Managing Shot Coke: Design & Operation

by

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INTRODUCTION

Delayed cokers that produce fuel grade petroleum coke are operated for best economic advantage to maximize the production of clean liquid products. When feedstocks for these cokers are high asphaltene content vacuum residues, the resultant minimal coke yield is heavily influenced by the asphaltene portion of the feedstock frequently resulting in the familiar shot coke structure. If not properly managed in a safe and efficient manner, the production of shot coke can cause operational issues.

SHOT COKE

Shot coke is characterized by green delayed coke forming as small round pellets (BB's) typically ranging 1.5 to 4 or 5 mm in diameter which are frequently loosely bound together. The term, "shot", is believed to derive from the fact that the pellets are reminiscent of those used in shotgun ammunition. Frequently, the BB's bond into "ostrich egg" sized pieces. While shot coke may look like it is entirely made up of shot, much shot coke is not 100% shot. Interestingly, even sponge coke may have some embedded shot coke. The test for such a quantitative measurement is not precise but a very low shot coke percentage is often specified for anode grades of petroleum coke, typically less than 5%. In the case of fuel coke production, there is a general belief that shot structure of coke means that the coker is being run at the most economic conditions based on upgrading of heavy lower cost crudes. Shot coke types fall into several categories generally referred to as:

- <u>Bonded (or agglomerated) shot coke</u>: This form is characterized by the shot BB's being stuck to each other and, mostly, not loose until broken apart by mechanical or hydraulic forces. These BB's can be formed into the classic ostrich egg or cannonball structure which when broken will be seen as a mass of bonded shot BB's.
- <u>Loose shot coke</u>: Free flowing shot BB's which form loosely without bonding in the drum. Loose shot BB's are also frequently formed by attrition of bonded shot coke by flow dynamics, especially hydraulic cutting, and by shattering as the coke drops from the drum.
- <u>Embedded shot coke</u>: Shot BB's embedded in and often hidden in a matrix of sponge or amorphous coke. The latter mixture can be expected to have poor quench characteristics due to low porosity and permeability.

While changes in operating conditions can increase or decrease shot coke formation, the characteristics of a feedstock are dominant factors. Parameters such as microcarbon residue (MCR), heptane insoluble asphaltenes (HI), metals and heteroatom contents, especially nitrogen content, solids content as well as knowledge of the crude origin are used to predict the tendency of a residue to form shot coke. A well known rule of thumb is that shot coke is likely to be produced when the ratio of MCR: HI is less than 2. A method with greater validity is to calibrate based on ratios of coke yield to HI for residues with specific crude origins. These approaches need to be tempered for general use by experience and account for some of the other factors mentioned above. The impact of asphaltene properties and relative solubility also needs to be considered as these will vary based on crude origin or source of residue, e.g. fluid catalytic cracker slurry oil.

Interactions leading to the formation of the shot coke structure are:

> *As the feed is heated, vaporization occurs and cracking reactions begin. The reactions taking place in the liquid phase may lead to the precipitation of the asphaltenic components which will continue to react to form pre-coke and eventually, coke. The pre-coke material is a high viscosity material having high plasticity. The two-phase flow and the resultant velocity in the fired heater transfer line and in the coke drum, combined with the surface tension of the pre-coke material, act to shape this material into small spherical "beebees" or BB's, characteristic of shot coke. Liquid agitation and back mixing in the coke drum further cause formation of ovoid to spherical shaped "eggs".*

SHOT COKE ISSUES

Shot coke can disrupt coke drum operations because it has a high bed density; it is frequently loosely bound; and quenching is a non-ideal cooling operation. Specific operational issues that can occur from time to time, depending on coker design and operations include:

- Unquenched hot spots in the coke bed. This issue is not limited to shot coke production but is often seen as more prevalent in shot cokers.
- Blowbacks and eruptions of steam and coke resulting from water impacting unquenched hot spots.
- Plugging of the bottom nozzle of the coke drum during drum drains.
- Coke beds dumps that trap drillstems during cutting or overwhelm the coke handling equipment and require costly cleanups.

