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Revision Memo**12/04**

Highlights of this revision are:

1. Additional details on pig decoking
2. Modified decoking facility requirements.
3. Minor revision of **Figure 3**. Pig Decoking Piping Detail.

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1 SCOPE

Coke deposits inside heater tubes can lead to higher tube metal temperatures, shorter run lengths, and can increase the potential for tube failure. Methods for removing coke include pig decoking, steam-air decoking, onstream decoking, and "Sand jetting". This section of the Design Practice describes some of the mechanisms leading to coking, and provides design considerations and procedures for applying these methods of coke removal. A definitive guide to major aspects of decoking is contained in Report EE.79.E87, *Guide for Fired Heater Decoking*. Decoking procedures for Steam Cracking furnaces are maintained by Exxon Chemicals and are outside the scope of this document.

2 REFERENCES

- Matta, G.M., *Guide for Fired Heater Decoking*, ER&E Report No. EE.79E.87.
- Juedes, D.L., *Monitoring Fired Heater TMTs with Infra-Red Imaging Systems*, ER&E Report No. EE.48E.88.
- Juedes, D.L., *Decoking Guidelines for Visbreaker Fired Heaters*, ER&E Report No. EE.44E.82.
- Quilan, T.E., *Delayed Coker Heater Coking - Commercial Correlations Study*, Report No. 2004RESID12

3 BACKGROUND

Coke can be defined as a carbonaceous deposit on the inside tube walls of fired heaters. Coke is composed primarily of carbon, with smaller amounts of hydrocarbon, sulfur and inorganic compounds. Its composition and mechanical properties will vary widely depending on heater feed properties, process conditions, and the length of time it has been in place. Coke can either be gradually deposited over a number of years, or may be formed suddenly following a process upset. A change in feed composition can alter the rate of coke formation. Nearly any hydrocarbon feed can form coke under the right combination of conditions; however, permanent decoking facilities are normally specified only if the service is such that coking is likely to occur during normal operation.

Coking may be caused by many factors, including tube-side flow maldistribution, excessive heat flux (general or localized), contaminants in the feed (asphaltenes, salts, inorganic compounds, particulates, etc.), incompatible feed blends, excessively high coil outlet temperatures, or a poor job of coke removal during the previous decoking.

3.1 METHODS OF DECOKING

Pig Decoking, also referred as "mechanical decoking", employs polyurethane projectiles, or pigs, and water to mechanically remove coke from the tubes. The pigs have metal appendages, or pins, attached radially along its exterior for cutting the coke. The pigs are propelled through the tubes with water. Compared to the other off-line decoking methods, pig decoking is generally preferred because of its shorter downtime requirements, the avoidance of severe operating temperatures, the lower probability of tube damage, and for the reduction of capital investment cost. A specialty contractor conducts pig decoking, so it may not be available at some locations. This method of decoking can remove very hard inorganic deposits left in the coil from years of decoking by other methods, and can also remove deposits located in areas (i.e. return bends) where removal by steam-air decoking is not possible. A clear benefit of pig decoking is that the furnace does not have to be fired, allowing other work to be carried out within and around the heater during decoking. Prior to entering the heater during pig decoking, the heater's condition should be evaluated to assess risks associated with entry (i.e. potential for injury from falling refractory, etc.).

Steam-Air Decoking is the removal of tube-side coke by the combined action of steam and air. The complete process is conducted while the heater is out of service and consists of two parts, "spalling" and "burning." During spalling, steam or condensate is admitted to the heater coil at high rates while the heater is fired. The coke is removed by: (1) the cracking and breaking of the coke due to the expansion of the tubes caused by higher than normal tube metal temperatures, and (2) the scouring action of the high-velocity coke particles. With proper operation, nearly all the coke can be removed in this manner. During the burning phase, air removes the remainder of the coke by supplying oxygen to support combustion of the coke. Steam is injected along with the air to control the combustion and tube metal temperatures. In some cases, it is necessary to reverse the direction of flow (i.e., coil outlet to coil inlet) during spalling and burning in order to increase the decoking effectiveness. This is known as "reverse-flow" decoking. This requires additional facilities that cannot generally be justified unless the service is unusually severe.

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Onstream Decoking applies the spalling phase of steam-air decoking on a pass by pass basis while the heater is in operation. While it is not normally as effective as conventional steam-air decoking, it allows run length of some types of heaters to be extended without requiring a unit shutdown. It has been applied with considerable success in delayed coking service.

Low Velocity Decoking utilizes lower steam spalling velocities and a slower heat up rate to produce an effluent plume which is less heavily loaded with coke. It has been applied in heaters that were very heavily loaded with coke, such as Visbreakers, as well as locations in which stack plumbing is regulated by local authorities.

