Coker Furnace On-Line Spalling
- Safe, Clean, Proven, & Profitable

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ABSTRACT: On-Line Spalling (OLS) is an operation implemented in a Delayed Coker Unit (DCU) to remove coke deposits from the inside of the coker furnace tubes.

Today's competitive refinery industry forces each refiner to seek technology to maximize profitability. The primary benefit of OLS is that OLS allows the delayed coker to remain in operation while one or more of the tube passes of the coker furnace(s) is being decoked, thereby improving stream factor and profitability. The number of decokes required annually, depend on many things, including coker furnace operating severity, crude oil type and quality, furnace design, etc. On-Line Spalling is proven, environmentally friendly, and in use at many delayed coker units.

OLS, if used in-lieu of steam-air decoking or pigging, can improve refinery revenues by:

- Reducing the number of shutdown days for decoking the furnace to two - four days per year or more in some cases from 10 – 20 days per year, dependent on the number of decokes required yearly. Thus, the annual through put production increases by around 8 to 16 days per year.
- Improving the safety on the unit by reducing the number of shutdowns and startups.

The primary objectives of this paper are:

(1) To outline the economic and environmental benefits, issues, and steps of on-line spalling, and

(2) To identify the need for a good design of the spalling system, and a detailed and carefully developed procedure for each on-line spalling application, i.e., no generic OLS procedure is appropriate.

Background

Delayed coking is a refinery process to thermally crack vacuum residue, one of the heaviest portions of crude oil, and other high boiling range materials such as solvent de-asphalted pitch and slurry oil into components for conversion into refined products, such as gasoline and diesel fuel. A byproduct is petroleum coke. For the history, fundamentals, and advances in delayed coking, see cited references [1, 2, and 3].

A typical coker flow scheme wherein OLS is applicable is shown below as Figure 1. This schematic is an advanced design of a DCU including distillate recycles.

