Fired Heaters
Key to Efficient Operation of Refineries and Petrochemicals

Ashutosh Garg
Furnace Improvements Services
Sugar Land, TX
Typical Refinery Process Flow Diagram
Major Refinery Building Block

❖ Majorly used in refinery processes which require very high temperatures
  ▪ Crude Unit – 650-750°F
  ▪ Vacuum Unit – 700-800°F
  ▪ Coker Unit – 950°F
  ▪ Reforming Unit – 1000°F

❖ Heating options-
  ▪ Steam
  ▪ Hot Oil/Molten Salts
  ▪ Electric
Fired Heaters in Petrochemical Industry

❖ Most common petrochemical classes - Olefins & Aromatics
❖ Processes involved:
  ▪ Steam Cracking – To Produce Olefins (Using Ethane to Gas Oils), Propane Dehydro to produce Propylene
  ▪ Catalytic Reforming – To Produce Aromatics (Using Naphtha)
❖ Global Production
  ▪ Ethylene – 140 Million Tonnes
  ▪ Propylene – 100 Million Tonnes
  ▪ Aromatics – 85 Million Tonnes
Steam Cracking

Steam Cracker

1600°F

Optional gas feeds

Optional liquid feeds

Methane

Ethane

Propane

Butanes

Methane

Ethylene

Propylene

Benzene

Butadiene

Byproducts

Produced by cracking any of the optional feeds

Produced only by cracking any of the liquid feeds

Petroleum Refinery

Natural Gas Processing

Raw Natural Gas

Crude Oil

Naphtha

Gas Oil

Ethane

Propane

Butanes

Methane

Benzene, Toluene, Xylenes

BTX

Engine coolant

Polyesters

Polyvinyl chloride

Propylene glycol

Polol

Epoxy resins

Polystyrenes

Polyurethanes

Nylons

1600°F
Steam Reforming

- Desulfurization
- 1500°F Steam Reformer
  - Synthetic Gas: CO + H₂
  - F Fischer-Tropsch Synthesis
  - Water-gas-shift Reaction
- Hydrogen
- Ammonia Synthesis
- Ammonia
- Methanol Synthesis
- Synthetic Fuels
- CH₃OH Dimethylether
- Natural Gas
- Naphtha
Heat transfer modes

❖ Conduction-Solids
  ▪ Heat is transferred by direct contact between two objects

❖ Convection-Fluids
  ▪ Heat is transferred with in a medium due to movement of molecules

❖ Radiation
  ▪ Transmission of heat from a heated body by electromagnetic waves
Heat transfer requires difference in temperature of two bodies

Flue gas
(Higher temperature)

Tube
(Lower temperature)

1,500 °F

800 °F

Heat transfer is proportional to temperature difference.

www.heatflux.com
How is Heat Transferred to the Fluid?

- Direct Radiation from hot gases to tubes
- Re-radiation from refractory walls to tubes
- Convection from hot gases to tubes
- Conduction through wall of tubes
- Convection into process fluid

www.heatflux.com
Fired Heaters Evolution

- Developed in late 1800s for growing demand of petroleum products
- Earlier designs – Shell Still-Batch Process-unable to heat viscous liquids efficiently
- Led to development of tubular coil arrangements in 20th century
- Earlier designs were based on convection section heat transfer and flue gas recirculation

Courtesy- Refinery Operations by Bill Berger
FLOW DIAGRAM OF EARLY DUBBS UNIT

www.heatflux.com

Courtesy- Refinery Operations by Bill Berger
Fired Heaters Evolution

May 22, 2017

(A) BURNERS TO STACK

(B) BURNERS

(C) BURNERS

(D) BURNERS TO STACK

(E) BURNERS

(F) BURNERS TO STACK
Fired Heater Evolution-2

(G) TO STACK

(H) TO STACK

(I) TO STACK

(J) TO STACK

(K) TO STACK

(L) TO STACK

May 22, 2017

www.heatflux.com
Fired Heater – Evolution

- Fired heaters- initially box type radiant shape with horizontal tubes and end wall fired burners
- Initially two rows of tubes backed by the refractory
- In 1950s, designs used single row of tubes
- New designs go for double fired tubes
- Vertical tube configuration with Vertical Cylindrical Radiant Section
- Vertical up fired burners
Fired Heaters - Importance

