2010). In addition, lowering the drum pressure leads to an increase in the gas velocities. Increasing gas velocities can cause more fines to be lifted and carried into the overhead lines and to the fractionator tower. Another contributing factor leading to fines carryover is the height in the drum and the amount of foam present (Sayles & Romero, 2013). Measuring this carryover is an added benefit of the gamma continuous level system. Since the radiation is transmitted across the drum and is not only localized as is the case with the NBS, the gamma point detector at the top can detect these changes in density. The temperature and pressure are the same during the coking stage of the cycle, any changes in the vapor density can be inferred to be entrained coke fines or pitchy materials (Sawarkar et al, 2007). Figure 7 shows an increase of the vapor density at the end of the cycle. This increase is caused by the entrained particulate matter with vapor. By measuring this effect towards the end of the cycle, an operator can make a more informed decision about their process depending upon the amount of carryover the unit can handle.

The most important purpose of a gamma continuous level system on the coke drum is to monitor the foaming characteristics and help optimize the usage of anti-foam. Without a good knowledge of the foam level inside the drums, designers must take into consideration other parameters such as foaming tendencies of the crude, and anti-foam effectiveness. With the use of continuous gamma level detectors, the operator can make a better-informed decision not only on the use of anti-foam, but also on increasing the run time (Sawarkar et al, 2007). As parameters change inside the drum, the conditions that create the foam changes, causing the foam level to increase or decrease. These parameters include blending of different crudes, coker heater outlet temperature, drum overhead pressure, recycle rate and cycle time (Sayles & Romero, 2012). By having a continuous level measurement of the foam, decisions can be made to better utilize the available drum space. Some operators have even implemented the use of automatically injecting anti-foam based on foam level (Romero, 2013). These control algorithms can be simple or complex. They can be as simple as turning on anti-foam when foam level reaches a specified height in the drum or more complex, for instance when the foam height reaches 25%, turn on anti-foam at 25% flow and when the level reaches 50% level, increase anti-foam rate to 50%, etc. The gamma continuous levels can also be used to measure the effectiveness of the anti-foam. By recording the drop in the foam layer when anti-foam is injected, the amount and type of anti-foam chemical can be measured to see if a different type is more effective or if the amount can be reduced. In Figure 8, point 1 anti-foam is injected for a specific amount of time and turned off. At point 2, anti-foam is turned on again but this time, it is left on. After the anti-foam is turned off at point 1, the foam level builds back to about the same height it would have been without anti-foam injection. After point 2, when anti-foam was injected, the amount of foam afterwards is greatly reduced.

Fig. 6 Trend graph of a nuclear density point located at the top tangent of a coke drum

