Addressing Increased Fouling Rates in Delayed Coker Heaters – A Case Study Identifying the Factors Behind the Increased Fouling Rates

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Delayed Coker Heater fouling

- In late 2018, Becht Engineering was asked to assist in evaluating rapid fouling in a Delayed Coker heater.
- Heater run lengths had been as long as 15 months between decoking the furnace.
  - Recent runs had been only 2 months in duration.
- Focus of initial request was heater design and burner performance.

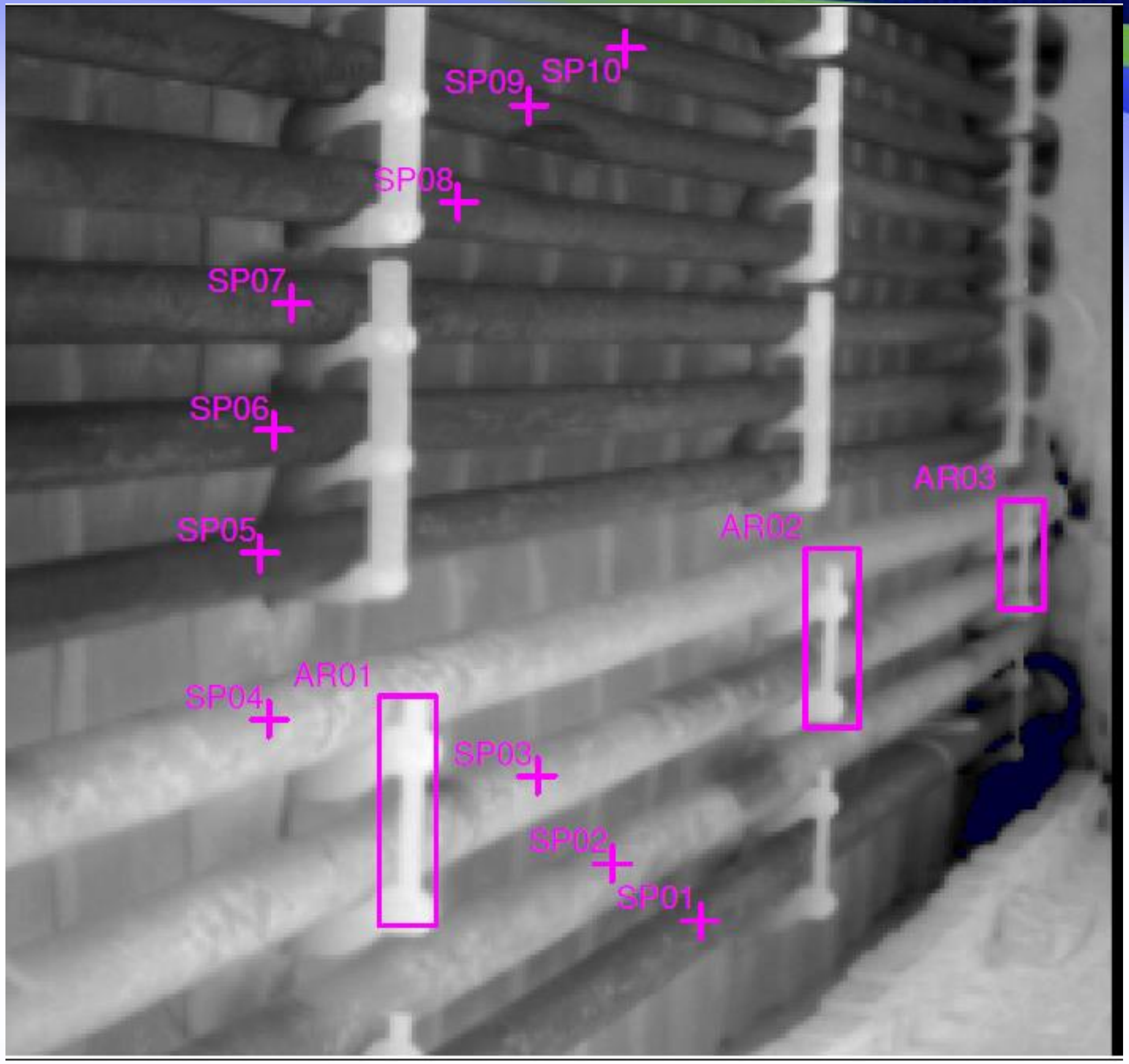
Initial investigation

- Unit operation was typically at 60% of heater design throughput
- Heater was replaced 10 years prior assuming purchased feed would increase unit feed rate.
- Crude slate processed at the site is a light, sweet feed slate that typically has only 10% by volume vacuum bottoms
- Lots of infrared thermography information available. Last 4 tubes are larger diameter than the rest and the skin temperature of those tubes sets the heater run length
- Coil outlet thermowells and transfer line in general have a history of excessive coke deposition
  - Outlet thermowells have coked up previously and read a lower temperature that has resulted in the heater increasing the fired duty

