Shot Coke: Design & Operations

by

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INTRODUCTION

Delayed cokers that produce fuel grade petroleum coke are operated for best economics 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 derived mainly from the asphaltene portion of the feedstock frequently resulting in the familiar shot coke structure. Production of shot coke causes operational issues that need to be dealt with safely and efficiently.

SHOT COKE

Shot coke is characterized by small round spheres of coke, the size of bb's, loosely bound together. Occasionally, they agglomerate into ostrich egg sized pieces. While shot coke may look like it is entirely made up of shot, most shot coke is not 100% shot. Interestingly, even sponge coke may have some measurement of embedded shot coke. The test for such a measurement is not precise but a low shot coke percentage is sometimes specified for anode grades of petroleum coke. 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.

Shot coke formation is mainly dependent upon feed properties. The potential to form shot coke in a maximum liquid yield delayed coker is higher when using feedstocks having an asphaltene content which starts to approach half of the micro-carbon content. Parameters such as microcarbon residue (MCR), heptane insolubles (HI), metals and heteroatom contents as well as knowledge of the crude origin are used to predict the tendency of a residue to form shot coke. While changes in operating conditions can increase or decrease shot coke formation, the characteristics of a feedstock are dominant factors.

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 velocity of this two-phase flow 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 spheres of various sizes, typically found in shot coke.*

SHOT COKE ISSUES

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

- Unquenched hot spots in the coke bed.
- 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 bed dumps that trap drillstems during cutting or overwhelm the coke handling equipment and require costly cleanups.

Additionally 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
- Increased frequency of poor drum drains
- Mis-operation

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

MINIMIZING SHOT COKE PRODUCTION

Refiners with older cokers that have not been modified to deal with shot coke are frequently reluctant to make shot coke even when processing heavy crudes. This 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 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.

The addition of FCC slurry into the coker feed will help to inhibit shot coke formation because of the solubilizing effect of the slurry oil, which contains aromatic molecules, on the asphaltenes. If a high percentage (above 15 to 20 percent) of slurry oil is blended into the vacuum residue a recycle of slurry oil can build up between the coker and the FCCU. Use of slurry oil may also limit the amount of fresh feed that can be processed.

Higher temperature 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.

SHOT COKE DESIGN DETAILS & OPERATIONS

Dealing with Shot Coke production can be managed by a three-prong approach:

- Design Details
- Operational Techniques
- Operating Instructions and Training

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 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 with ventilation; line-of-sight to coke drum head and chute outlet.
- Full OSHA requirements for egress (two egress options).
- Teflon®-lined drill stem guide mounted on cross head rails to eliminate 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.
- Top unheading device for remote opening of top head with optional automated unbolting
- 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:

- Hydraulic unheading system with full capability to hold coke and water in drum; remote operation with integrated chute raising.
- Optional automated unbolting.
- Automated Grayloc® coupling, pipe alignment and flange separator systems.
- Heavy barrier concept to segregate and bunker coke drum bottom environment from operators during unheading and facilitate cleanup if there is a spill. Dual access provided to unheading area during “safe” periods (drum heads in place).
- Remote location for operator station for bottom unheading. Monitoring via dual camera system.
- The coke drum bottom head inlet should be provided with a device to minimize the likelihood of loose shot coke bb’s or “eggs” from plugging the nozzle. A raised vortex breaker or distributor is effective.
- The bottom inlet line of the coke drum should be provided with the capability for a high rate of sweep steam.

Interlocks: The following interlocks should be included for prudent design:

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 is 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 automated unheading system and Grayloc® coupling 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.

Online Expert Systems: The Foster Wheeler Delayed Coking On-Line Advisor (FWDCOA™) is a software application, which provides real-time delayed coker process monitoring, control, optimization and diagnostics. The software encapsulates Foster Wheeler's proprietary delayed coker expertise in a single intelligent application. The software uses artificial intelligence techniques to monitor operations, detect events and provide warnings of events and operational advice based on expert best practices. As a flexible knowledge-base containing Foster Wheeler design experience it can be integrated with the refiner's best practices and used to interpret current operating data and process model predictions.

Specific to the issues mentioned above when dealing with shot coke and short cycles the capabilities of this expert software include:

- Dynamic scheduling of coke drum cycle
- Detect and diagnose operational problems.
- Provide upset warnings
- Recommend operating strategies

Operational Techniques

Operational techniques include improved coke drum quench and dynamic manipulation of the operation to minimize the occurrence of hot spots and premature bed dumps 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.
    - Slow, optimized quench rate based on experience minimizing hot spots.
    - Optional techniques: 1 or 2 hour soak time or overflow operation

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 and less prone to create hot spots.

- Optional: 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.

- 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 pores prior to cooling water access; steam must be introduced prior to switch.