Short coking/ decoking cycle operations can increase the following problems associated with shot coke due to faster quenching, draining and irregular cycles respectively:

- Increased frequency of hot spots occurring following coke drum quench.
- Increased frequency of incomplete drum drains.
- Misoperation due to the pressure to stay on cycle time.

One additional issue: when operating at high temperatures for maximum liquid yield operations, it is possible to produce shot coke that is low in volatiles and very hard, i.e. it will have low Hardgrove grindablity index (HGI), which can be difficult to market.

MINIMIZING SHOT COKE PRODUCTION

Refiners with older cokers that have not instituted operational measures and/or modified their coker to deal with shot coke might be reluctant to handle shot coke when processing heavy crudes. This avoidance of shot coke production requires that they use a number of measures to ensure that the coke produced is low in the percentage of shot coke it contains by employing methods such as feed blending with lighter feed stocks that do not produce shot coke or operating the coker at conditions where the coke production is not minimized and the yield of clean liquid products is not maximized.

Shot coke formation can be suppressed by increasing the delayed coker pressure and/or the recycle. Higher pressure will inhibit hydrocarbon vaporization, resulting in a dilution of the reacting asphaltenes in the liquid phase and a reduction in the concentration of these species and the overall reaction rate. Higher recycle will achieve a similar effect. Also, the reduction in vaporization associated with the higher pressure will result in an overall reduction in the velocity of the reacting mass in the fired heater. When using higher pressure operations, higher reaction temperatures may be required to maintain appropriate coke properties.

The addition of fluid catalytic cracker (FCC) slurry oil into the coker feed will help to inhibit shot coke formation because of the solubilizing effect of the aromatic slurry oil on the asphaltenes. If too a high percentage (typically above 10 to 15 percent on total feed) of slurry oil is blended into the vacuum residue, a recycle of slurry oil can build up between the coker and the fluid catalytic cracking unit. Use of slurry oil may also limit the amount of fresh vacuum residue feed that can be processed.

Higher temperatures will tend to promote shot coke formation. Lower temperatures may therefore be considered desirable. However, the temperature must not be so low that the reaction does not proceed to coke.

Delayed cokers generally operate to a refiner's best economic advantage when processing vacuum residue from lower cost heavy crudes. Manipulation of coker operations to avoid shot coke production is typically not economically advantageous for the refiner because of the resultant loss of liquid yield and coker throughput.

SHOT COKE DESIGN DETAILS & OPERATIONS

Foster Wheeler normally suggests a 3 prong approach for dealing with shot coke involving:

1. Coker design,
2. Operating technique,
3. Operating instruction.

Most of these recommendations can be considered good practice regardless of the type of coke produced in the delayed coker.

Design Details

A number of design details can be effective in dealing with shot coke production. These revolve around providing safe and effective operations on the operating decks of the coke drum structure and in the control room.

Top (Cutting) Deck: This is the top operating level of the coke drum structure. It is the location for unheading the top flanged opening of the coke drum and the station for the operator cutting the coke using the high pressure jet pump coke cutting system. Design details for this operating level should include:

- Enclosed operator shelter provided with ventilation, personnel protection, and line-of-sight to coke drum top head and the coke chute exit. Advanced designs that provide a station for remote operations for top and bottom unheading devices as well as remote coke cutting are now being employed. These remote operations are monitored via video.

- Multiple paths for emergency egress from the structure. Egress paths from all levels of the coke drum structure should be protected. New designs employ fire barriers and may additionally include water spray systems.

- Teflon®-lined drill stem guide mounted on cross head rails to eliminate the need to have personnel at open top manway to guide the drill stem into or out of the manway guide plate.

- Cutting system: Complete interlocked safety system (see below).

- Advanced design unheading device for remote opening of top head. Top head enclosures for cutting tools are now being marketed that may offer benefits to contain and divert hot spot blowouts especially when using automated switch cutting tools.

- An additional coke drum level detector near the top, which can be used to confirm that the coke bed is sufficiently submerged below the quench water level.