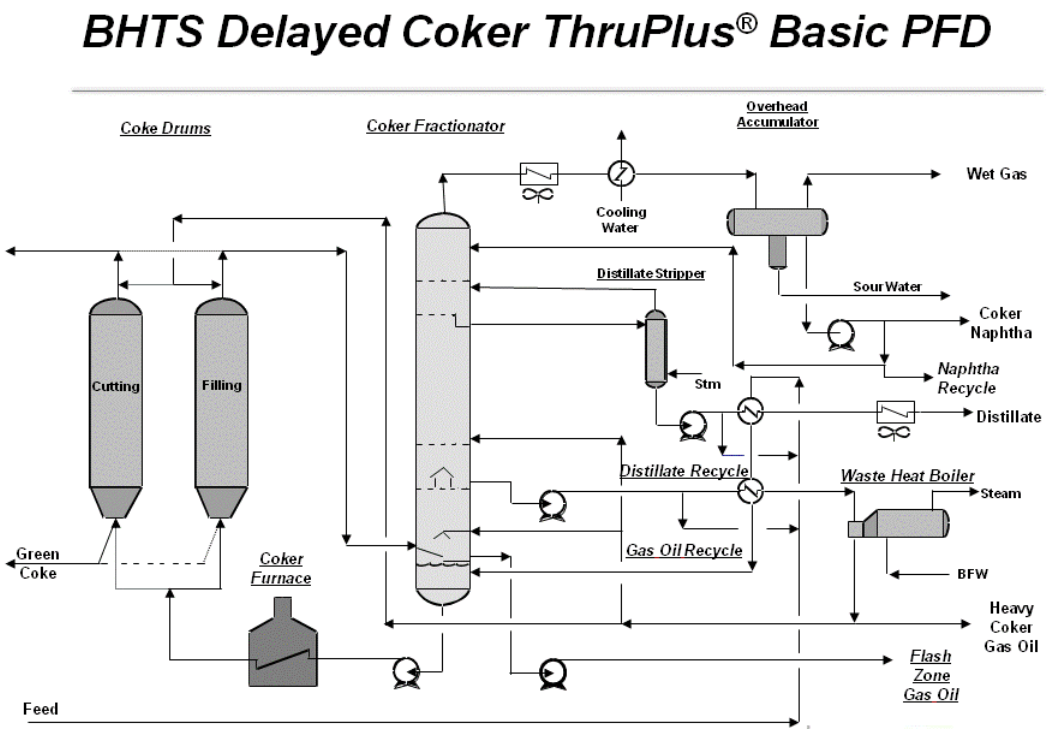

Figure 1; Typical Basic Process Flow Diagram of a Delayed Coker Unit
(Schematic provided by Bechtel Hydrocarbon Technology Solutions, Inc.)

The delayed coker is designed for the coker furnaces to heat the residue to cause cracking to occur in the coke drums at 875 - 940 ºF. Coking furnaces use a combination of furnace tube geometry, high in-tube velocities, residence time, coker natural and distillate recycle streams, and steam to minimize carbon lay down inside the furnace tubes. But even with advanced furnace designs, a thin carbon layer of coke is gradually deposited on the inside of the tubes. As the thickness of this layer of coke increases, the coker furnace process tube temperatures increase.

When the tube temperatures reach the design maximum tube temperature at the operating pressure in the furnace, either the coke laid down on the inside of the tubes has to be removed or the firing rate of the furnace has to be reduced. Reducing the firing rate usually means the coker throughput has to be reduced, but in some instances the furnace outlet temperature can be reduced slightly. Reducing throughput means a loss of refinery revenue which is not acceptable. And reducing the furnace transfer temperature is not good either, since more low value coke is produced rather than the higher value liquids and gas streams.

Therefore, removal of this coke layer from the inside of the furnace tubes (decoking the furnace) is necessary to return the furnace to its start-of-run operating conditions (tube skin temperatures). Assuming the furnace tube metallurgy is 9Chr-1Mo the furnace tube skin temperatures of the lower eight rows of tubes will increase from about 1050 °F at

the start-of-run to a maximum tube wall temperature of about 1200 to 1275 °F before decoking the furnace is required;

- Many recently large cokers that have been built have two or more furnaces operating in parallel with multiple coke drums and with each furnace having multiple tube passes. Design of these coker furnaces vary in furnace firing duty, number of tubes and their orientation, tube design and geometry, box design, number of tube passes and furnace cells, etc., but all require decoking the furnace tubes at some time. Coker furnaces built prior to the early 1990's were normally the single fired type.

  Today's coker furnaces are typically double fired furnace designs like those shown in Figure 2. Enhanced double fired or modified double fired furnace designs are proven and superior to single fired designs. Figure 2 illustrates the arrangement of the tubes and the burners for both types. A critical factor in on-line spalling design and operating procedure development is the overall coil geometry and configuration of the furnace convection and radiant sections.

  Generally accepted methods to decoke large, multi-furnace cokers are on-line spalling, steam-air decoking, and mechanical pigging.

- On-line spalling has the advantage of allowing possibly one, but usually two tube passes of a coker furnace, to be decoked while the rest of tube passes in the coker's heater(s) remain on-line.

- Some smaller, older delayed cokers that have only one coker furnace were usually decoked by mechanical decoking and/or steam-air decoking. On-line spalling may or may not be an option for them because it can sometimes be difficult to prevent either exceeding the maximum temperature/pressure limits of the furnace coil being spalled or the finned tubes in the convection section due the high tube temperatures needed to spall the coke out of the tubes.

