

Principles & Practices Session
Crude/Vacuum Distillation & Coking

***FIRED HEATER DESIGN &
DECOKING TECHNIQUES***

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Topics of Discussion:

- Overview of Heater Design
- Factors that Influence Coke Formation
- Overview & Discussion of Decoking Methods
- Examples of Rapid Fouling on Coker Heaters
- Example of Design that Would Promote Coke Formation

Operating & Design Parameters **Specified by the Process Engineer**

- Process Unit & Heater Type
- Number of Passes (target)
- Heat Absorbed
- Fluid Flowrates, Temperatures & Pressures (inlet and outlet)
- Fluid Properties (API, viscosity, specific heat & thermal conductivity)
- Pressure Drop Allowable
- Fouling Factor (or coke laydown thickness)
- Average Heat Flux
- % Vaporization
- Injection Steam/Condensate Requirements
- Turndown, Alternate Cases and Overdesign Operating Capabilities

Other Special Requirements that Influence the Heater Design

- Thermal Efficiency Required (Combustion Air Preheat)
- Forced Draft Fans & Drivers
- Induced Draft Fans & Drivers
- Sootblowers
- Stack Emissions
 - Burner Type (Low NO_x Burners, heat release)
 - Post Combustion (SCR)
- Fuel Characteristics (burner and pilots)
- Process Fluid Pass Control
- Heat Input Control
- Decoking Requirements

Typical Heater Design Parameters

Crude Heater

- Thermal Cracking Tendency: Low
- Outlet Temperature, °F: 625 to 700
- Pressure Drop, psi: 150 to 250
- Target Mass Velocity, lb/(sec-ft²): 250 to 350
- Radiant Heat Flux, BTU/(hr-ft²): 10,000 to 12,000

Typical Heater Design Parameters

Vacuum Heater

- Thermal Cracking Tendency: Low/Slight
- Outlet Temperature, °F: 715 to 800
- Pressure Drop, psi: 50 to 75
- Target Mass Velocity, lb/(sec-ft²): 250 to 350
(except outlet tube)
- Radiant Heat Flux, BTU/(hr-ft²): 9,000 to 12,000
- Size outlet tubes for less than sonic velocity.

Typical Heater Design Parameters

Visbreaker Heater

- Thermal Cracking Tendency: Medium/High
- Outlet Temperature, °F: 840 to 890
- Pressure Drop, psi: 210 to 350
- Target Mass Velocity, lb/(sec-ft²): 300 to 400
- Radiant Heat Flux, BTU/(hr-ft²): 8,000 to 12,000
(soaking/preheating)
- Minimum Cold Oil Velocity, ft/sec: 6

Typical Heater Design Parameters

Delayed Coker Heater

- Thermal Cracking Tendency: High
- Outlet Temperature, °F: 920 to 940
- Pressure Drop, psi: 350 to 400
- Target Mass Velocity, lb/(sec-ft²): 350 to 450
- Radiant Heat Flux, Btu/(hr-ft²):
 - Single Fired Heaters 8,000 to 10,000
 - Double Fired Heaters 12,000 to 15,000
- Minimum Cold Oil Velocity, ft/sec: 6

Standard Heater Specifications

- Heat Duty
- Process Flow Rate
- Temperatures In/Out
- % Vaporization
- Pressure Drop Allowable
- Fuel Composition

Special Design Conditions

- Fouling Factor (Coke Thickness)
- Average Heat Flux
- Inside Film Temperature Limit
- Tube Side Velocity Requirements
- Residence Time Requirements

Heater Designer View

- Process Duty- Large or Small Heater
- Off-Design Cases- Variability Needed
- Heater Type- OK or Suggest Other Type
- Heat Flux- Indication of Fluid Sensitivity
- Fouling/Coking Tendencies- Tube Size

Chemical Fouling (Coking)

- This fouling is a function of the fluid composition and the residence time at the temperature range that decomposition, cracking and/or coking can occur. (Source: TEMA)
- Coking has an impact on Pressure Drop, while fouling factor does not.

Crude Heater Flux Selection

- Non-Fouling/Coking Services
12,000 Btu/hr-ft²
- Mildly Fouling/Coking Services
10,000 Btu/hr-ft²
- Highly Fouling/Coking Services
< 9,000 Btu/hr-ft²

Effects of Lower Heat Flux

- More Radiant Surface Area Required
- More Process Fluid Pressure Drop
- More Passes to fit Pressure Drop
- More Expensive Heater
- Lower Inside Film Temperature

Inside Film Temperature

- Primary indicator of fouling potential for fouling or coking services.
- Empirical and not directly determined.
- Can be ‘translated’ into something that can be directly measured:

Tube Metal Temperature – TMT

Effects of Higher Fluid Velocity

- Higher Inside Coefficient (Direct Function)
- Lower TMT (Film Temperature)
- Higher Pressure Drop (Squared function)
- Potential Return Bend Erosion

Heater Design is a Compromise of Velocity and Pressure Drop

- The number of passes and tube diameter are adjusted to match a ‘Good’ mass velocity while meeting the allowable pressure drop.
- Too little pressure drop for a viscous fluid can promote fouling and shorter run lengths.