Typical thermal scan result

- Bottom four tubes are hotter than the other tubes in the heater
- Tube hangers are all about the same temperature.
- No obvious hot spots on the refractory which would indicate a non-uniform heat flux

- Concluded that problem was not fire side related



Potential process side causes of fouling

- Excessive heat flux
- Low velocities in the heater coils resulting in long residence times
- Inorganic contaminants
  - Sodium
  - Other metals
- High coke precursor concentrations
  - High microcarbon residue (MCR) values
  - Precipitated asphaltenes

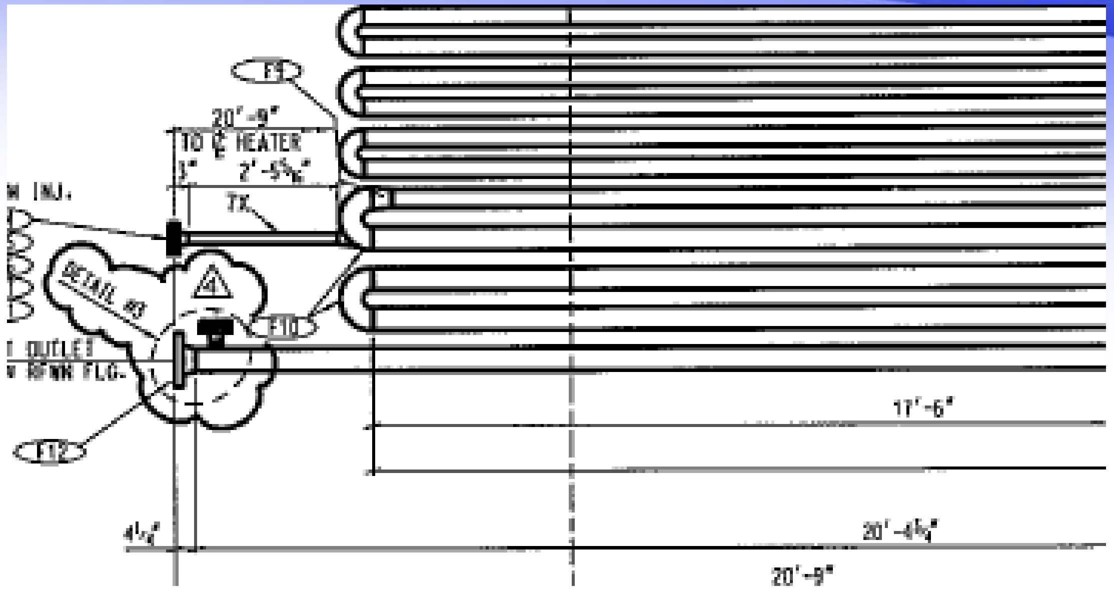
Typical Delayed Coker Heater Design Parameters and Preliminary Findings

- Design Parameters
  - Average radiant heat flux
    - Less than 9000 BTU/hr-ft2 for single fired heater
    - Less than 13000 BTU/hr-ft2 for double fired heater
  - Mass flux greater than 350 lb/ft2-sec
  - Cold oil velocity greater than 6 ft/sec for conventional feeds
  - Less than 30 sec residence time above 800°F
  - Transfer line minimum velocity
    - $V_{min} = 60/\sqrt{\rho_{mix}}$

- Preliminary findings
  - Mass flux of 300 lb/ft2-sec in small diameter tubes
  - Mass flux of 170 lb/ft2-sec in larger diameter tubes
  - Cold oil velocity of 4.6 ft/sec in smaller tubes, 2.6 ft/sec in larger tubes
  - Transfer line velocity was low in some sections

Coil configuration

- Each pass had the tube diameter increase for the last four tubes to reduce the pressure drop through the coil
- Existing heater coil had the ability to add velocity steam to the first of the larger diameter tubes.
- No velocity steam had been connected to this injection point since initial construction



Heater detailed analysis – process side

- DC-SIM as part of Petro-SIM software from KBC was used to model the heater
- A detailed tube by tube evaluation was done on the current heater coil configuration at the typical feed rate. Analysis showed:
  - Average radiant heat flux was low at 7200 BTU/hr-ft2
  - Mixed phase velocity at coil exit was low at 80 ft/sec
  - Residence time above 800°F was 35 sec, so longer than desired
- Typical feed properties would allow heater to run more than 6 months between heater decoke