The **Sand-Jet** method of decoking requires an abrasive agent such as flint or steel shot that is propelled through the heater coil by a nitrogen carrier. It was developed by the Union Carbide Company and has been used intermittently in the past with limited success throughout ExxonMobil. It is a highly costly process and has not proven to be as effective as other decoking methods. However, it can be applied to heater coil configurations that cannot be pig decoked and have no permanently installed steam-air decoking facilities. Due to its limited application, no additional information is provided in this Design Practice section.

3.2 WHEN TO SPECIFY DECOKING FACILITIES

- Decoking facilities shall be specified for all fired heaters in normal coking services, such as atmospheric and vacuum pipestills, and delayed cokers. When available locally, pig decoking facilities should be specified for atmospheric and vacuum pipestills. A combination of pig decoking and single-direction steam-air decoking facilities are recommended for delayed cokers. Site preference or past experience may dictate otherwise. For heaters in heavy coking service, such as thermal cracking and Visbreaker heaters, reverse-flow decoking facilities may be required. This need should be established based on experience with the feed and expected operating conditions. If there is no previous experience available, the Heat Transfer Equipment Section of EMRE's Plant Engineering Division should be consulted.

Decoking facilities should not be specified for services known to be non-coking under normal or common upset conditions. This usually includes heaters processing all vapor, such as POWERFORMER or Treat Gas heaters, and most liquid hydrocarbon services with coil outlet temperatures below 600°F (315°C). Liquid streams containing asphaltenes, salts, or solids may be prone to coking at lower temperatures than other services. For coker heaters, see report 2004RESID12 for coking correlations. If in doubt, feed samples can be tested in the laboratory under simulated field conditions to determine the stream's susceptibility to coking. Connections for future pig or steam-air can be specified during the design stage for a relatively small incremental investment.

4 APPLICATIONS

4.1 PIG DECOKING PROCEDURE

4.1.1 Equipment Description

- A contractor specializing in pig decoking carries out the operation. Pigging contractors generally are equipped with all necessary specialty equipment to complete the pigging process. This includes the pig propulsion pumps, hoses, valves, data recorders, reservoir and strainer tanks, pig launchers and pigs. The refineries are generally required to supply electrical connection, water (typically from nearby fire hydrant), crane, compressed air or nitrogen, diesel fuel, miscellaneous hoses, spool pieces and other fittings for water supply and drainage. Additionally the refinery must supply a vacuum truck to remove coke and other deposits from the contractor's equipment after decoking is complete.

Pig Launchers are used to launch and receive the pigs. They are installed at the inlet and outlet of the pass being decoked. Locating launchers at grade reduces set-up and dismantling time, and eliminates repetitive climbs to the launcher during the pigging process. Full-port ball valves allow the pig to pass to and from the launcher. Separate connections on the launcher allow the pressurized water from the propulsion pump to push the pig through the coil. The same connections on the pig "catcher" serve as drain lines to carry waste water and deposits to a strainer tank. A quick-opening cover is provided to enable pigs to be changed rapidly. A decoking skid, also provided by the contractor, contains the propulsion pump, clean water suction tank, a strainer tank, and instrumentation, which includes a pressure trend recorder. This equipment is illustrated in [Figures 2 and 3](#).

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Several different pigs will be used during the decoking operation. A light foam pig is used first for sizing of the initial decoking pig and establishing that the flow path is clear. It is followed by decoking pigs, which have a number of metal appendages or pins protruding radially from the base of the pig. The size of the decoking pigs will increase as coke is removed from the inner tube wall. Soft pig technology is preferred over the older hard pigs. Like hard pigs, soft pigs have a relatively hard polyurethane shell but also have inner core filled with foam, gel or air. The soft pigs with their inner core navigate plug headers and return bends better than hard pigs, are not likely to damage the tubes and are more likely to rupture from the water pressure if the pig is temporarily lodged in the coil. Upon rupturing, the broken pig can be washed away, which avoids a potential downtime extension to remove a solidly lodged pig. Also the older hard pigs generally use large appendages, commonly with a hard tungsten-carbide coating, and are rigidly attached to the body of the pig. These pigs had been a subject of past controversy over damaging the internal side of piping. Soft pigs tend to use smaller appendages that are inserted shallowly into the molded polyurethane shell. These appendages may have the tungsten-carbide coating, but rather than gouging the tube metal, these appendages will either compress towards the soft inner core or tear away from the pig when the pig is pressed forcefully against the metal.