Bottom (Unheading/Switch) Deck: This is the lower operating level in the structure where operations for switching coke drums, unheading the bottom flange, and lining up auxiliary systems for steaming, quench drain, etc. take place. Design details for this operating level should include:

- Slide valve unheading-reheading devices with remote operator stations to avoid operator exposure to coke and hot steam discharges which can be a hazard otherwise. Appropriate installation of the bottom unheading slide valve system includes a fixed chute for carrying the cut coke out of the drum to the recovery system. The fixed chute has the benefit of containing and diverting shot coke fallouts from the drum. The use of slide valve bottom unheading is the single most important improvement in safe cutting and handling of shot coke around the coke drum.

- Remote location for operator station for bottom unheading. Monitoring is via a dual camera system.

- The bottom inlet line of the coke drum should be provided with the capability for a high rate of sweep steam.

While there are design details for improving shot operations if a slide valve device is not used, they are not recommended over the use of slide valves. Some of these details are:

- Use of remote operated advanced hydraulically operated unheading devices that constitute an improvement over old cart unheading systems. This should include remote hydraulic operation for the coke chute.
- The coke drum bottom inlet should be provided with a device that minimizes the likelihood of loose shot coke BB's or "eggs" plugging the nozzle. A raised vortex breaker or distributor is effective.
- For bolted bottom head manual operations use of a sufficient number of "long bolts" to prevent head collapse when the partially lowering the bottom head if a hydraulic unheader is not used.
- Consider a barrier between the bottom unheading control station and unheading device to provide a physical isolation for the operator.
- Use automated graylock fitting for inlet connections.

Interlocks: The following interlocks should be included for prudent design regardless of type of coke being produced:

1. Permissive interlock of Switch Valve, Inlet Isolation Valves (SP-6's) and Utility Isolation Valves (SP-7's): This is a permissive system that performs the following functions:

   - Prevents a switch valve from being switched into a closed inlet isolation valve thereby dead-ending the heater.

   - Prevents the Utility Isolation Valves (SP-7) from being opened if the respective Inlet Isolation Valve is open. This prevents transfer line hot oil from being inadvertently directed to the drain line.

   - Requires that the Utility Isolation Valve (SP-7) be closed before the switch valve can be switched to its respective drum.

   - Prevents the Inlet Isolation Valve from being closed if the switch valve is positioned to feed into it.

2. Permissive Interlock of Coke Drum Overhead Relief and Vent: A motorized block valve is located on the discharge of the coke drum relief PSV's. This is especially important when there are multiple drum pairs to prevent backflow of blowdown vapors to an open coke

drum. This valve is interlocked to prevent its inadvertent closure unless the respective coke drum vent and / or top head are open. The interlock alarms if the PSV discharge valve is not closed immediately after opening the vent valve.

3. Permissive interlock to the hydraulic power unit for the unheading system signaling that it is OK to unhead the drum. Without the permissive signal, the unheading system cannot be powered up preventing accidental coke drum unheading. The permissive signal is generated by a logic controller which in turn requires multiple positive signals that allows it to ensure that there is a correct and safe alignment of the coke drum isolation and vent valves.

4. The bottom head is prevented from opening unless the top head is confirmed open. The top head is prevented from closing unless the bottom head is confirmed closed.

5. The coke drum overhead isolation valves (SP-1 & SP-2) are prevented from closing if the main feed valve (SP-6) is open, and the main feed valve (SP-6) is prevented from opening if the overhead valves (SP-1 & SP-2) are closed.

6. Interlock of the coke drum outlet isolation valves and the valves to the blowdown system to manage mis-alignment.

7. Heater pass flow, fuel pressure and combustion air interlocks.

8. Coke cutting system valving, drill stem insertion, rotating equipment operators and jet pump operation interlocks.

Total automation features: Many refiners want maximum automation of the coker structure operations with the goal of minimizing operator attendance and eventually eliminating the scheduled need to have operators in the structure. The systems and designs required to accomplish this are extensive and include motor operators on many valves that were previously operated manually; top and bottom slide valve devices; and an auto-shift cutting tool. The goal is to require that complete coke drum operations over the entire cycle including coke cutting and valve switching be performed from a remote location off the structure rather than being handled by an operator located on the coke structure.