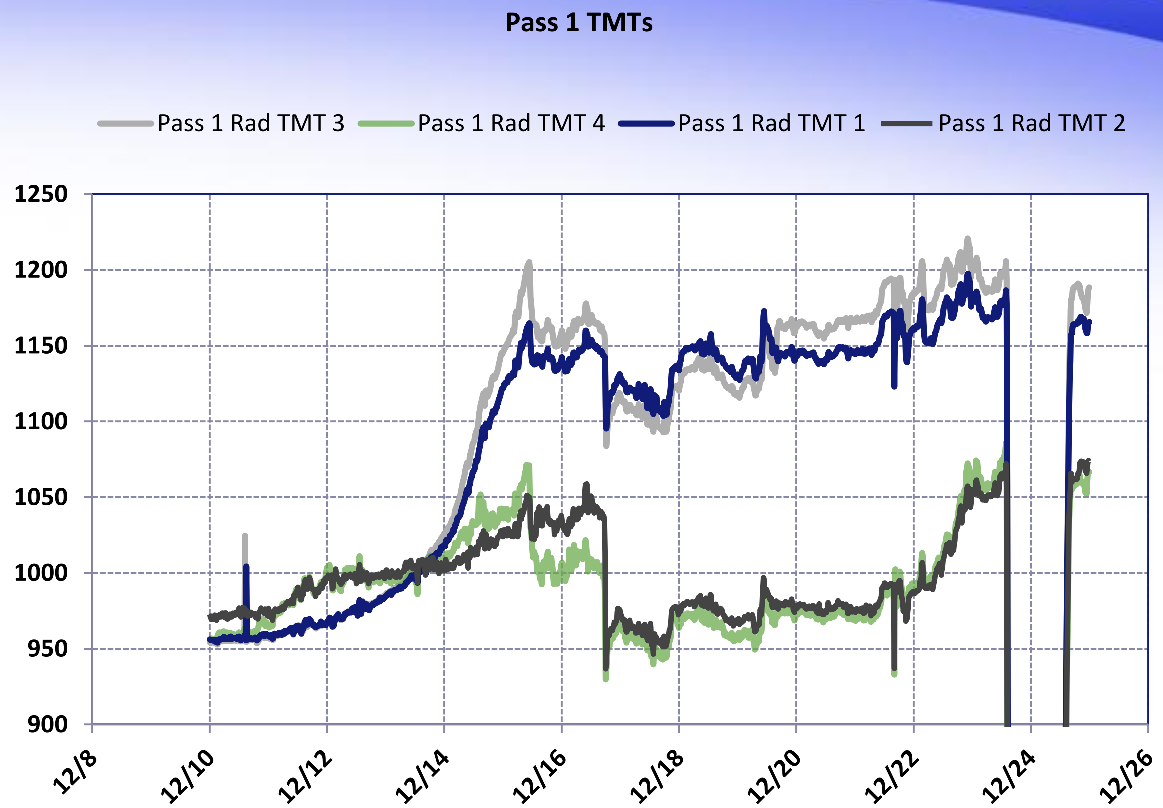
- Low velocities and mass flux in large tubes explained high tube metal temps in those tubes
- Short runs were not explained by design or operational issues

Coke properties

- Coke was extremely hard, dense, non-porous
- Larger tubes were cut out and replaced as replacing was faster than pigging due to the coke hardness
- Coke analysis showed extremely high concentrations of iron, calcium, sodium
- During low fouling rates the iron, calcium and sodium concentrations in coke are still high.
- Sodium in VTB is less than 15 ppm typically with occasional peaks to 30 ppm.

Crude slate impact

- Recent very high fouling rate was coincident with receipt of “heavy” crude into overall crude slate at a relatively low percentage
- Desalter performance showed evidence of increased emulsion layer thickness
- Coker heater fouling started shortly after this event