- Major energy consumer
- High temperature
- Exposed to flames
- Major source of greenhouse gases
- Major source of NOx emissions
- Coking of tubes
- Run length
Fired Heaters in Refining Industry

- About 3000 Heaters in the USA
- Natural Draft Heaters - 89.6%
- Forced Draft Heaters - 8% without APH
- Balanced Draft Heaters - 2.4% with APH
- Natural Draft Heater - 72 MMBtu/hr (Avg. Size)
- Balanced Draft Heater - 110 MMBtu/hr (Avg. Size)
Heater Nomenclature

❖ Three major components
  ▪ Radiant Section
  ▪ Convection Section
  ▪ Stack

❖ Radiant / Convection split
  ▪ In refinery heaters, radiant section heat transfer is predominant (60-80%).
  ▪ In high temperature heaters the radiant heat duty drops down to 50% of the total duty.

www.heatflux.com
Major Refinery Heaters

❖ Four major building blocks
  ▪ Atmospheric heater
  ▪ Vacuum heater
  ▪ Coker heater
  ▪ Catalytic Reforming heater
Atmospheric Heater

- Crude or topping heater
- Inlet temperature: 400-600°F
- Outlet temperature: 625-725°F
- Outlet pressure: 25 psig
- Pressure drop: 100-200 psi
- Typical run lengths: around 3-4 years
- Avg. Radiant heat flux: 10,000-12,000 Btu/hr ft²
- Coil material:
  - 5 Cr -1/2 Mo
  - CS for sweet crudes, low temp. service
Coker Heaters

- Converts all the bottom of the barrel into gases, naphtha and coke.
- Coke is shipped to other countries for burning in powerplants.
- Very popular high gasoline demand
- Endothermic reaction-heater supplying the heat
Reformer- Furnace Radiant Section

**Reforming**

\[ \text{CH}_4 + \text{H}_2\text{O} \leftrightarrow 3\text{H}_2 + \text{CO} \]

**Shift**

\[ \text{CO} + \text{H}_2\text{O} \leftrightarrow \text{H}_2 + \text{CO}_2 \]

Hydrocarbon → Steam → ID Fan → Fuel → Process Side Catalyst-Filled Tubes → Radiant Furnace Side → Reformed Gas

Convection Section → Stack
Typical Operating Conditions

- Steam to Carbon Ratio of 2.5 to 4.5
- Radiant section
  - Temperature, in / out - 950/1560 F
  - Pressure, in / out - 330/290 psig
- Radiant section efficiency: 45-50%
- Overall thermal efficiency: 88-92%
- Typical tube diameter - 3-5 inches
- Typical lengths - 25-45 ft.
- High Chrome Nickel tubes
Down Fired Steam Reformer

Burner and Tube arrangement

Pipe Support
Inlet Pigtails

Inlet Manifold

Pent House

Observation Doors

Outlet Pigtails

Flame

Tubes with catalyst

Air inlet

Windbox

Damper

Burners at the reformer roof
Pyrolysis-Cracking Furnaces

- Breaking the molecule with fire or heat
- Heavier parafinnic hydrocarbons are heated to a high temperature at a low pressure to produce ethylene, propylene, butadiene etc.
- Tubular furnace in the presence of steam.
### Historical data for cracking heaters

<table>
<thead>
<tr>
<th>Year</th>
<th>Max TMT (°F)</th>
<th>Avg. Flux (W/m²)</th>
<th>Tube Matl.</th>
<th>Arrngmt.</th>
<th>Burners</th>
<th>Heater Size (MMBtu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1940</td>
<td>1400</td>
<td>14400</td>
<td>321 H</td>
<td>Horizontal</td>
<td>Wall&amp;Roof</td>
<td>30</td>
</tr>
<tr>
<td>1970</td>
<td>1950</td>
<td>25000</td>
<td>Cast 310</td>
<td>Vertical</td>
<td>Floor&amp; side</td>
<td>200</td>
</tr>
<tr>
<td>1990</td>
<td>2050</td>
<td>30000</td>
<td>3545Cr Ni</td>
<td>Vertical</td>
<td>Floor</td>
<td>400</td>
</tr>
</tbody>
</table>