4.1.2 Heater Preparation

- Depending upon the coil length and pig decoking equipment available, tube passes can be decoked either in series or individually. Many of the pigging contractors have two pig propulsion pumps on one truck, which is called a "double-pumper" arrangement. This permits two independent passes to be decoked simultaneously.

In preparation for pigging, each pass should be freed of hydrocarbon and isolated from the remainder of the process piping. All orifices or protruding instruments (i.e. thermowells) that may impede passage of the pig must be removed. Pig launchers are installed at the inlet and outlet of the pass being decoked. This may require piping modifications, although in some cases, it may require only the removal of a spool piece. Note that pig decoking requires a continuous path throughout the coil. If radiant and convection sections have a different number of passes, or intervening manifolds, launchers must be installed to avoid these discontinuities; however, non-branching coils that increase in tube size along its length as often is the case on vacuum pipestill heaters can be successfully pig decoked. The pig launcher is then hooked up to the propulsion pump and drain systems.

4.1.3 Cleaning Procedure

- Basic procedures for pig decoking are outlined below. However, since each fired heater is different, they should be modified accordingly.
 - Line up valves at launchers to provide water flow to one launcher and return from the other.
 - After filling clean water (suction) tank, start pump, open appropriate valves and fill heater coil with water. For stainless steel tubes, adding soda ash or other neutralizer to the water is required to prevent polythionic acid stress corrosion cracking. Make up water should be continuously fed into the clean water tank during the initial filling of the heater coil to prevent pump cavitation.
 - Flush heater coil with water until clean of oil and coke debris.
 - Conduct an initial water flow test on the coil. This flow test generally consists of three water flow rate measurements. The resulting pig propulsion pump speed and water pressure are recorded for each flow rate. The test results will be compared to a final flow test, which will be conducted after pigging is complete.
 - After coil is filled, flushed and flow tested, shut down the pump, close valves, and install full sized foam pig.
 - Realign valves as above, and start pump. The pig's location in the coil can be determined by observing the trend on the pressure recorder (a "spike" will occur when the pig reaches each U-bend).
 - Maintaining a pig speed of approximately 8-12 ft/s (2.4-3.7 m/s) push the pig through the coil until it reaches the other launcher. Shut down pump, close valves, and drain pig receiver.
 - Remove the foam pig and inspect to size the initial decoking pig and to determine if thermowells or other obstructions were accidentally left in the coil.
 - If no problems occurred with the foam pig, install a decoking pig and make one pass. Remove pig from receiver and inspect for damage and confirm that the pig traveled the entire coil. Reinstall and continue shuttling the pig through the coil, reversing flow direction as necessary by manipulating the water valves. After several passes back and forth, replacing the pig will be necessary because of physical damage to the pig or a larger pig is required. This process will continue until an oversized pig (generally 1/4" (6 mm) larger than tube inner diameter) can smoothly travel the entire coil without indications of remaining coke.

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- Afterwards, several of the pigging contractors will follow up with either a "bolted" (bare soft pig that has short aluminum screws randomly screwed into the polyurethane body) or silica-coated polishing pig to complete the decoking process.
- After decoking is determined to be complete (see below), conduct final water flow test, drain water from heater and install a foam dewatering pig in the launcher. After ensuring that all personnel are out of heater, use nitrogen or air to pressure pig through coil to other launcher, which will remove residual water. Shut off nitrogen or air supply and disconnect launchers.

4.1.4 Checking for Completeness

- The progress of decoking can be checked by monitoring the pressure profile and the condition of the effluent water. When an oversized pig travels the entire coil length producing only a small amount of dirty effluent and when a relatively constant pressure profile can be observed across all tubes then the coil can be considered clean. For multiple pass heaters, the final water flow test should be approximately equal for all passes. Other methods for checking tube cleanliness are radiography of suspected coked areas and boroscope of the tubes, which is currently limited to the inlets and outlet tubes. Measuring tube temperature rise with infrared thermography after introducing warm water has been used successfully to identify areas of remaining coke when tubes are free of external scale. Acoustic monitors have been employed as well.

4.2 NORMAL STEAM-AIR DECOKING PROCEDURE

The general steam-air decoking procedure given below applies to both normal and severe coking services. It should be used as a guide only with the understanding that modifications for individual heaters may be necessary. In addition, the procedure for a given fired heater may require modifications depending on the properties of the coke deposits. In some cases, a combination of normal steam-air decoking, followed by pig decoking, may be required. To be successful, steam-air decoking must be closely observed and controlled by personnel who are familiar with all aspects of the operation. A schematic of the typical piping arrangement is given in [Figure 1](#).