Conclusions

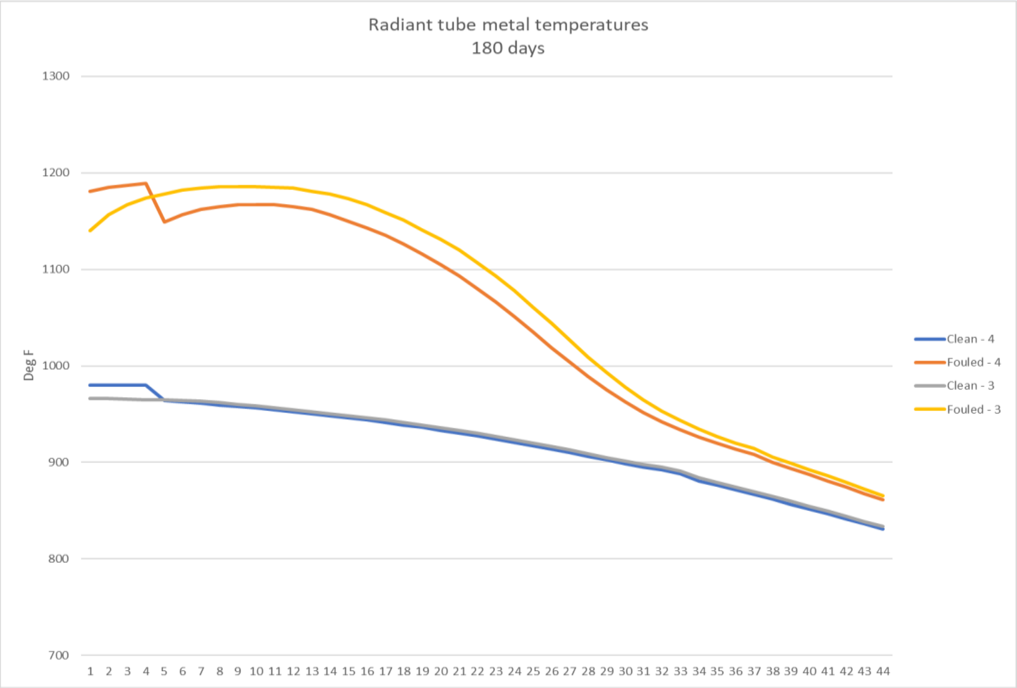
- The very rapid fouling in the last run and shorter prior runs was the result of asphaltene precipitation in the Coker feed
- Coker feed is very paraffinic with Watson K-factor of 12.0 and higher
- Any crude with higher than average asphaltene content will have the asphaltenes precipitate due to the paraffinicity of the feed.
  - The separated asphaltenes coke very rapidly
  - The coke formed from asphaltenes is very hard and non-porous, similar to what was found.
- Asphaltene precipitation from uncontrolled crude oil blending coupled with low velocities in Coker heater are the cause of these very short runs.

Visual inspection for Asphaltene precipitation

- Visual inspection of crude oil under a microscope will show asphaltene precipitation
- Magnification of 100x is typically sufficient to show precipitation. Severe cases do not require any magnification.
  - Photo is an example of crude oil with precipitated asphaltenes and not from this site