Residence Time

- Time above a specific critical operating temperature can determine tube size, pass arrangement and tube length.
- It can override previous design considerations.

Heater Types

- Vertical Cylindrical
- Cabin
- Horizontal Tube Box
- Double Fired Horizontal Tube

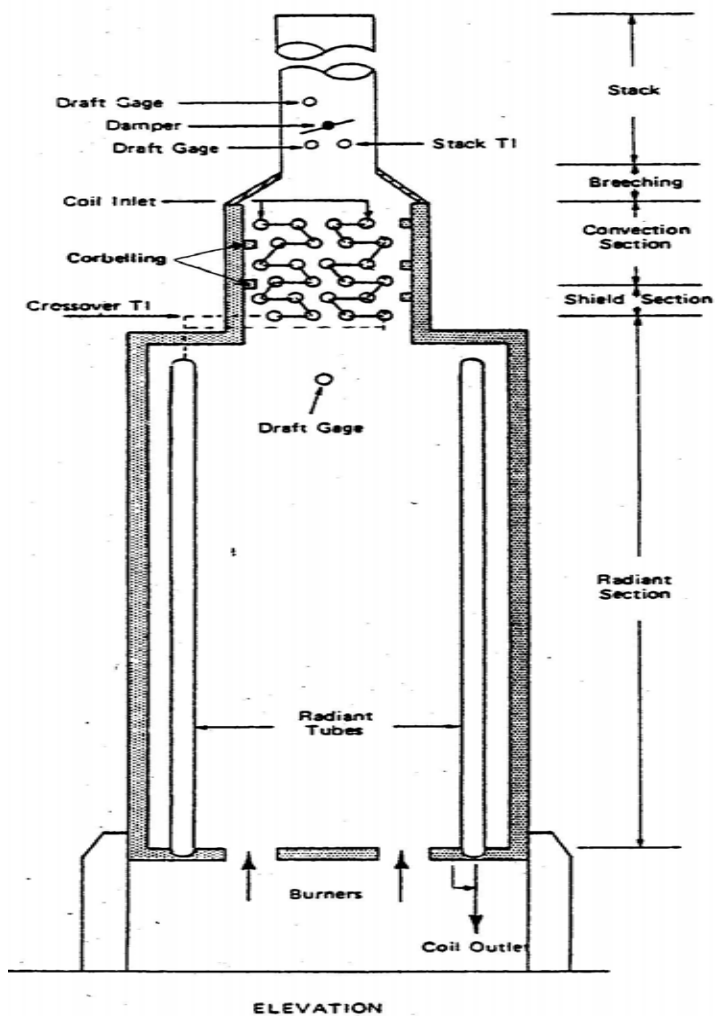
Types of Heavy Oil Fired Heaters

- Crude & Vacuum Heaters
 - Vertical Cylindrical Tube- Low Fouling Fluid
 - Horizontal Tube Cabin/Box- Higher Fouling Fluid
- Visbreaker & Coker Heaters
 - Horizontal Tube
 - Single or Double Fired Design

Vertical Cylindrical Heaters

- Lowest Plot Space (Tube Pulling is Upward)
- Usually Least Cost
- Highest Radiant Flux Variation- Top to Bottom
- Typically used for 'Clean Services'
- Can be Mechanically Pigged