- 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 prevent loose coke dumps and to contain flow-outs. This can be especially effective when combined with the low to high temperature heater ramp technique described above.

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.

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

- Prior 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 shelter any time the cutting system is pressurized and cutting is underway.

- Unheading personnel to remain at remote location after the unbolting phase of bottom head removal, until cutting has been completed. Access for head cleaning, reheading, drum preparation, etc., available only after completion of cutting.

- Proper use of Personnel Protective Equipment (PPE) to be used at all times during the head removal.

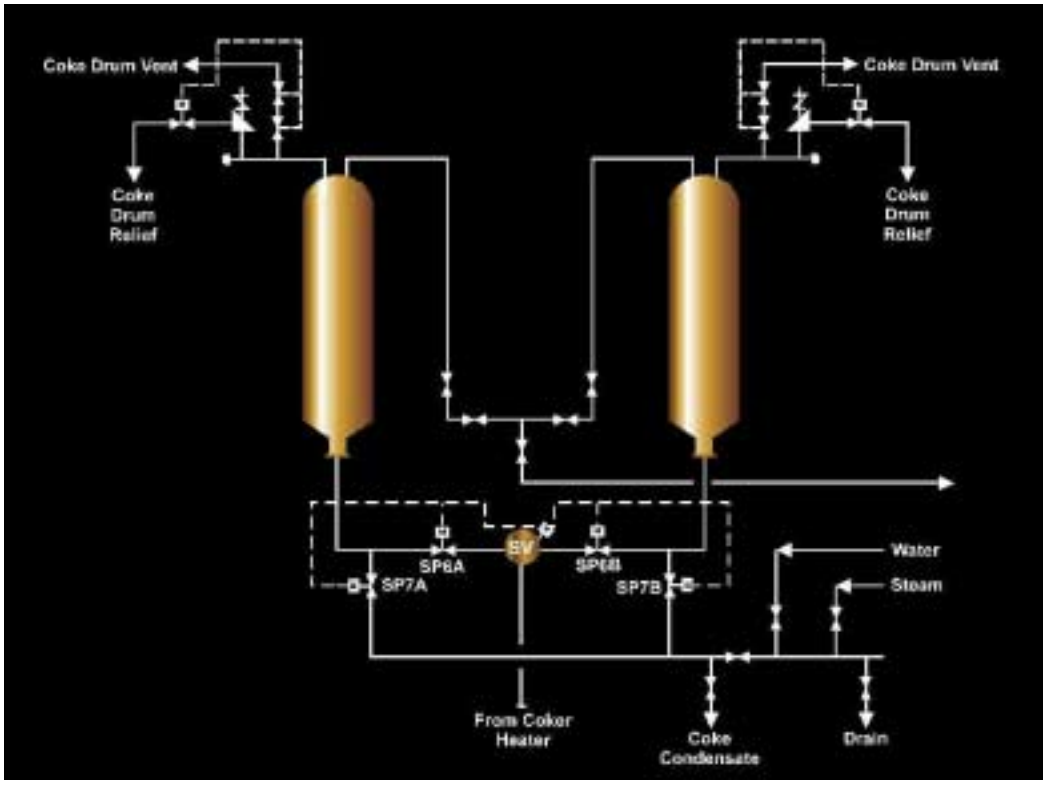
- When blowing the transfer line clean with steam, observe normal safety precautions for personnel safety.

- 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.

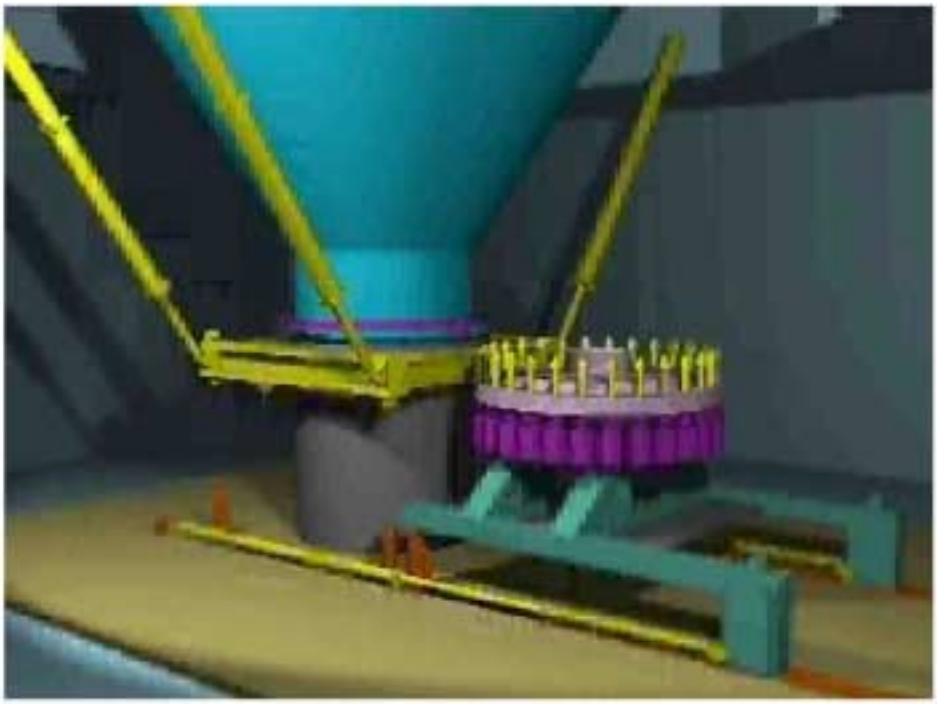
Conclusions: Coker operations can produce shot coke when heavy feedstocks are processed for maximum liquid yield. Manipulation of operating conditions to minimize or avoid shot coke production is generally not economic. Fortunately the operational issues caused by shot coke production can be addressed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

