Process Design & Engineering Module

Training Title – **Fired Heater Design**

INGENERO

Excellence Through Insight

FIRED HEATERS

- Fired heaters provides high temperature energy, where steam may not be economical or viable
- Fired heaters are similar to boilers
- Fired heaters, boilers and Electric power provide prime energy
- Fired heaters are large fuel consumers and major sources of emission

FIRED HEATERS

When fired heaters are used:

- Steam is the primary heating medium for heat exchangers but it has a upper temperature limit due to the corresponding pressure levels required
- 40bar steam is at 250C and can only heat fluids economically to about 225C as an example.
- For the next higher level for heat exchanger heating services is Hot Oil. These fluids are typically special and expensive chemicals that degenerate at temperatures above 370C. Heating fluids in heat exchangers to about 275C is about the limit
- For any fluid requirement above these temperatures or when a hot oil system is not economical, then a Direct Fired Heater is needed
- Many direct fired heaters are found in oil refineries. In petrochemical plants there are few applications for fired heaters and they are typically special designs

FIRED HEATERS

- Development: Open pan pot still to modern design
- Temperature: 300 to 1100°C & Duty: 0.5 to 150 MW
- Fire Box: Vertical cylindrical, Box, Cabin, Multi-cell
- Coils: Vertical, Horizontal, Arbor, Helical
- Service: Heater and Reactor (with or without catalyst)
- Firing: Single and Double Sided
- Burner: Floor or Hearth, End wall, Side Wall and Roof
- Draft: Natural, Forced, Induced and Balanced
- Others: Waste Heat, Air Pre-heater, Water Bath, Gas Turbine Exhaust WHRU
- Design: Heat transfer, fluid flow, combustion, refractory, metallurgy, structural

FIRED HEATERS GEOMETRY

Heat Exchanger VS Fired Heater

- Passes
  - Exchanger passes are the number of times flow pass along the length of the tube
  - Heater passes are the number of parallel fluid flow circuits
- Tube Sizes
  - Exchangers use small diameter tubes ¾″ and 1″
  - Heaters use nominal pipe sizes from 3″ up to ~10″
- Data Sheet Information
  - Exchangers are well defined by TEMA designation and applicable Code (ASME for instance)
  - Heaters have great degrees of variability in design and API 530/560 design requirements
- Design Criteria
  - Exchangers are designed by determining the overall HTC and the LMTD
  - Heaters are designed with a Heat Flux selected based on experience with the process fluid

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FIRED HEATERS GEOMETRY

- Heat transfer coil : CS, C-Mo, Cr-Mo, Cr-Ni
- Coil: Plain & Extended Surface
- Convection Section: Rectangular box on top / side of fire box
- Radiant Section: Vertical cylinder or rectangular box
- Heat transfer:
  - Direct radiation from flame (minor)
  - CO_2 /H_2O components of flue gas (major)
  - Radiation from refractory (minor)

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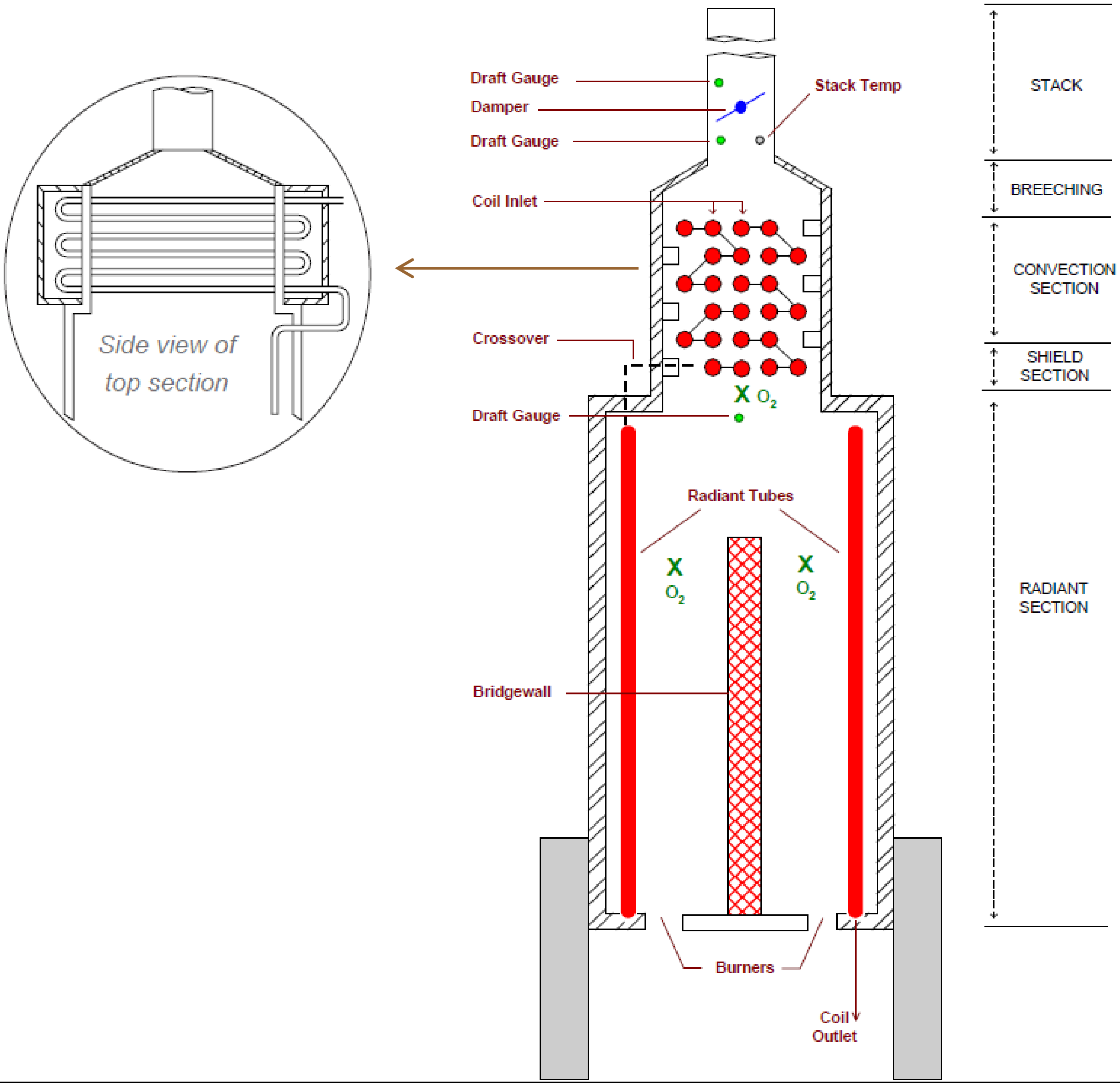
FIRED HEATERS GEOMETRY