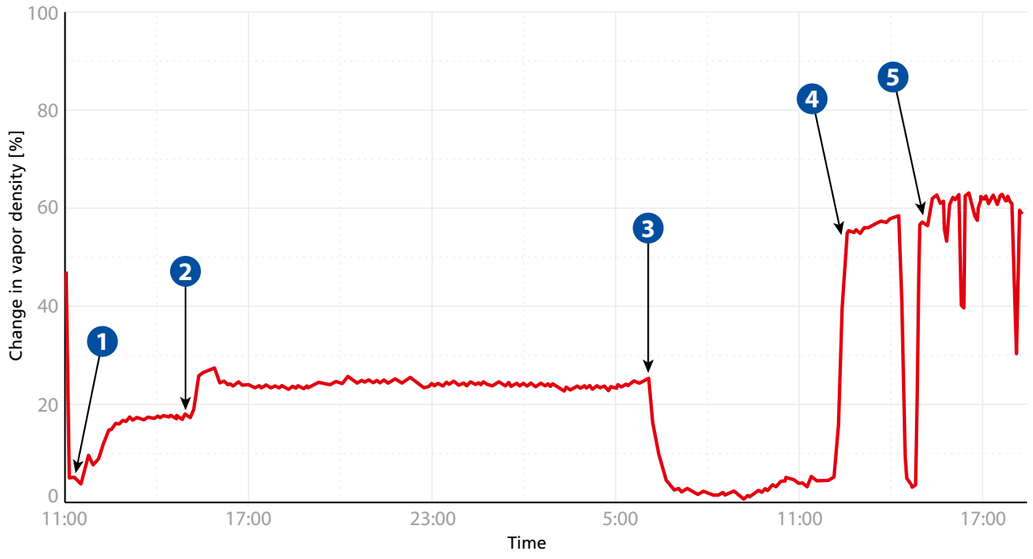
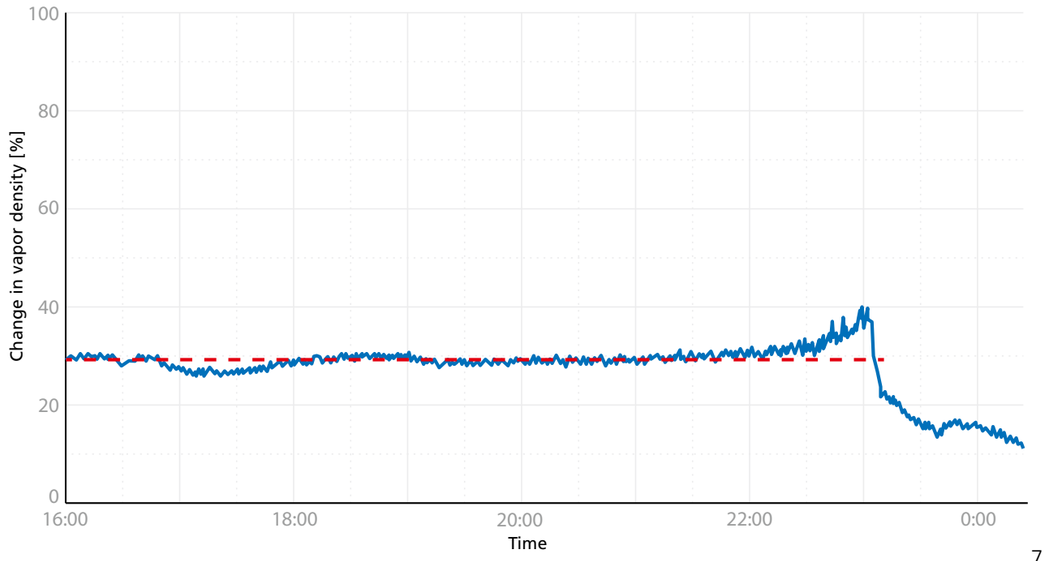


Fig. 7 Trend graph of vapor density showing vapor carryover

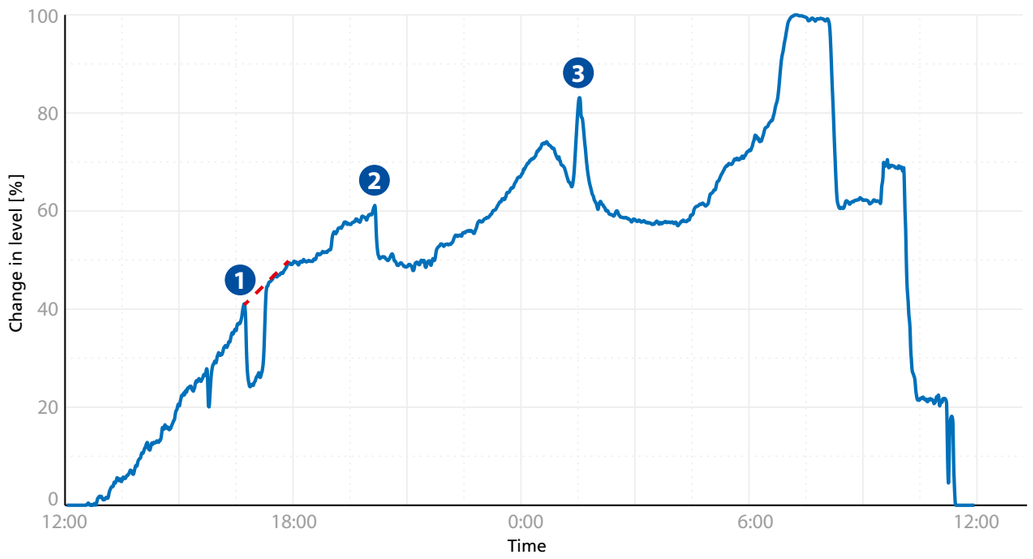


The use of gamma continuous levels on delayed coke drums has greatly enhanced the operator's ability to increase throughput to the delayed coking unit. This enhancement contrasts with the use of neutron backscatter devices which are only point measurements.