Operational Techniques

Operational techniques include improved coke drum quench and dynamic manipulation of the operation to (1) minimize the occurrence of hot spots and (2) premature bed dumps for non-slide valve operations by modifying the coke structure in the bottom of the drum.

a. Coke drum quench to minimize hot spots:

- Completely fill with water to a provided additional nuclear level detector level located above the top of the coke bed. Since most hot spots occur near the top of the coke bed it is important to make sure the top of the bed is well quenched.
- Slow, optimized quench ramping the rate based on experience minimizing hot spots.
- Optional techniques: ½ to 1 hr soak time or, in extreme situations, use of an overflow operation.
- Track quench and blowdown system water flows to verify that the coke drum is flooded with water.
- Maintain a pressure on the coke drum during quenching to improve water contact with hot coke.`

b. Dynamic Manipulation of Operation

- Raising heater outlet temperature for the last 2 to 4 hours of the coking cycle produces lower VCM coke in the bed top, which is harder, easier to quench, and less prone to create hot spots. Optionally, use lower temperature following switch and ramp the heater outlet temperature over the coking cycle to a high weighted average temperature.

- Switch Techniques: Always maintain a forward flow of fluid to minimize likelihood of uncoked tars in drum from back-flowing in the drum coke bed and plugging coke structure pores prior to cooling water access; steam must be introduced prior to switch.

If a bottom slide valve unheading device has not yet been retrofitted, the following can be considered to minimize fallout problems when producing shot coke:

- Use lower temperature following switch to modify the coke structure formation in the bottom of the coke drum to denser coke, which is less likely to experience dumps and better able to contain minor blowouts due to hot spots. The heater outlet temperature is ramped up following the initial period.

- Optional use of FCC slurry oil diluent to solubilize feed asphaltenes to coke. The asphaltenes producing shot coke can be solubilized with decant oil changing the coke structure to a less loose coke matrix. If the decant oil is charged for 1 or 2 hours following the switch into a drum, the coke in the drum bottom can act as a significant plug to contain flow-outs of loose shot coke. This can be especially effective when combined with the temperature heater ramp techniques described above. However the use of slurry oil in this manner may back feed out of a coker operating at full capacity and may therefore not be considered economic.

Operating Instructions

The following safety measures are among those that should be adhered to during unheading and cutting operations. These are considered good practice in all coker operations.

- Audible alarms on decks and at grade at the start of unheading, light alarms / warning beacons until cutting / reheading complete.

- Do not unhead the coke drum top until the drum is vented and then drained. This is necessary to prevent boil-overs of scalding water and steam in the event of poor drum quenching due to hot spot operations.

- All non-essential personnel to be off drum structure, or at safe locations, during the unheading and cutting operation.

- Prior to and during draining, unheading and cutting, operators must be alert for telltales of possible hot spots, such as high “banana” leaning of the drum, rumbling sounds and differential skin temperatures, and take timely action accordingly.

- Cutting operators to remain in their shelter any time the cutting system is pressurized and cutting is underway.

- Ensure sufficient positive forward flow of steam and/or water as feed is switched out of the drum to keep the inlet line from plugging. When blowing the transfer line clean with steam, observe normal safety precautions for personnel safety.

- Cutting operators to verify that operators of any crane, front-end loaders, etc. have been notified that coke will be issuing from the coke chute.

For conventional and non-slide valve unheading systems:

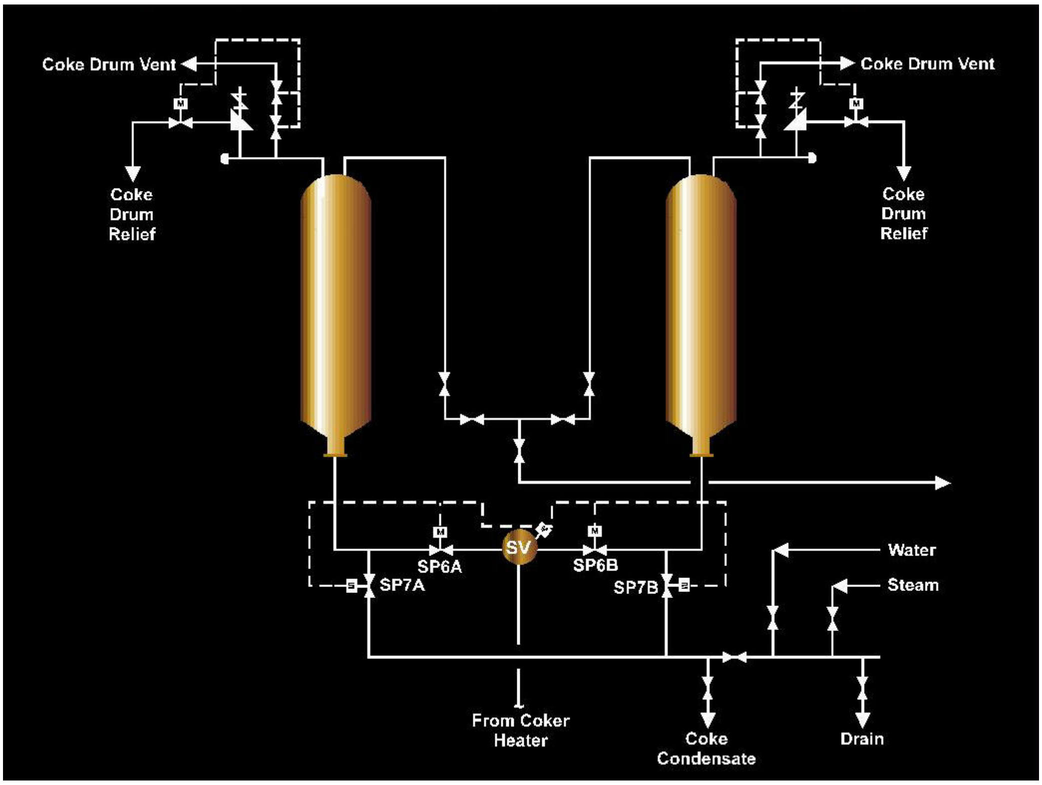
- Unheading personnel to remain at the remote location after bottom unheading, until cutting has been completed.
- Access for head cleaning, reheading, drum preparation, etc., should be available only after completion of cutting.
- Proper use of Personnel Protective Equipment (PPE) to be used at all times during the head removal.

Conclusions:

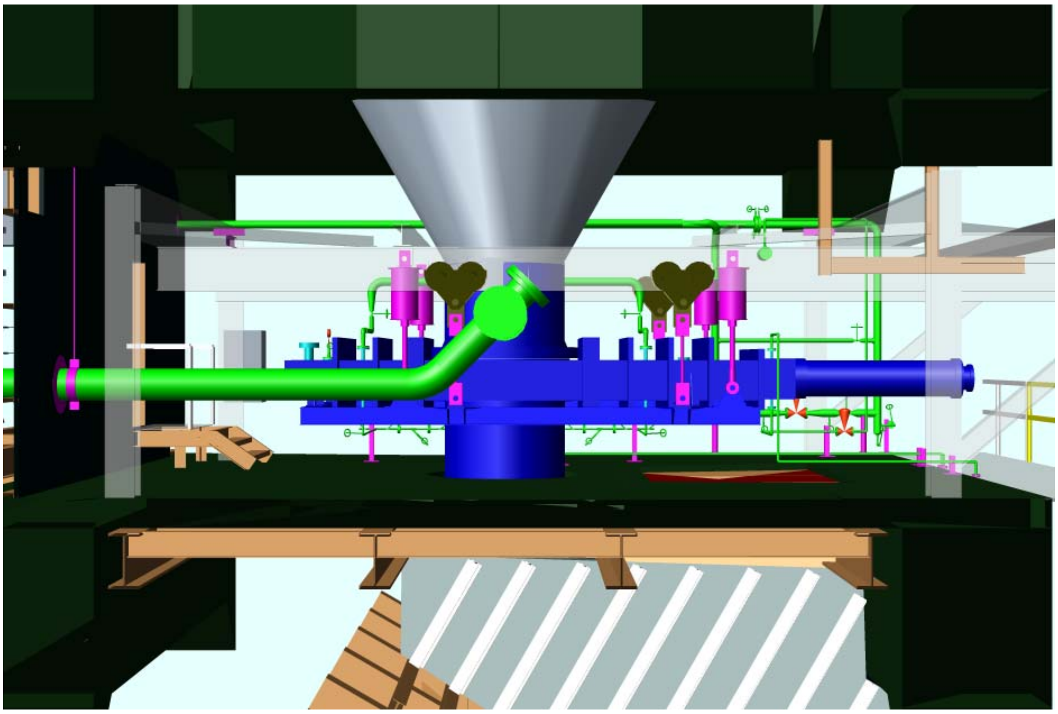
Coker operations can produce shot coke when heavy feedstocks are processed for maximum liquid yield. Manipulation of operating conditions to minimize or avoid shot coke production is generally not economically advantageous. Fortunately the operational issues caused by shot coke production can be addressed by application of design details, operational techniques and operating instructions such as those given above.