4.2.1 Pre-decoking Boilout

When the coke deposit contains a large amount of water soluble salts, a pre-decoking boilout is performed to ensure that all deposits be removed. After the heater coil has been drained and purged of hydrocarbons, it should be blinded off from the upstream and downstream equipment and filled with treated, fully softened, water. The coils must be vented to the atmosphere to prevent pressure buildup during the boilout process.

The heater should then be fired to maintain a bridgewall temperature of 250°F (120°C) for about 12 hours, using as many burners as possible to ensure even heat distribution. Each coil should be refilled with water as necessary to maintain level. The effluent from the boilout should be periodically tested for sodium and chloride content. When the salt concentration in the retained effluent has reached a maximum, the boilout can be considered to be complete. The coils should then be flushed with fresh water and drained. Any remaining water (in vertical coils) can be removed by increasing bridgewall temperature to about 400°F (200°C) until steaming subsides. The bridgewall temperature should then be increased to 650°F (340°C) for final dryout. The heater may then be prepared for conventional steam-air decoking.

Note that the procedure above applies to a static boilout only, and may not be fully effective in removing deposits from convection section tubes. If significant convection section deposits are suspected, or if there are significant salt deposits in the preheat exchanger train, a hot water rinse using boiler feedwater or a recirculating boilout can be performed. However, this procedure is more complex and is not addressed here. See Report EE.79E.87 or consult the Heat Transfer Equipment Section for more information.

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4.2.2 Heater Preparation for Spalling

The key steps in preparing the heater for decoking are isolating the coil from the remainder of the process, and heating the firebox such that uniform temperature distribution is obtained. The following steps are required:

- Isolate coil from upstream and downstream process piping and connect to decoking system.
- After purging the firebox, light off burners following normal procedures using gas fuel (if available). To obtain uniform heat distribution in the box, high excess air and as many burners as possible should be used.
- When the bridgewall temperature reaches 400°F (200°C), decoking steam may be introduced. Adding steam to the coil when the box is cold can cause some or all of the steam to condense.
- Begin increasing steam rate until a mass flow rate of 18 lb/sec-ft² (90 kg/s-m²) is achieved in all passes, while increasing firing until a coil outlet temperature of 500°F (260°C) is reached.

4.2.3 Spalling

The majority of the coke should be removed during the spalling process. One key factor in determining the operation's success is maintaining a sufficiently high tube metal temperature on all tubes to ensure that they expand sufficiently to mechanically crack the coke. Key elements of the spalling procedure are listed below.

- Begin water quench of effluent to maintain a temperature of approximately 500°F (260°C). This temperature should be held during the entire decoking process.
- Increase coil outlet temperature (COT) in increments of approximately 200°F (110°C) until spalling begins, as indicated by a slightly black stack plume from the decoking pot and/or a darkening of a condensed sample of steam effluent. Usually, this begins around 1000 to 1100°F (540°C to 590°C).
- Hold COT constant until spalling subsides. At this time, the COT should be slowly increased until spalling resumes, or the maximum allowable Tube Metal Temperature (TMT) is reached. Note that this limit is typically set by metallurgical considerations rather than by the tubes' mechanical strength. Typical TMT limits are as follows:

Carbon steel	1275°F	690°C	Dark Cherry Red
2-1/4% chrome	1325°F	720°C	Bright Cherry Red
5% chrome	1350°F	730°C	Bright Cherry Red
9% chrome	1375°F	745°C	Bright Cherry Red
18 Cr - 8 Ni	1700°F	925°C	Light Orange
HK-40 (25 Cr - 20 Ni)	2050°F	1120°C	Light Yellow

Note that it is not essential that the actual TMT be continuously measured at this time, as radiant TMTs will typically be 35-50°F (20-30°C) higher than the Coil Outlet Temperature. However, TMTs do provide a reference point to ensure good heat distribution in the heater. In some cases, temporary thermocouples, such as those employed by heat treating contractors, can be used to monitor a larger portion of the firebox. In critical applications, instrumentation can be supplemented with portable infrared imaging equipment. Tube color can also be monitored to estimate the magnitude of the temperature.

- If spalling subsides, it can be re-initiated by using short bursts of air or by temporarily reducing the steam rate. Air bursts of approximately 1.2 lb/sec-ft² (6 kg/s-m²) of increasing duration (from 3-20 seconds) should be used. If this fails to initiate spalling, steam flow to the troublesome coil can be reduced to about 1/2 the normal rate for a short period of time (about 30 seconds).
- Spalling is considered to be complete when it cannot be re-initiated by further air bursts or steam flow changes, while at maximum TMT. This should have removed the majority of the coke from the tubes. The remaining coke will be removed during the burn phase of the process.