The use of gamma continuous levels not only can increase the throughput but can also increase the operability time by reducing the potential of foam-overs. Referring to Figure 8, at point 3 there is a foam-up that is being recorded by the gamma continuous levels system. Most foam-ups happen after the switching of drums, which is primarily due to the reduction of pressure in the drum. This reduction allows the vapor velocities to increase, causing the foam front to rise higher in the drum. By having a gamma continuous level system that can accurately measure the foam-up after the switch, this allows the operators to act before the rising foam front can reach the overhead lines. Foam-overs are costly events that not only cost a lot of time and manual labor to clean them up, but the unit can also be down for an extended period of time during the clean out.

As a conclusion, gamma continuous level measurements are being increasingly used within the delayed coking unit. Compared to neutron backscatter gauges, they are not only more readily available and easier to install, but also improve the measurement. These improvements include reading the level change in real-time; thus allowing determination of rates of change not only for the charging of the drum but also when anti-foam is injected. These rates of change allow operators to better understand their process which leads to better decision-making. Gamma levels can measure the small coke fines and particulate matter that is constantly being carried over into the vapor overhead lines. The improved usage of anti-foam chemical injections not only saves on the amount of chemicals used, but also helps prevent poisoning catalysts downstream. The reliability of the units is increased by catching foam-ups and allows operators to respond before the foam is carried into the overhead lines and fractionator.

Fig. 8 Trend graph showing influences of anti-foam injection



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Outstanding long-term stability

A reliable measurement is vital for the operation of a process and is therefore, our highest priority. Berthold's detectors operate consitantly irrespective of changes in ambient temperature. Even drastic temperature shifts, e.g. from winter to summer don't influence the measurement drift. Due to various patented technologies for detector stabilization and the use of cosmic radiation as an external reference source, the detectors output has an accuracy of under 0.001% per °C temperature change. Apart from employing these cutting-edge technologies in our detectors Berthold is also the only supplier that compensates degradation caused by natural aging. The result: many years of operation without the need for recalibration or maintenance and a measurement that you can absolutely rely on!

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Non-destructive testing e.g. for weld inspections can become really distressing if nothing is done to protect the radiometric measurement against interfering radiation. Every Berthold detector employs the X-ray Interference Protection (XIP), whereby the system is able to detect interference. As a result the measurement value is locked before a false level signal can be communicated. By no means are Berthold detectors harmed by the excessive radiation and automatically return to normal operation after the disturbance is over.
By employing Berthold's unique Co-60 rod sources in combination with our patented Radiation Interference Discrimination (RID) feature, it is even possible to continue the measurement despite non-destructive testing is being carried out. This secures a safe process and makes you indepentant from actions that might even occur in neighboring plants.

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Berthold detectors are highly sensitive to gamma radiation. With a scintillation crystal of 150 x 150 mm the SuperSENS is the most sensitive detector on the market. Due to their excellent efficiency the detectors can be operated with very low source activities, which is important for our customer's HSE programme and also a major cost saving factor. In fact Berthold detectors can be retrofitted on existing measurements where the source has become too weak to work with the current detector.

SIL2 / SIL 3 certified

The SENSseries LB 480 detectors are certified for use in SIL2 applications. Even SIL3 is achieved with homogenous redundancy. The certificate covers all measurement applications, from high level or low level alarms to continuous level and density measurement. Thus safe operation of critical processes is guaranteed.

[SIL 2] [SIL 3] [EX]

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