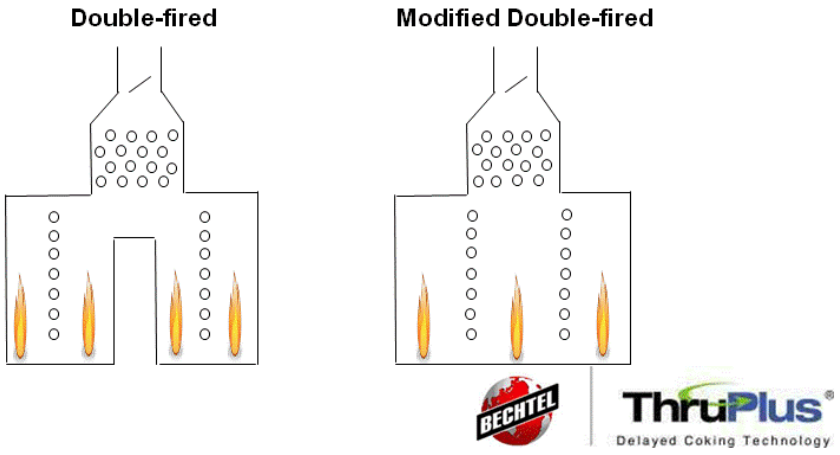

Figure 2; One Cell of a Double Fired and Modified Double Fired Furnace

Introduction of On-Line Spalling

On-Line Spalling (OLS) is usually done on one cell at a time of a multi- cell furnace. The other cells continue in operation while the one furnace cell with either one or two passes per cell is off-line being decoked, i.e., the furnace tubes in one furnace cell are steam spalled while the other furnace cell(s) on all the rest of the coker unit can remain in operation.

All coker products and spalling streams go to the operating coke drum as before the decoking started. OLS improves coker profitability of the refinery by improving the on-stream factor of the unit and refinery significantly by allowing the continued operation of the coker during decoking.

The OLS begins with the residue flowing to the furnaces being replaced by steam. Consistent relative high velocities are preferred during this change from residue to spalling steam. An increasing controlled amount of spalling steam continues into the furnace tubes as the resid feed is reduced. OLS uses the steam rate, steam and tube skin temperature, and thermal contraction and expansion of tubes to remove the coke deposits from the inside of the tubes and deposit the coke in the coke drums. Thus, the process uses steam velocity and tube temperatures to provide the energy to remove coke from inside the furnace tubes.

OLS is considered the safest of the three decoking methods when used with a carefully developed procedure, with operator “buy-in”, and with careful management of the OLS process. Because OLS reduces the coker shutdowns, it also reduces the potential of safety issues which can occur during shutdowns and startups of cokers and coker furnaces.

Care must be taken in the design of an OLS procedure to assure operator safety, to protect equipment and piping, and to complete a good spall.

Topics discussed in this paper are:

I. On-Line Spalling Overview and Basic Procedure.

II. Furnace Design Considerations.

III. Typical Time Requirements for OLS, Pigging, and Steam-Air Decoking.

IV. Summary.

Notice: Details of each delayed coker must be considered in the development of the OLS procedure. Each delayed coker’s design and operation are unique and furnace and piping designs vary. It is critical for the success of the on-line spalling procedure to consider furnace and piping design, metallurgy, relief valves, furnace tubes configuration, steam or boiler feed water conditions, and operating strategy. This paper provides a road map and guidelines for developing an OLS procedure, but use of an experienced design team is necessary when putting it into your coker.

I. On-Line Spalling (OLS) Overview and Basic Procedure

OLS of a delayed coker furnace can use high pressure steam or boiler feed water for implementing the "spall." At spalling conditions, boiler feed water is converted to steam, thus, it is essentially a steam spall, but minor adjustments to the procedure are needed.

Background / Responsibilities

The normal operation of delayed coker furnaces results in the slow build-up of coke within the coker furnace tubes. Decoking is the process of periodically removing the coke from the inside of the tubes to keep the furnace efficient. The period between decoking the furnace varies dependent of the coker operation, crude source, desalting and crude oil treating, furnace design, and many other coker criteria. Some cokers decoke every 2-4 months and others run as long as 12-24 months. Many newer delayed cokers have multiple coker furnaces (heaters) operating in parallel and utilize OLS and off-line pigging as the two normal procedures for removing the coke from the inside of the coker furnace tubes. Older units and some new units may utilize all three of the typical decoking procedures mentioned earlier.