Major Sections of Fired Heater

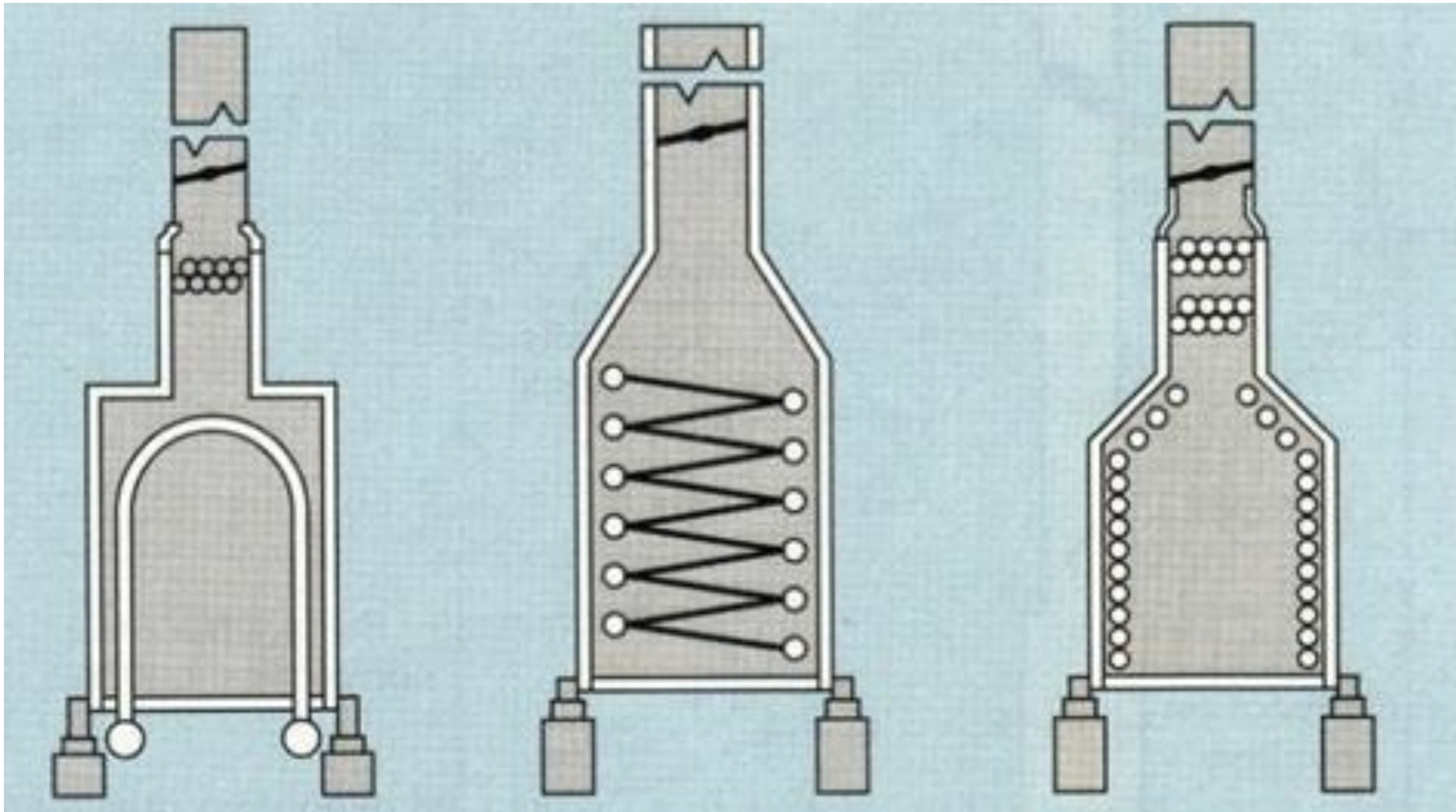
- Radiant section - controls the heat released from the burner flames to the process inside the tubes using radiant heat transfer
- Convection section - recovers some of the remaining heat from the flue gases leaving the radiant section to process or other fluid service tubes using convection heat transfer
- Breeching or ducts - collect the flue gases into a exit pipe (stack)
- Stack height - provides the draft to maintain the entire flue gas side of the heater below atmospheric pressure
- Burners - provide the high temperature radiant heat and hot flue gases to transfer heat to the tubes

FIRED HEATERS GEOMETRY

- **Basic Components**
  - Refractory Lining
    - Heat absorbing surfaces
  - Radiant Section
    - Receives heat from flame / hot flue gas
    - Houses burners
  - Convection Section
    - Recovers heat from hot flue gas

FIRED HEATERS GEOMETRY

- **Types of Heaters**
  - Process
    - Reaction Type
      - Visbreaker Heater
      - Thermal cracker
      - Coker Heater
    - Non-reaction Type
      - Crude Oil Heater
      - Reboiler Heater
      - Feed Heater
  - Construction
    - Vertical
    - Box
    - Cabin