Vertical Cylindrical Heater



Horizontal Tube Heater

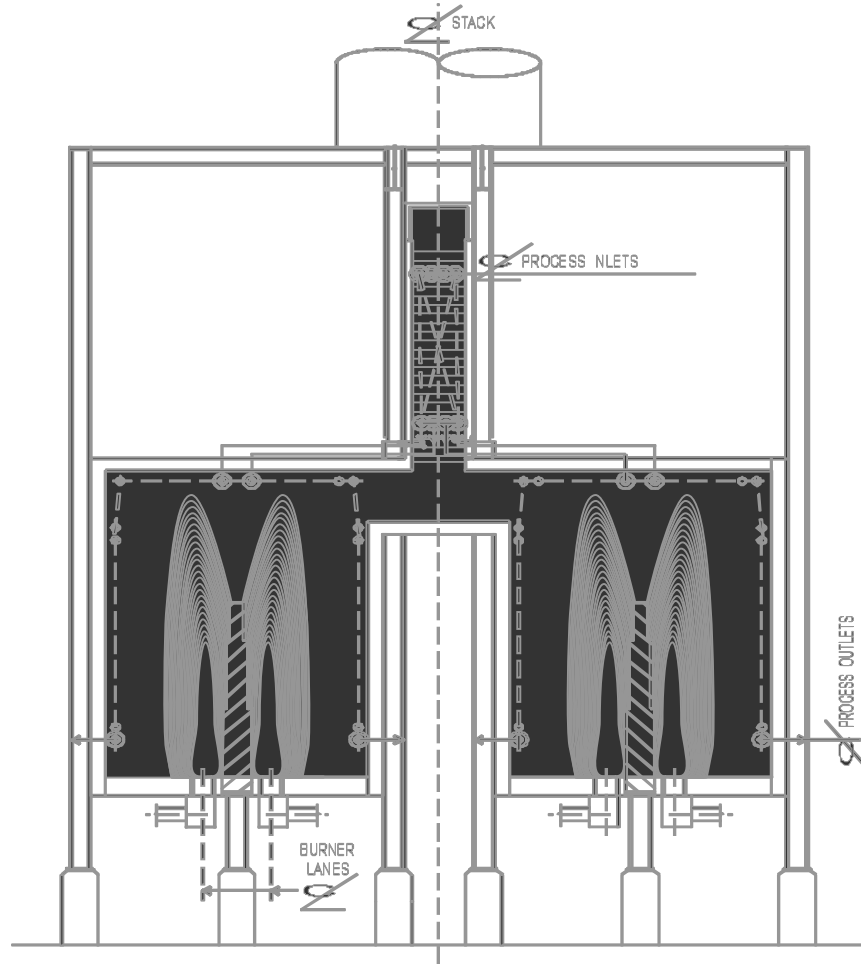
- Even Heat Flux to Full Tube Length
- Better Heat Flux Profile- Top to Bottom
- Large Plot Space (Tube Pulling Outward)
- Can be Mechanically Pigged
- Better Design for Severely Fouling Service

Singled Fired Heaters

- The most common firing pattern for Heaters
- Used on Light, Non-asphaltenic VR
- Peak Flux is 80% above Average Heat Flux



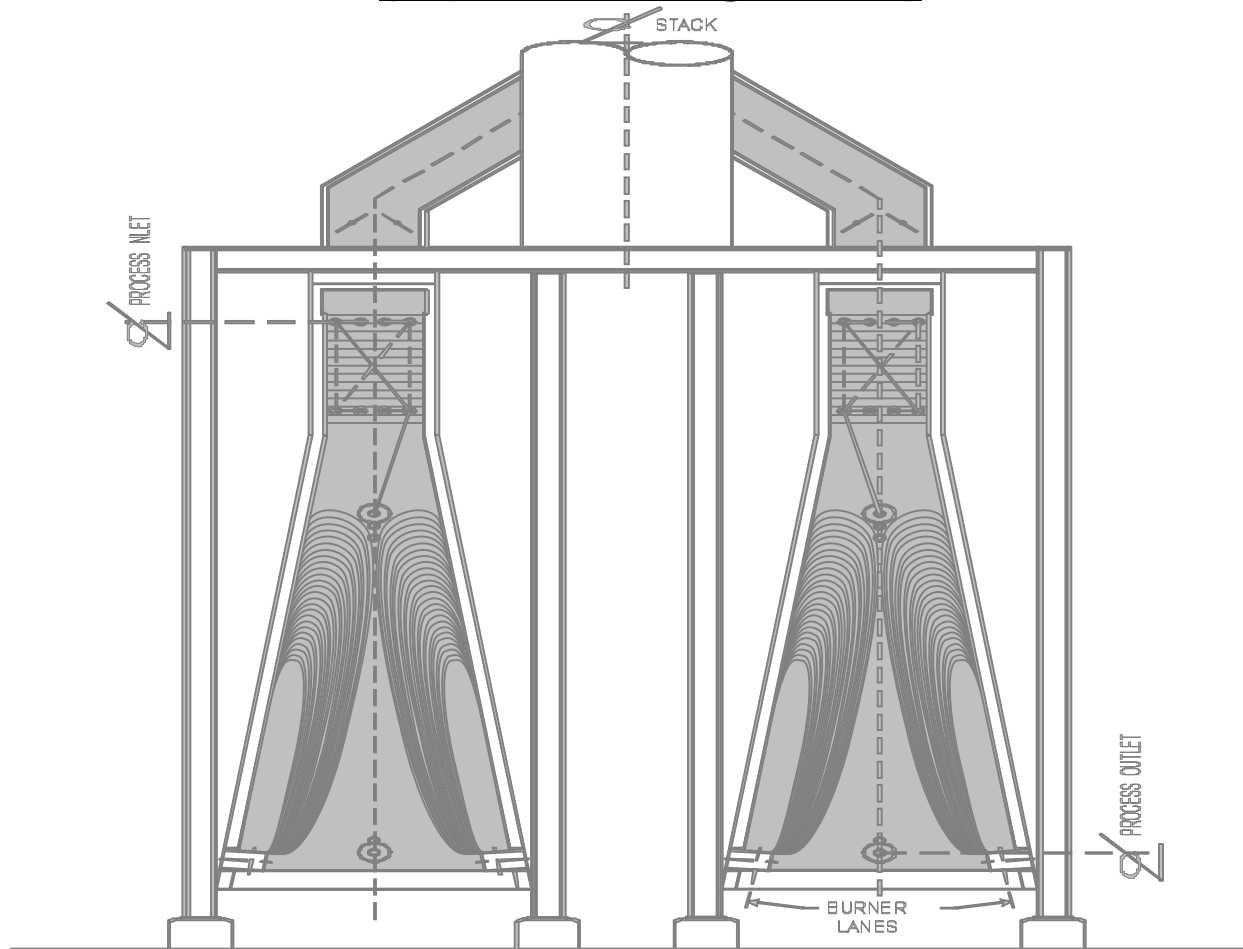
Single Fired Horizontal Tube Heater (4-pass arrangement)