In general only OLS can be implemented with the coker in service. Steam-air decoking and pigging require the coker to be shutdown and unit taken off-line. An on-line pigging procedure is being developed and proven as an alternate to consider. 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 from the tubes, such as iron sulfide. Non-organic fouling material is typically removed with the pigging process.

Objective of OLS - OLS removes coke from inside the furnace tube walls using a high velocity steam flow to spall off the coker and temperature management to thermally contract and expand the tubes. Contracting and expanding the tubes cracks and dislodges the coke from tube walls and deposits the coke into the on-line coke drum.

OLS of a furnace begins with the careful removal of the residual oil and replacement with steam. Many coker furnaces have multiple tube passes and/or cells, if the coker furnaces have two tube passes in the same box or cell, then the OLS process is carried out in both tube passes simultaneously. The other furnace(s) or furnace cells in the coker remain in service providing feed to the coke drums.

RESPONSIBILITY - It is imperative that the Lead Operator or Operating Engineer who is responsible for oversight of the OLS process be knowledgeable of the procedure, past history of decoking the furnace, familiar with the overall coker operations, mechanical limitations, and process limitations of the coker furnaces and transfer lines. He/she must have the authority and knowledge to make necessary changes in the time cycle, injection steam rate (flow), and temperature settings of the OLS procedure in case of a temperature excursion, tube blockage, or other unusual circumstances.

REPORT - The responsible person must assure preparation of a follow-up report. The report should define the steps, time, temperatures, and any deviations taken to the On-Line Spalling procedure for future reference.

On-Line Spalling Considerations

On-Line Spalling (OLS, "spall" or "spalling") of delayed coker furnaces is preformed to remove coke from radiant furnace tubes in one individual furnace or box at a time using a high velocity steam flow while thermally contracting and expanding the tubes. This contracting and expanding cracks and dislodges the coke from the tube walls and deposits the coke in the on line drum.

A. **Delayed Coker Furnaces** – Many new cokers are designed to allow decoking of furnace tubes by both OLS and by off-line pigging. Steam-air thermal decoking equipment is often not even installed to save capital.

OLS spalling is preferred for a multi furnace cell coker because the coker remains in operation (on-line) while one coker furnace cells is off-line being spalled. If the furnace cell has two furnaces tube passes in the same box, like the double fired and modified double fired furnace cells shown in Figure 2, both radiant tube passes should be spalled at the same time.

B. **OLS Usage**. - OLS is completed successfully in multi-furnace cokers and can be completed again and again;

- The main purposes for using OLS, instead of steam-air decoking, is to reduce shutdowns and improve the coker unit and refinery on-line service factor.
- OLS also results in fewer emissions than steam-air decoking.
- Certain refineries implement off-line pigging after every few spalls to insure any inorganic solids (fouling) that are not removed from the tubes by OLS are removed.
- OLS is generally safer than the additional shutdowns required for steam air decoking or pigging. Reduced shutdowns generally improve safety.
- Superheated steam, if available, is the preferred media for doing the OLS.
- Engineering must be completed to determine the design pressure requirements to prevent over pressuring the furnace tubes and furnace transfer line while operating at the targeted on-line spalling temperatures. BHTS does not design utilizing a relief valve on the furnace transfer line. A detailed furnace geometry and tube design review will help to determine the overall feasibility of on-line spalling, as well as the general spalling velocity requirements, velocity limits, and operating guidelines.
- If not properly managed, excessive spalling steam velocities 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 also cause serious plugging in the furnace tubes due to slugs of coke fines.
- High pressure Boiler Feed Water (BFW) is an acceptable OLS media, but BFW requires more attention to the OLS process than steam injection. The maximum tube wall design conditions and furnace outlet piping design conditions must be considered when using high pressure BFW.

C. **Inorganic Compounds Effect**. - OLS may not remove all of the inorganic scale that can foul the furnace tubes.

These inorganic compounds are inherent in certain crude oils. They can also be introduced by either the desalter operations or by chemicals used in the production of the crude oil.