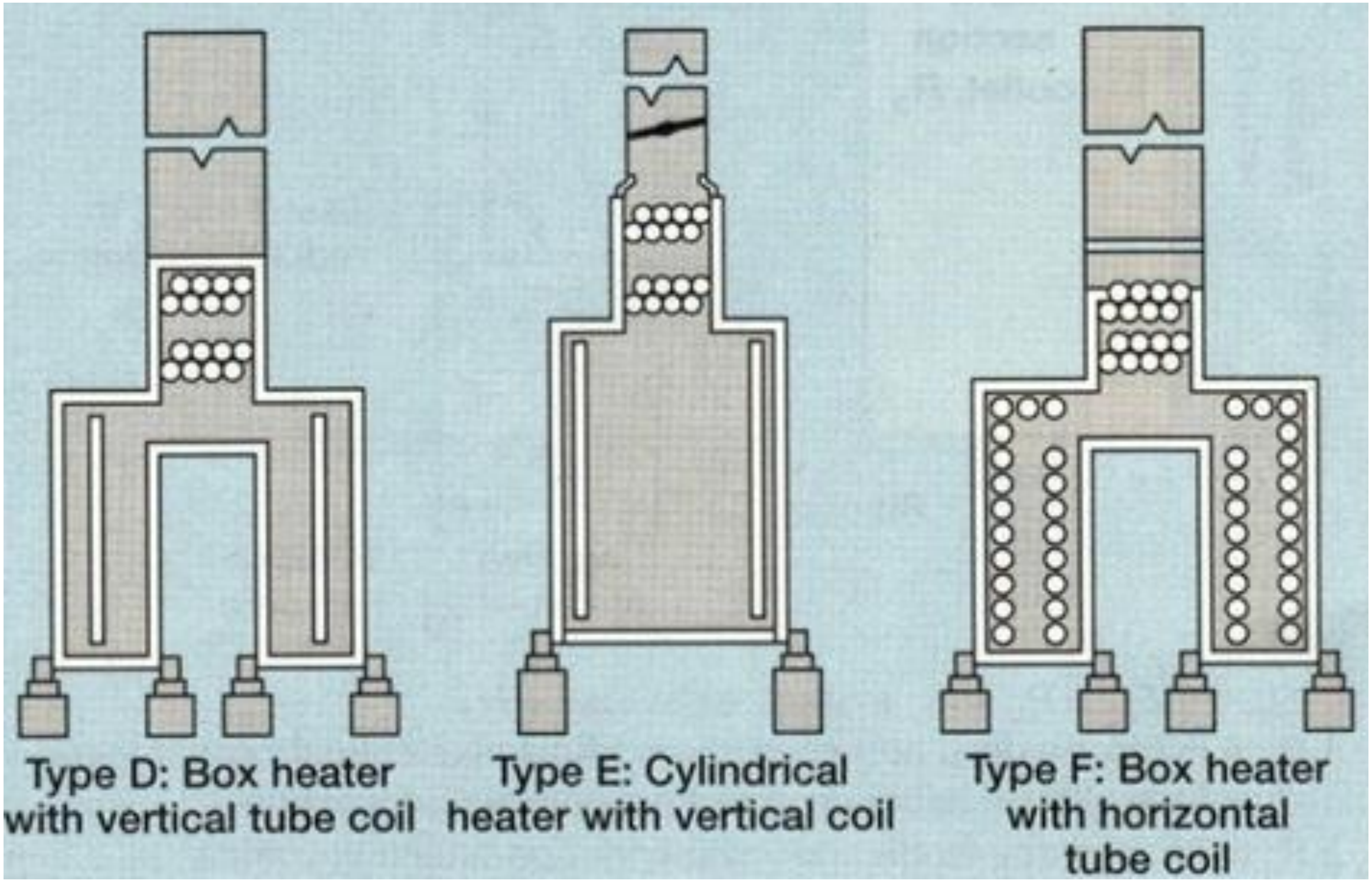


Type A: Box heater with arbor coil

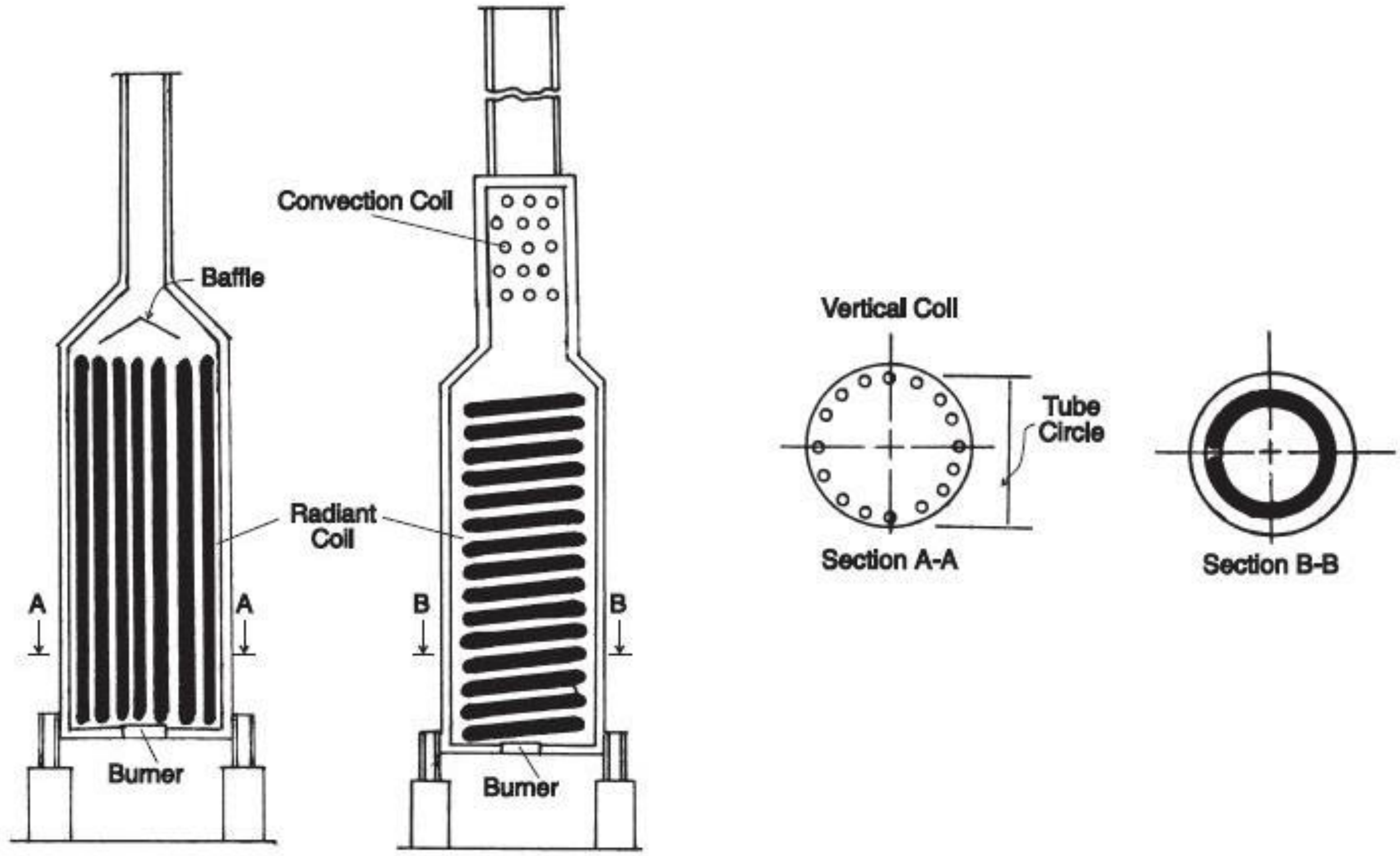
Type B: Cylindrical heater with helical coil