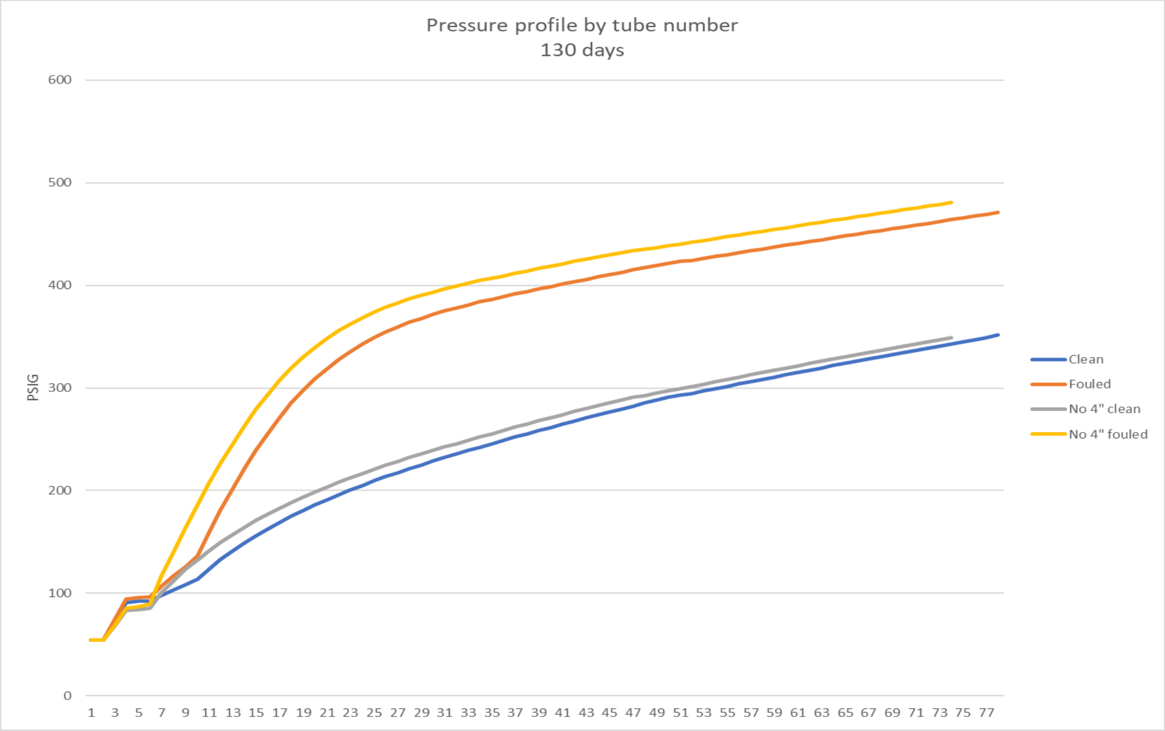
DC-SIM modeled alternate configurations

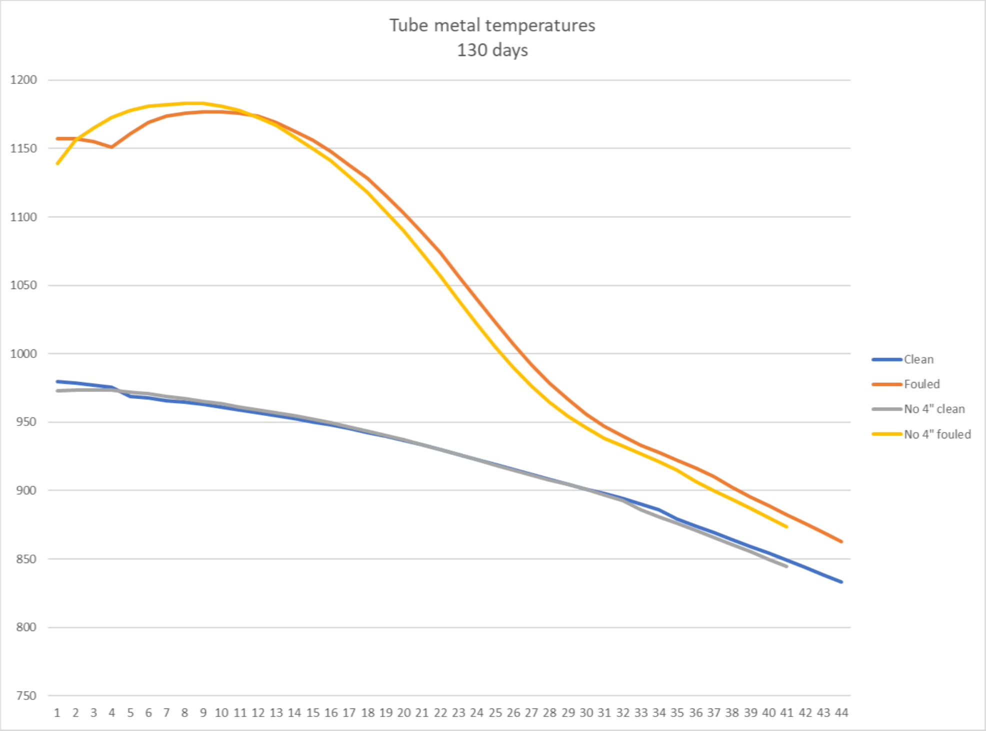
- Alternate coil configurations were evaluated to answer the following questions:
  - Could the larger tubes be replaced with same size tubes as rest of heater?
  - Could the larger tubes be removed completely?
  - Could more velocity steam prevent the fouling?



DC-SIM modeled alternate configurations

- Results of modeling showed adding velocity steam to first of the larger tubes and maintaining the existing coil configuration had the fewest objections





Model results

- Larger diameter tubes were necessary to limit heater pressure drop at end of run
- Removing large diameter tubes caused average radiant heat flux to be 7900 BTU/hr-ft2 at the reduced throughput. In tube velocity was high and would limit future capacity. Additionally, that modification did not resolve low velocity in transfer line
- Velocity steam was required in the first of the larger diameter tubes to limit fouling. This also increased velocity in transfer line
  - Checked velocity in coke drum to prevent coke fines carry over
  - Preliminary check on C-factor in fractionator flash zone
  - Checked on fractionator sour water pump capability

Path forward

- Site implemented crude oil testing to manage compatibility
- Velocity steam was added to first of the large diameter tubes on each pass

- These modifications have been in place since Jan 2019 with good results