Source: [www.heatflux.com](http://www.heatflux.com)
Furnace Configuration

- Vertical coils fired from both sides
- Tubes are supported from top by spring hangers
- Burners are located on floor and side walls
- Radiant flux density, Btu/hr ft²
  - Ethane /Propane - 20,000-26,000
  - Naphtha - 24,000-30,000
Air Pollution by Fired Heaters

❖ Nitrogen Oxides
  ▪ 50% of total NOx emissions are from industrial processes
  ▪ 2 types of NOx produced:
    • Fuel NOx (due to fuel bound nitrogen)
    • Thermal NOx (due to high temperature)

May 22, 2017

www.heatflux.com
Air Pollution by Fired Heaters

❖ Carbon Dioxide
  ▪ Generally 200,000 BPD capacity refinery emits 1.5 million tons/year of CO2 (2/3rd is from Fired Heaters)

❖ Carbon monoxide
  ▪ produced by incomplete combustion
  ▪ EPA limit is 50 ppmvd

❖ Sulfur Oxides
  ▪ By-products of combustion
  ▪ Fuel gas contains upto 160 ppm of H2S

❖ Others– trace amounts of VOCs, PM10 and PM2.5
Typical NOx emissions

- Gas firing - 0.05-0.2 lb./MMBtu
- Oil firing - 0.2-0.4 lb./MMBtu
- A 100 MMBtu/hr gas fired heater will emit approx..... 5.5-22 lb./hr or 20 -80 tons /year.
- A typical refinery having 40 heaters will be emitting approx......--- 8,00-3,200 tons/year.
Low NOx/ Ultra Low Burners

Low NOx Burner Development History

- Standard
- Staged air
- Staged fuel
- Internal Flue gas recirculation
- New Generation

Selective Catalytic Reduction Systems

- Nitrogen Oxides are reduced to Nitrogen by the addition of Ammonia in the presence of catalyst.
- First tried out in Japan in 1963.
- First commercial installation began in 1978.
- Most proven technology for reduction of NOx (can accomplish greater than 95% reduction).
How to reduce air pollution

❖ Improving heat recovery in the heat exchangers to minimize the heat duty
❖ Improving fired heater efficiency to 90+% to minimize the fuel firing
❖ Car pooling/Electric Cars
Coking in Tubes

❖ Coke deposits on the inside of heater tubes
❖ Pressure drop goes up
❖ High tube metal temperature
❖ Exceeds design limit- time for decoking
❖ Run length 9-12 months
❖ How to clean the tubes?
❖ Pigging vs. decoking vs. on-line spalling
Energy Consumption

❖ Typical Refinery
- 44 MMBtu/ BBL of oil
- 67% of the energy used in Fired heaters
- 134,000 BPD (Average Size)
- Fuel Cost-$3/MMBtu
- Energy Bill $4.32 Billion/Year
- Efficiency improvement 1%= 43.2 Million Dollars

A dollar saved is a dollar earned.
Fired Heaters Efficiency Improvement

- Fired Heaters Efficiency can be improved by:
  - Installing Air preheater
  - Waste Heat Steam Generator

- Efficiency improvement potential of 8-15%

- Low energy prices do not provide good payback
New Developments

❖ Better design correlations - still using 70 years old design methods
❖ CFD Modeling of the burners and heaters
❖ Better materials for tubes and refractory
❖ Better flue gas analyzers
❖ Better burner management systems and controls
❖ IIoT-Industrial Internet of Things
  ▪ Sensors
  ▪ Advanced analytical capabilities
CFD Modeling of Heaters

Existing Case with Vertically Fired Burners

Proposed Case with Inclined Firing System

Height in Feet

May 22, 2017

www.heatflux.com
Thank you very much!

www.heatflux.com