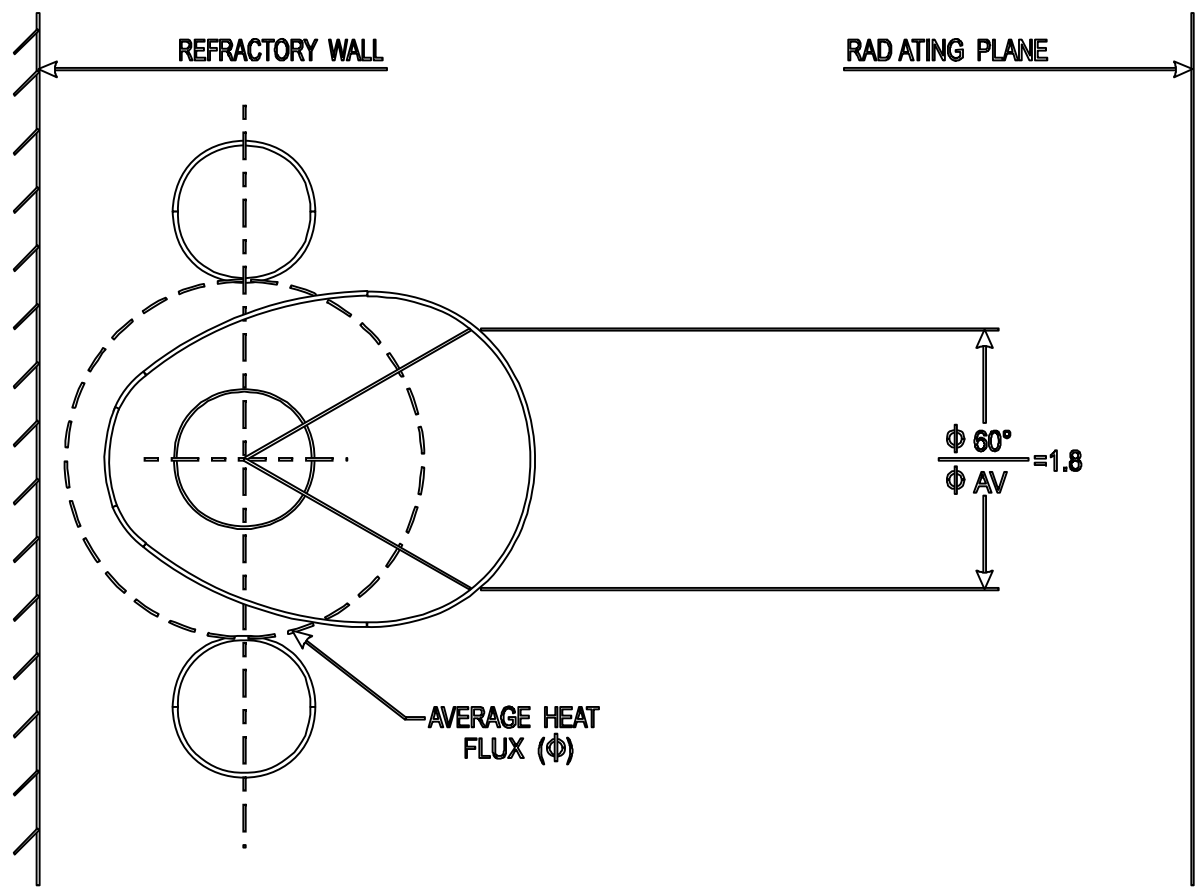


Double Fired Heaters

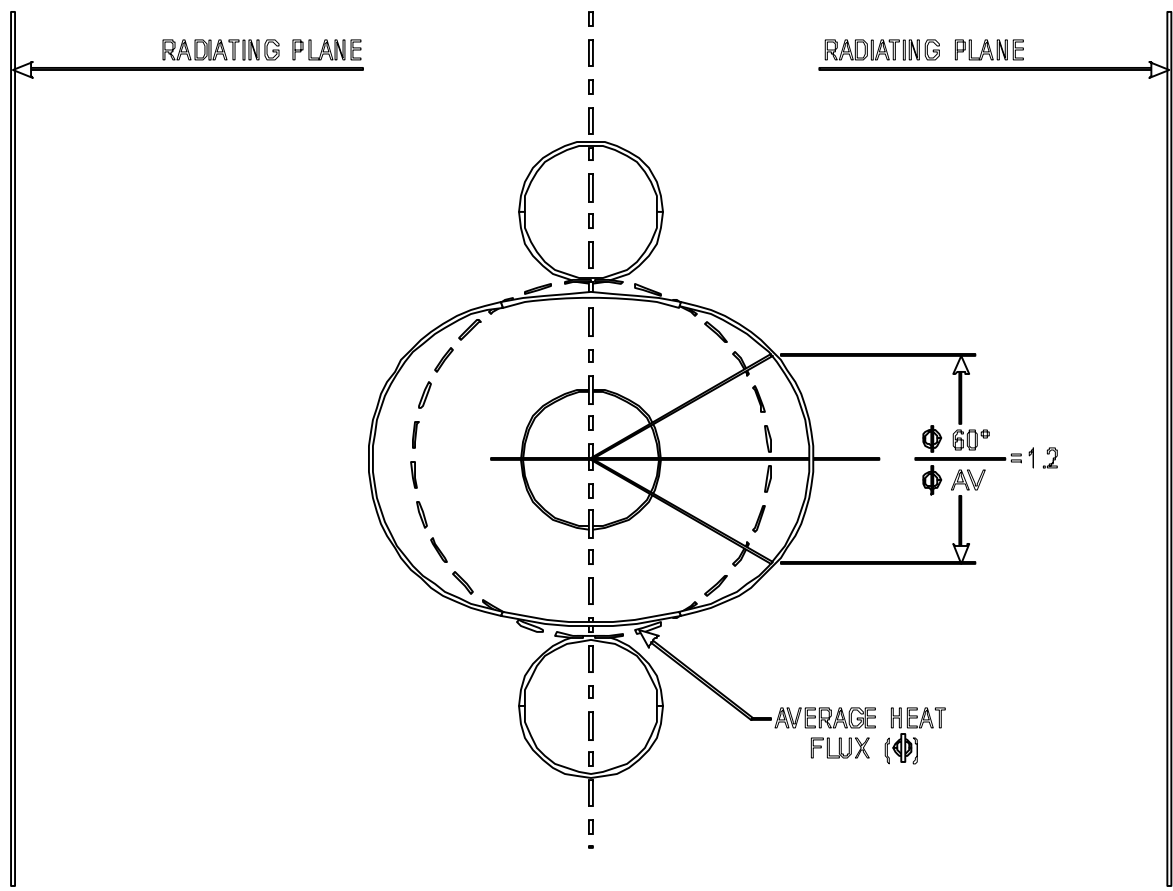
- Used on Difficult, High Fouling Feedstocks:
i.e. High Asphaltenes, Hydrocracked VR
- High in-tube Velocity, Short Residence Time in Radiant Section
- More Uniform Heat Flux Around the Tube
- Higher Average Flux for Same TMT, thus Less Radiant Surface Needed
- Peak Flux is Only 20% above Average Heat Flux

Double Fired Horizontal Tube Heater (2-pass arrangement)





CIRCUMFERENTIAL RADIANT HEAT FLUX DISTRIBUTION – SINGLE FIRED TUBES



**CIRCUMFERENTIAL RADIANT HEAT FLUX DISTRIBUTION –
DOUBLE FIRED TUBES**

Factors that Influence Coke Formation

- **Heater Charge Properties**

- Sodium Content – causes rapid fouling
- Asphaltene Content – increases fouling
- Calcium Content
- Flow Improvers- potential increase in fouling
- Crude Properties –API & viscosity