Type C: Cabin heater with horizontal tube coil

TYPES OF FIRED HEATERS



Vertical Cylindrical Fired Heaters

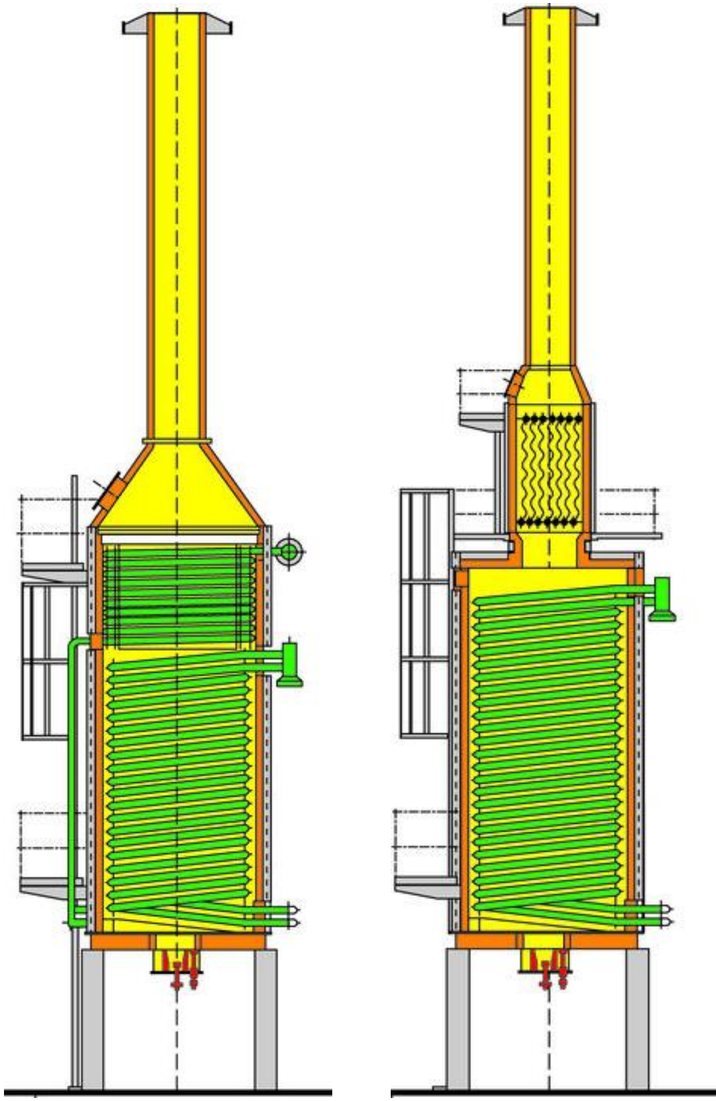


Vertical-cylindrical, all radiant

Vertical-cylindrical, helical coil, with convection section

Vertical Cylindrical with Helical coils

- Normally used for < 2.5 MW duty
- Generally all radiant type, no convection section
- Low efficiency, about 60%
- Normally Start-up heaters
- Olden designs may have baffle plate on top of radiant section
- Coil removal by removing the stack
- Good for free draining in molten salt service



TYPES OF FIRED HEATERS

Vertical Cylindrical with Helical coils

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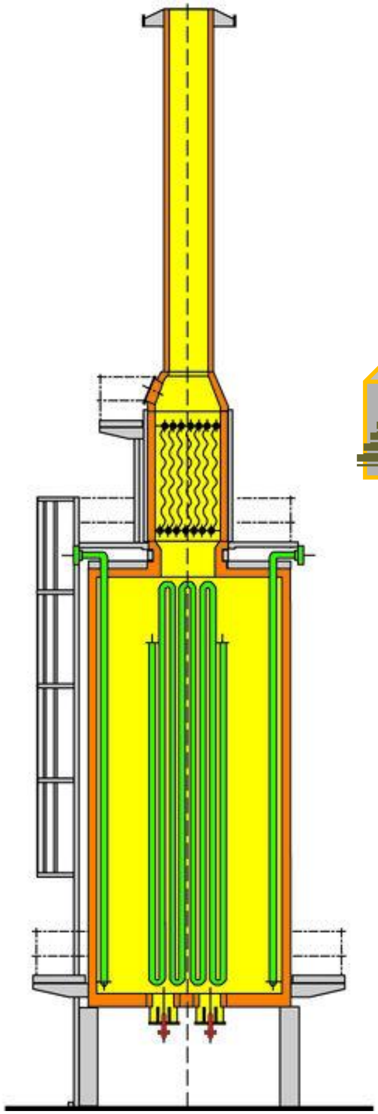
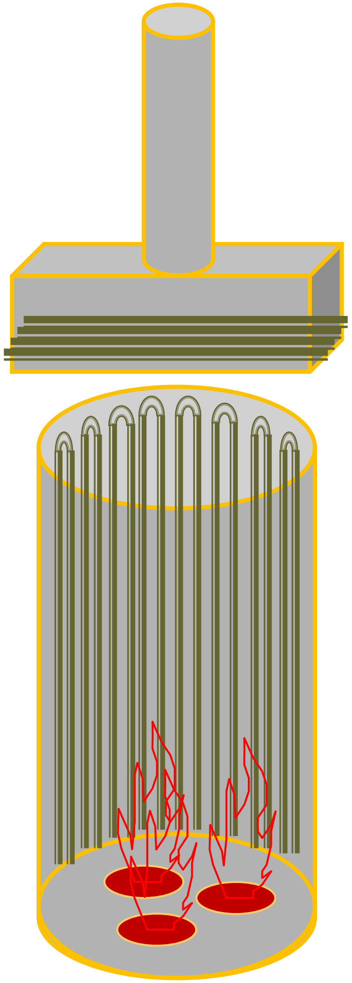
TYPES OF FIRED HEATERS

Vertical Cylindrical with Vertical tubes

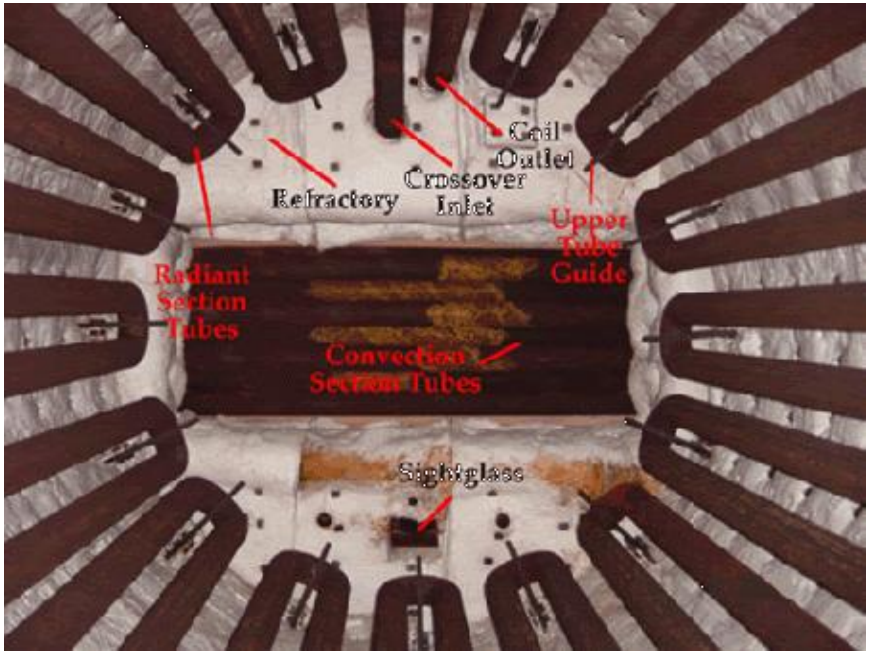
- General service and Most common type - 3 –30 MW duty
- Good efficiency
- Usually floor fired vertically up by burners in a circle on floor
- Low plot space / cost
- No separate tube pulling plot area
- Above 30 MW duty fire box is too tall
- Can accommodate more coil passes