Shot Coke (Partially crushed to show shot structure)

Sponge Coke

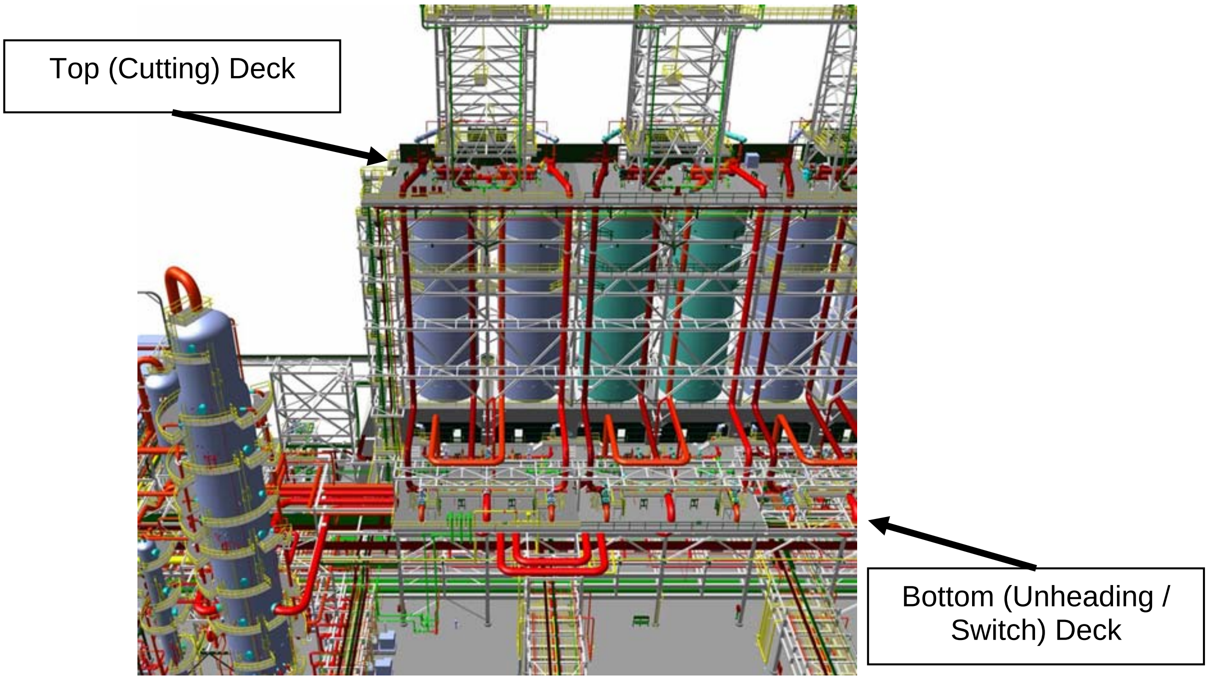


Coke Drum Valve Interlocks



Coke Drum Bottom Slide Valve Unheading System

Closed Slide Valve Unheading System
Courtesy of DeltaValve



Coke Drum Structure

Shot Coke Cannonballs on Coke Drum Bottom Head
(Non-slide Valve Unheading)

Shot Coke in Coke Pit after Chute Discharge