Factors that Influence Coke Formation

- Operating Parameters
 - High Heater Outlet Temperatures
 - Process Velocity
 - » Low Mass Velocity, Increases Film Temperature
 - » Loss of Velocity Steam
 - » Low Cold Oil Velocity (target 6 ft/sec minimum)
 - Uneven Heat Distribution - “hot spots or cold spots in firebox”
 - Residence Time Above Cracking Threshold
 - Low Flow (Turndown) or Poor Flow Distribution
 - Feed Interruptions

Factors that Influence Coke Formation

- Other Issues

- Changes Made During Heater Revamp:
 - » Change to Low NOx Burners
 - » Fuel Heating Value Changes
 - » Heavier API Crude Feed
 - » Addition of Air Preheat
 - » Change Size, Number, and/or Metallurgy
- Fuel Contaminants- Tip Plugging

Heater Decoking Options

Steam-Air Decoking (Steam & Air Burn)

- Performed when heater is off-line
- Heater box temperature is reduced/cooled

Mechanical (Pigging)

- Performed when heater is off-line
- Heater box temperature is cooled

On-Line Spalling

- Performed while heater is in service
- 1 pass is taken out of service while other passes remain on-line

Heater Decoking Option Summary Table

<u>Decoking Option</u>	<u>Type of Heavy Oil Heater</u>			
	Crude <u>Heater</u>	Vacuum <u>Heater</u>	Visbreaker <u>Heater</u>	Delayed Coker <u>Heater</u>
Steam Air Decoking	Yes	Yes	<input type="checkbox"/> Yes	Yes
Mechanical	<input type="checkbox"/> Yes	<input type="checkbox"/> Yes	Yes	<input type="checkbox"/> Yes
On-Line Spalling	N/A	N/A	<input type="checkbox"/> Yes	<input type="checkbox"/> Yes

Note: Decoking option shown boxed indicates recent client preferences to decoke heater.

Steam-Air Decoking Methodology

- Coke is burnt off the heater tubes by firing the furnace in a controlled decoking process by circulating a steam-air mixture at elevated temperatures.
- Air is used to burn the coke off the tubes.
- Steam is used to keep the burning temperatures low such that they do not exceed the maximum tolerable temperatures.
- Typical decoking time 24 to 48 hours per pass depending on amount of coke in tubes.

Mechanical Decoking Methodology (“Pigging”)

- Coke is removed from the heater tube by pumping a metal studded foam or plastic “pig” with water. The metal studded “pig” rotates such that it scrapes the coke off the inside of the heater tube.
- Different size and abrasiveness “pigs” are used in the decoking process. “Pigs” are slightly smaller than the inside diameter of the heater tube.
- Usually “pigs” are pumped through heater several times forward and backward until overall differential pressure across the tube (inlet to outlet) is restored to its original “unfouled” condition.
- Typical decoking time is 18 to 24 hours per heater depending on setup time.

On-line Spalling Methodology

- Procedure basis was originally developed by the late Mr. Lloyd Langseth and has been further developed by Foster Wheeler.
- Coke is removed from the heater tube by varying the steam or condensate flowrate on the fouled tube such that a thermal shock is created that breaks off the coke from the tube.
- The spalling medium will transfer the coke particles into the heater effluent where it will be collected in the downstream Coke Drum.
- One pass is spalled while the other coils of the heater remain in normal hydrocarbon service.
- Typical decoking time is 16 to 24 hours per heater pass.

Steam-Air Decoking

- Advantages:

- Removes almost all coke from the inside of the tubes
- Heater firebox does not need to be fully “cooled”
- Can be performed by Unit Operators- no outside vendor needed

- Disadvantages:

- Time & Cost (maintenance & unit loss production)
- Environmental concerns on venting to atmosphere
- Disposal of water/coke mixture
- Potential tube rupture
- Not found to be effective on crude slates containing inorganic material (i.e. Canadian crudes, some crude flow improvers)

Mechanical Decoking (“Pigging”)

- **Advantages:**

- All coke is removed from the inside of the tubes
- More environmentally safe than S.A.D. – no venting to atm.
- “Pigs” do not score inside of tubes
- Usually performed faster than S.A.D.
- Clients have reported longer run lengths than S.A.D.
- Requires outside vendor to perform decoking procedure- unit operators can spend more time on turnaround activities

- **Disadvantages:**

- Requires heater to be taken fully out of service
- Disposition of “dirty” water required
- Downtime is 1 to 3 days/heater
- Cost - specialized decoking vendor needed