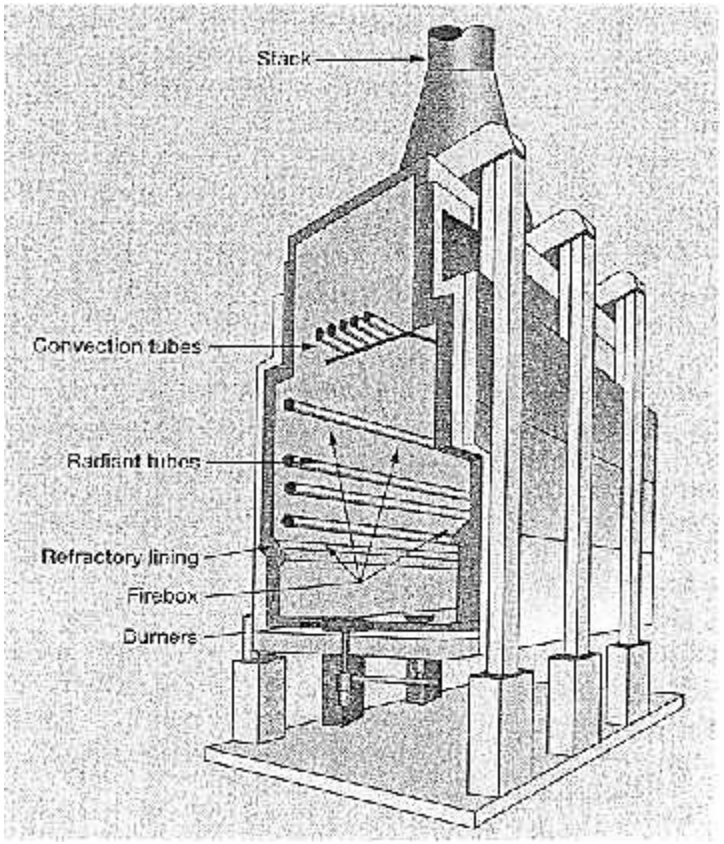
Vertical Cylindrical with Vertical tubes

Vertical Cylindrical with Vertical tubes



Box Type Heaters – Horizontal Tubes

- With Horizontal hairpin coil in fire box along the wall
- General service, common type for large heat duty, >30 MW duty
- Good efficiency
- Burners in a lane on floor, side or end wall
- Require separate tube pulling plot area
- Can accommodate 2,4,6 coil passes



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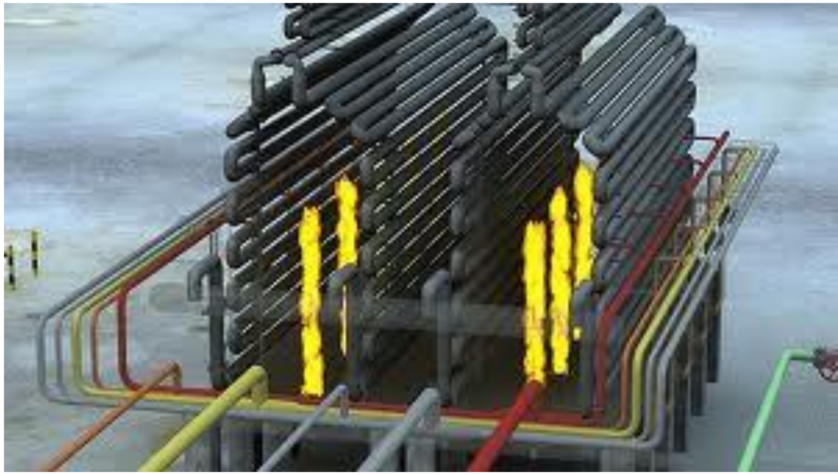
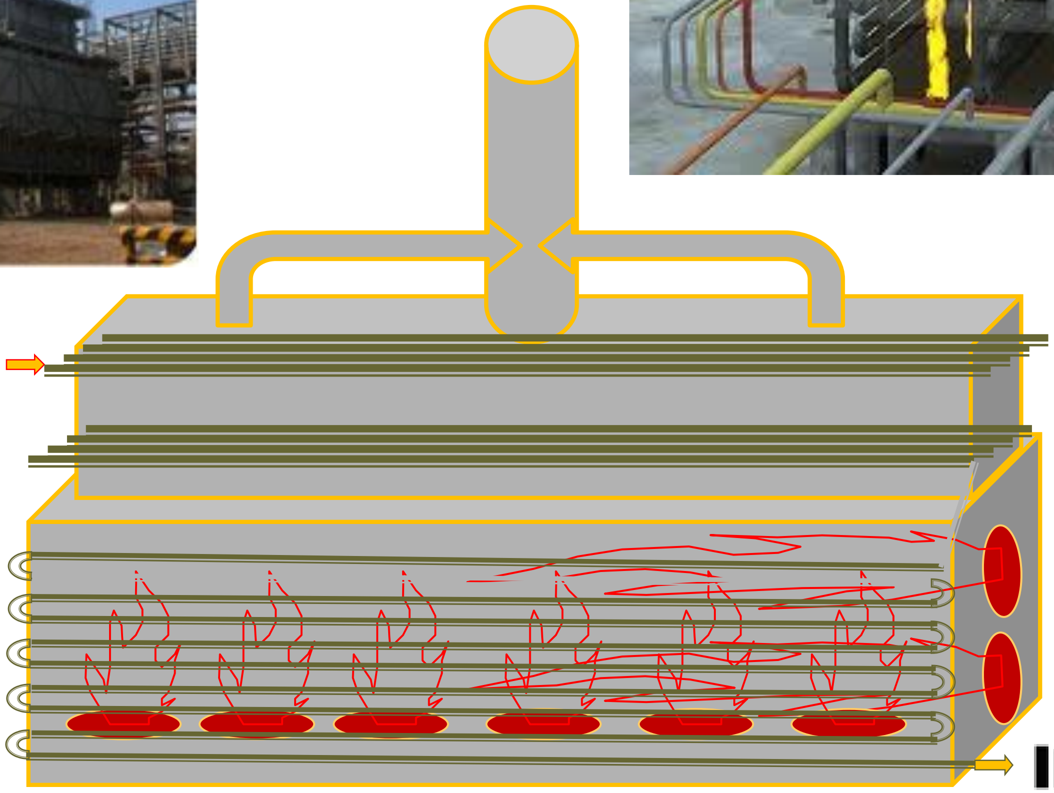
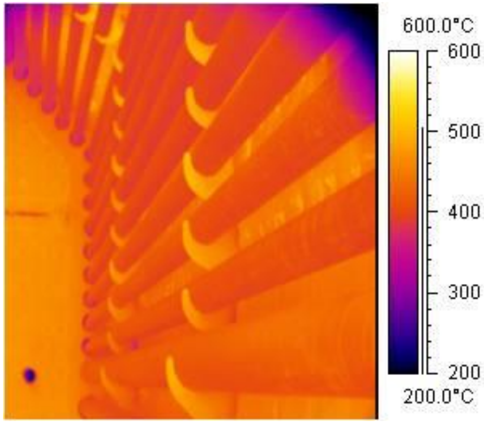
Box Type Heaters – Horizontal Tubes