Pigging is necessary at some refineries between every three to five spalls, due to inorganic solids that do not spall out. Pigging is not necessary with some crude oils assuming good desalting, but with the common refinery practice of running different crude oils from time to time, it is appropriate to be prepared to pig on occasions.

D. **Soft Coke Tube Plugging Risk** - Due to the risk of plugging the tubes, OLS should not be attempted if the tubes are heavily coked due to operating disruptions that has caused a large amount of soft coke to be deposited in the tubes (coke that is created in a short period of time).

E. **On-Line Spalling Steps**

Outlined below are the general steps to complete OLS:

1. The procedure begins with the normal coker feedstock (resid) and normal steam rates flowing to the furnace to be spalled.
2. The coker feedstock is reduced and the flow of high pressure steam is increased to maintain roughly constant velocity through the furnace tubes.
3. The steam rate is increased within velocity limits and the furnace tube spalling temperatures are increased and monitored until the targeted maximum tube wall skin temperatures is reached.
    - ❖ This maximum temperature is set by the operating company based on mechanical limitations of the furnace tubes while spalling.
    - ❖ The combination of steam rate, furnace pressure, and the process temperatures will be set at those conditions that are determined by the operating company.
    - ❖ For best on-line spalling, the OLS steam temperature needs to be set at about 25 to 50 °F above the maximum end of run (EOR) skin temperature at which the furnace tubes were operated prior to the spall in order to get a good quick spall of the furnace tubes.
    - ❖ Steam velocity should not typically exceed 350 - 375 feet per second or 105 - 115 meters per second.
4. A step called thermal shocks of the furnaces tubes are usually completed to ensure all the coke has been removed. Experience with the thermal shock step may allow the coker operator to decide that this step is not required.

This is because coker unit staff will learn what the minimum skin temperatures that can be obtained by spalling and will then have sufficient information to know, if a thermal shock step is needed or not.

5. Double block the flow of coker feedstock (resid) prior to raising the temperature of the steam to maximum spalling temperature. Otherwise, any resid leaking though the valves to the furnace being spalled will lay down coke in the furnace tubes while the spalling is taking place.
6. Spalling should begin three to four hours after switching the coke drums. Due to the relatively low temperatures of steam (and Boiler Feed Water) and hydrocarbons going into the coke drum, there will be a much higher foaming tendency of the material entering the new on-line coke drum and the refiner does not want to foam over a drum.
7. Spalling may not be complete before it is time to switch drums again and it is best not to bring the spalled furnace tubes back to the normal on-line processing conditions, unless this can be done with about three to four hours left before the coke drum switch. The drum switch should take place while the spalling temperatures are at their hottest.
8. During the spall, the combined feed and spalling steam result in the on-line coke drum being slightly cooler than normal and will receive (process) more water vapor (steam) than normal. Therefore, the foam level above the coke bed will tend to be higher than normal so antifoam will be injected during essentially the whole time the furnace is being spalled.
9. The switch from resid to steam through the furnace tubes occurs quickly and in large increments. Maintain temperature of steam as steam pushes the residue out of the tubes.
10. Fuel gas rates to the furnace being spalled will be much lower than normal. During on-line spalling, the fuel gas rate to the furnace cell being spalled is normally 10-20% of the normal operating (resid processing) fuel gas rate.
11. Take burners off-line, as necessary to control furnace temperature. Simultaneously, thought it is important to fire as many burners as possible (low rate) to provide uniform heat distribution throughout the firebox. Cold spots can result in poor spalling.
12. The intent is to slough off coke gradually. If a large volume of coke is sloughed off too quickly, the furnace tubes may plug off completely.

II. Furnace Design Consideration.

The operating company is responsible for the mechanical design, including the design temperatures and pressures at which the OLS occurs.