On-Line Spalling

- **Advantages:**

- Heater remains in service during procedure, one pass at a time
- Immediate feedback on effectiveness once pass is back in service
- Allows extended heater run length before “pigging” is required
- Coke is collected in downstream coke drum
- Regular decoking program can be developed by refiner

- **Disadvantages:**

- May not get all coke off a particular tube section-still need to eventually fully decoke
- Potential tube damage due to tube expansion/contraction
- Potential u-bend corrosion/erosion
- Potential coke blockage of tube – “pigging” required
- Can only be performed on 3 or 4 pass heaters with individual pass firing

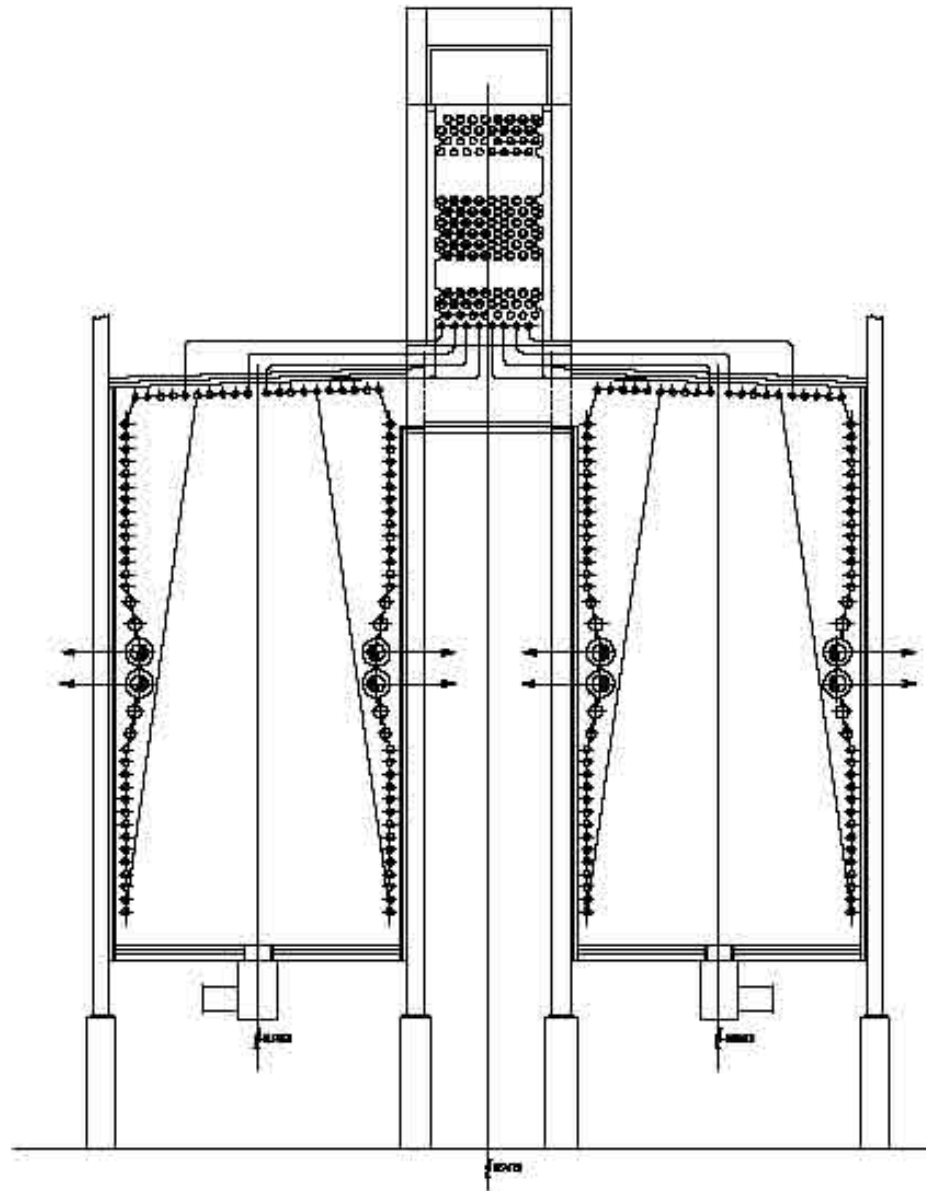
Rapid Fouling on Coker Heaters

Examples have included:

- Spike in Na Content
- Sludge Deposits/Pipe Scale- after T/A
- Chemical: Flow Improvers
 - » Added at Well Head
 - » Added in Crude Unit
- Mechanical: Air Leaks - leads to after burning
- Operation: Poor Flame Distribution