Box Type Heaters – Horizontal Tubes



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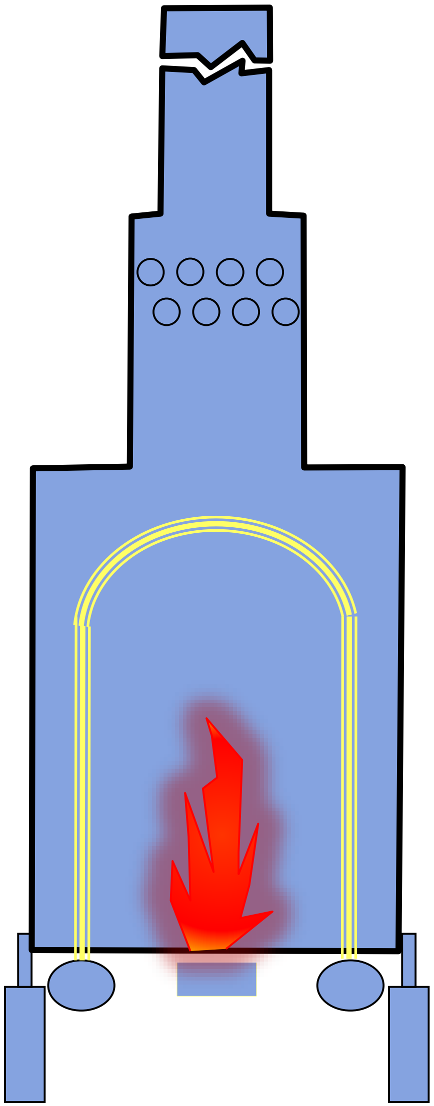
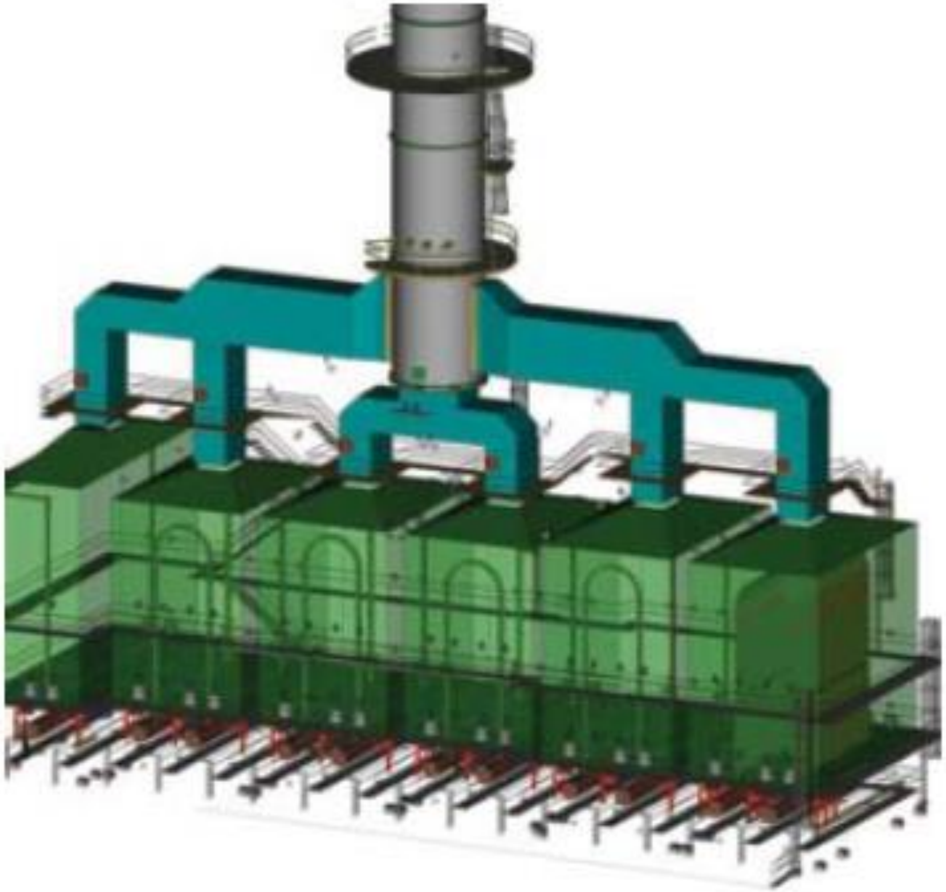
Box Type Heaters – Arbor Tubes

- Good for low pressure drop high capacity vapour heating service such as Reactor (Platformer / Cat Reformer) feed heaters
- Arbour coils avoid return bends and provide many parallel flow paths – Low Pressure Drop
- Two arrangements of manifolds are used, top mounted manifold (inverted arbor, U) and bottom mounted manifold (arbor, wicket)
- Burners in a lane on floor
- Single and double firing
- Do not require separate tube pulling plot area



TYPES OF FIRED HEATERS



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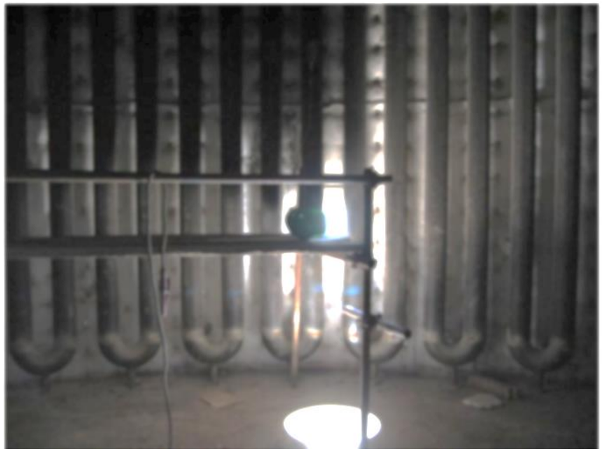
TYPES OF FIRED HEATERS