It is imperative that detailed analysis incorporate the tube's life, mechanical condition, metallurgy, design, etc. as a function of the temperature and time cycle of the OLS. This analysis is specific and no criteria can be set herein.

In general terms, the higher and the more even the OLS temperature is across the furnace tubes during OLS, the more complete and the more successful the spall. Similarly, the more even the temperature during operations, the longer the run will be between decoking. Some refiners are upgrading the tube metallurgy to improve run life.

III. Typical Time for OLS, Pigging, and Steam-Air Decoking.

Described below are three accepted methods for decoking a delayed coker furnace:

Steam-Air Decoking is historically a generally accepted practice for decoking coker furnaces. However today, it is being replaced by On-Line Spalling and Pigging. OLS reduces emissions.

Air is used to burn the coke off the tubes. Steam and the amount air injection rate are used to moderate the temperature so as to not exceed tube metal maximum temperatures. Steam air decoking requires a furnace shutdown and unit shutdown. It can be rough on the furnace tubes and is labor intensive. Environmental issues have caused some refiners to move to the other methods due to the emissions produced when burning the coke out of the tubes.

Typical decoking time is 3 – 5 days per furnace dependent of amount of coke in tubes, frequency of decoking, and experience. (Some refiners do better.)

Online spalling is the best method of decoking, but is not always possible depending on the mechanical design and configuration of the furnace and coker. Also, small cokers with few furnace tubes passes are more difficult to spall than larger cokers with multiple furnaces and/or furnace passes.

This process is attractive for cokers as it does not require a shutdown and loss of throughput and reliability problems are kept at a minimum. This procedure is a complex process and must be carefully monitored and thoroughly reviewed at each location.

The tube or piping flow path can plug, if the coke in the tubes is much more than ¼" thick or if the coke is spall too aggressively. The return bends in the furnace and elbows in a 90 degree bend can have erosion problems if not properly designed and operated.

Typical net lost production time is about 1 to 1.5 days per spalling event for all the furnaces in a given unit during which the coker and coker furnaces remain in operations.

Pigging is a popular method for decoking coker furnaces. Pigging normally requires the furnace(s) and coker to be shut down, but some cokers have developed isolation procedures where individual furnace boxes can be isolated and the furnace passes decoked without a complete coker shutdown.

The time required to pig the furnaces in a unit is approximately the same as steam-air decoking a furnace. Pigging can remove difficult inorganic solid foulant produced by solids in the coker feed. Inorganic solids generally foul in the upper radiant section or the convection section of the furnace. On-Line Spalling does not remove organics.

Typical decoking time for pigging is 3 - 5 days since multiple pigging units can be used simultaneously on a big unit with multiple furnace cells.

The process involves scouring the inside of the furnace tubes with abrasive metal studs that are held in place with a cylindrical or spherical plug that moves down the pipe. The plug is flexible and can negotiate the return bends in the furnace. To prevent damage to the furnace tubing, the abrasive metal studs must not be harder than the tube wall

IV. Summary.

On-Line Spalling, when used in-lieu of steam-air decoking and/or pigging, can generate economic benefits by:

1. On-Line Spalling will reduce the number of shutdown days for decoking furnaces to two – four days per year from 10 – 20 days per year, dependent on the number of decokes required yearly.

   The actual increase in stream factor and improved days on line depends on many things, include the number of decokes normally required yearly, coker severity, crude oil, furnace design, etc.
2. Safety is improved by reducing the number of shutdowns and startups.
3. More frequently decoking can improve yields by reducing coke production.
4. On-Line Spalling is proven and in use in many delayed cokers.
5. Reduced “wear and tear” on furnace tubes. Pigging and steam-air decoking results in greater tube deterioration and erosion of tubes.
6. Steam-Air Decoking investment not needed, especially for a new coker.
7. Certain refineries implement off-line pigging after every three to five spalls to insure any inorganic solids (fouling) that are not removed from the tubes by OLS are removed.

Obviously, the improvement in shutdown days per year is the biggest incentive towards implementing an On-Line Spalling program.

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