Shot Coke (Partially crushed to show shot structure)

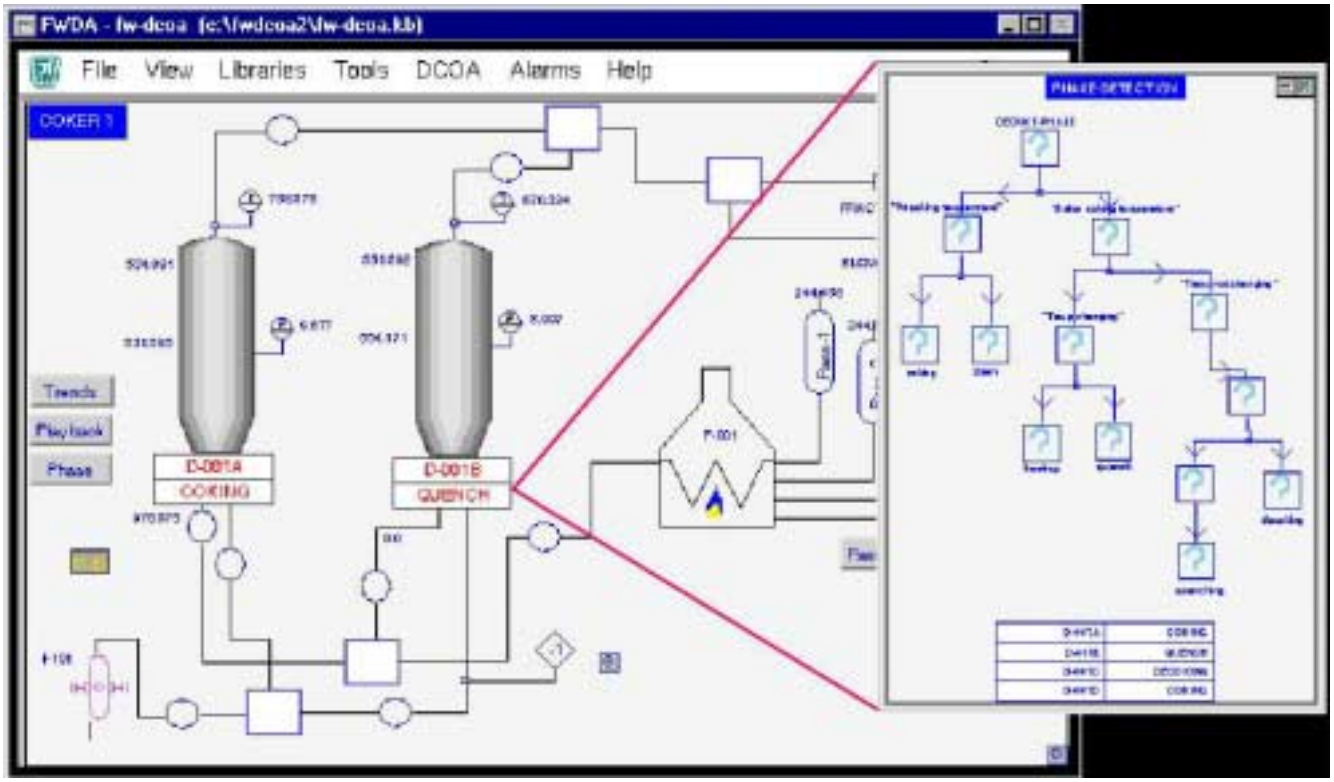
Sponge Coke



Coke Drum Valve Interlocks



Foster Wheeler Automated Bottom Flange Unheading System



Foster Wheeler DCOA Screenshot – Coking Cycle Phase Detection