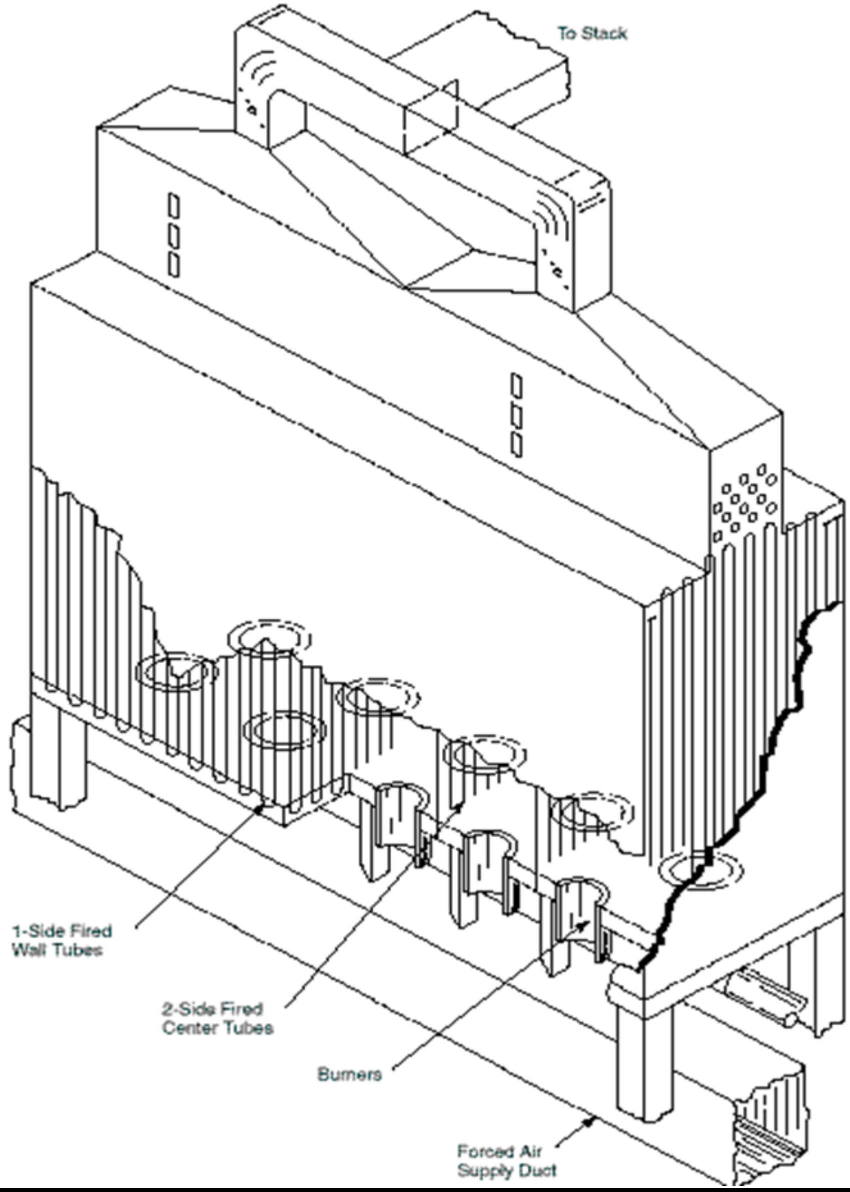
Box Type Heaters – Vertical Tubes

- With Vertical hairpin coil in fire box
- General service and common type >30 MW duty
- Good efficiency
- Burners in a lane on floor, side or end wall
- Single and double firing
- Do not require separate tube pulling plot area
- Can accommodate more number of coil passes



Box Type Heaters – Vertical Tubes

TYPES OF FIRED HEATERS



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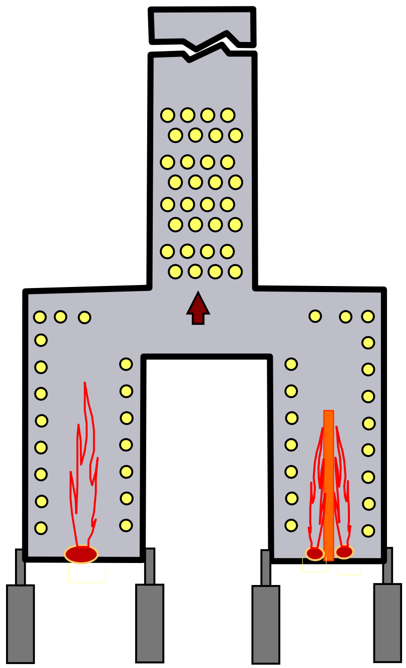
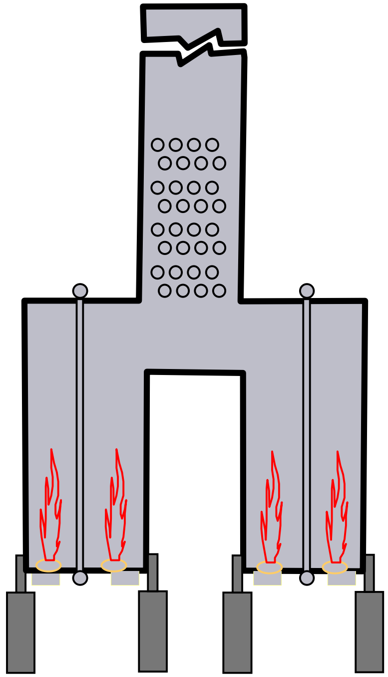
Box Type Heaters – Twin cells or Multi Cells

- For large duty, 30-75 MW, such as Crude Heaters
- Bridge wall fired for Delayed Coker and Visbreaker
- Zoned firing allows controlled cracking and soaking
- Double fired twin cells for fired reactors, such as EDC Cracker. Tubes in center and burners on either side
- Multi-cell heaters with vertical tubes are used for large crude heaters

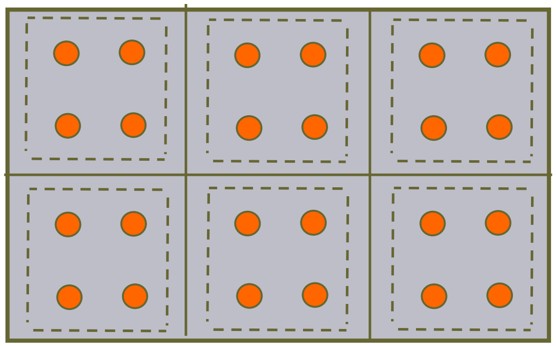
Box Type Heaters – Twin cells or Multi Cells