Example of Design That Would Causes Coke Formation

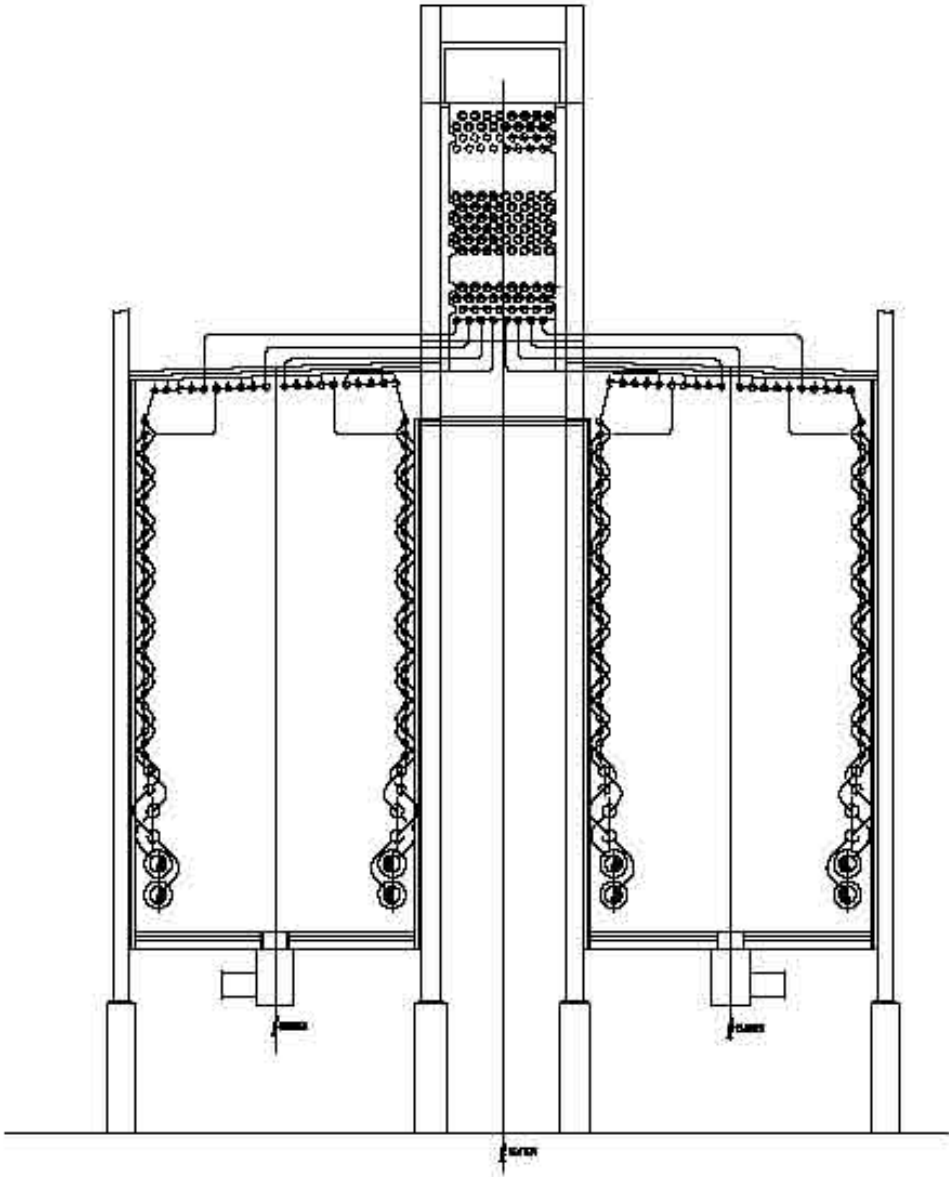
- Horizontal Tube Box Heater in Vacuum Service with multiple passes on each wall.
 - Mid-Wall Pass Outlet Arrangement
 - Nested Pass on Wall Arrangement



CENTRAL OUTLETS ARRANGEMENT

Example of Design Less Susceptible To Coke Formation

- Mid-Wall Pass Outlets cause different heat flux and heat input between top pass and the bottom pass on the radiant wall
- Lower initial cost
- Sized with similar Radiant Surface Area to the nested design



NESTED PASS ARRANGEMENT

Example of Design That Would Promote Coke Formation

- Nested passes on the radiant wall allow equal heat flux and heat input to each of the two passes
- More costly due to external jump-overs and the additional coil materials

Summary

As industry moves toward heavier crude slates, attention to fired heater specification and design selection, along with potential fouling tendencies, will become more important in maintaining historical heater run lengths and process unit performance.