Twin Cells – Horizontal tubes

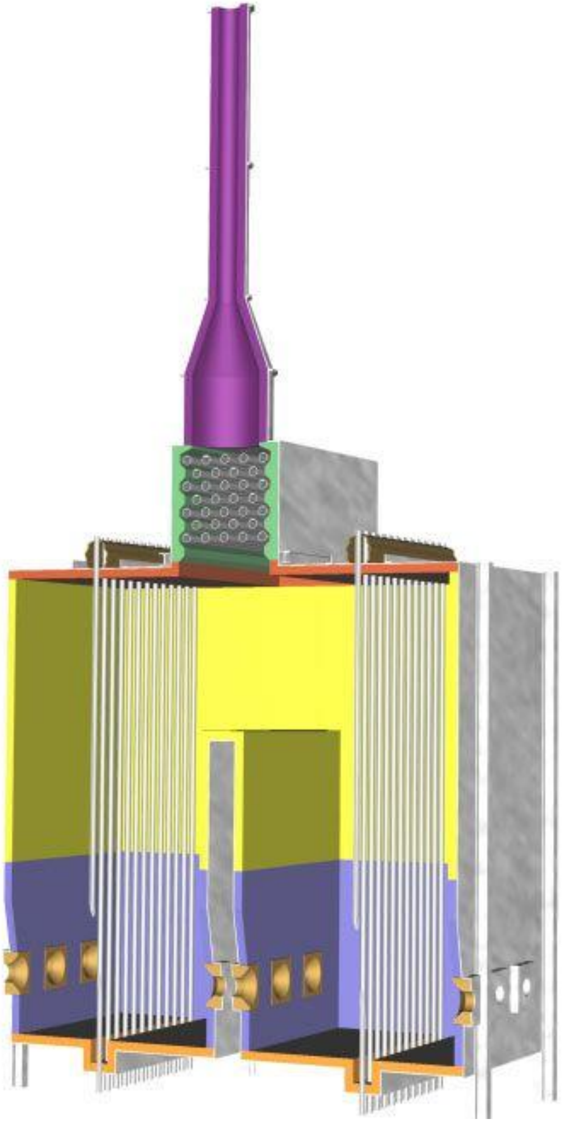


Twin Cells – Vertical tubes



Multi Cells – Vertical tubes

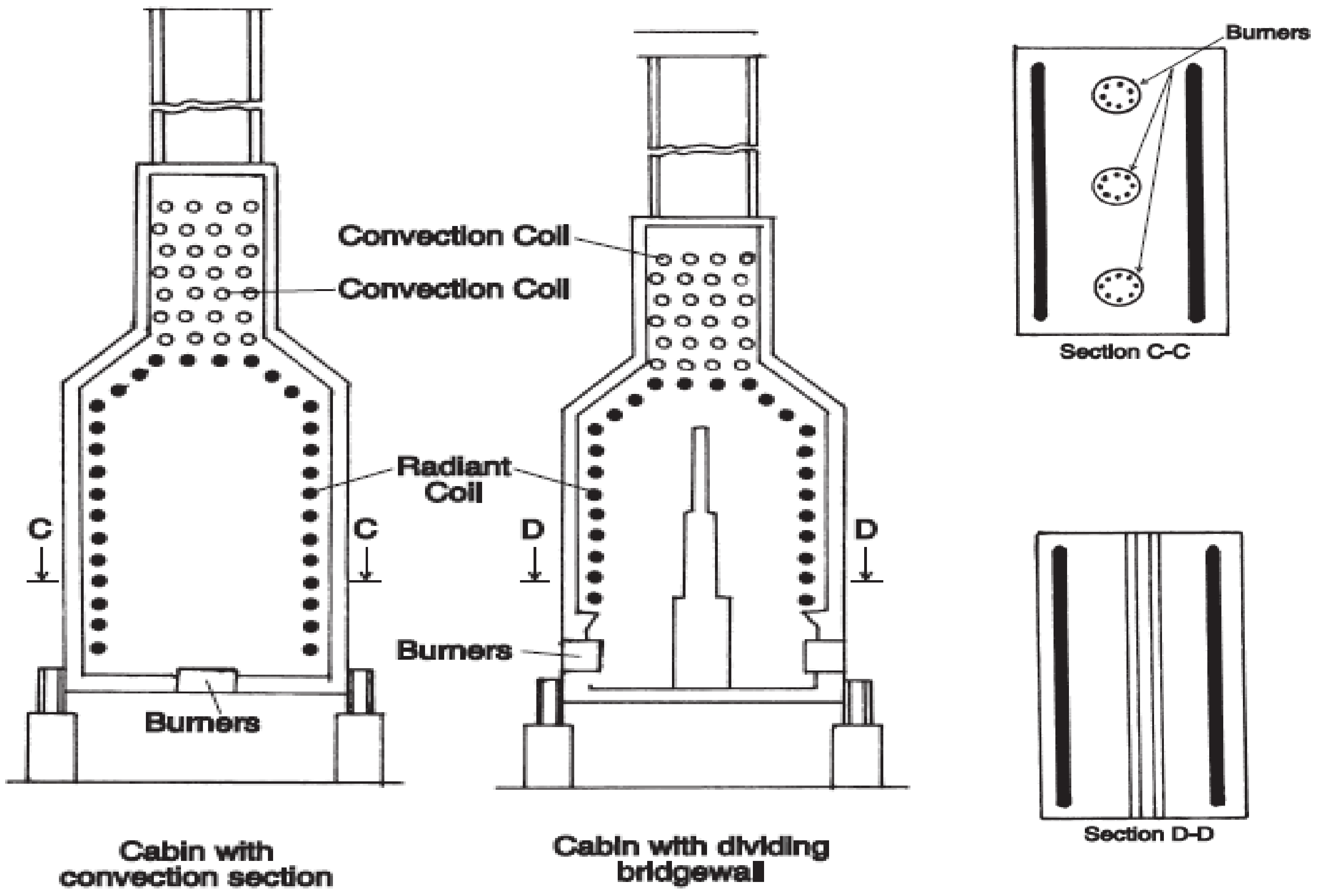
Box Type Heaters – Twin cells or Multi Cells



TYPES OF FIRED HEATERS

Box Type Heaters

Cabin Type Heaters



Cabin Type Heaters

- Large duty, 60 MW
- Single cell Crude Heater
- Box heaters have flat arch; Cabin heaters have sloped arch

Cabin Type Heaters

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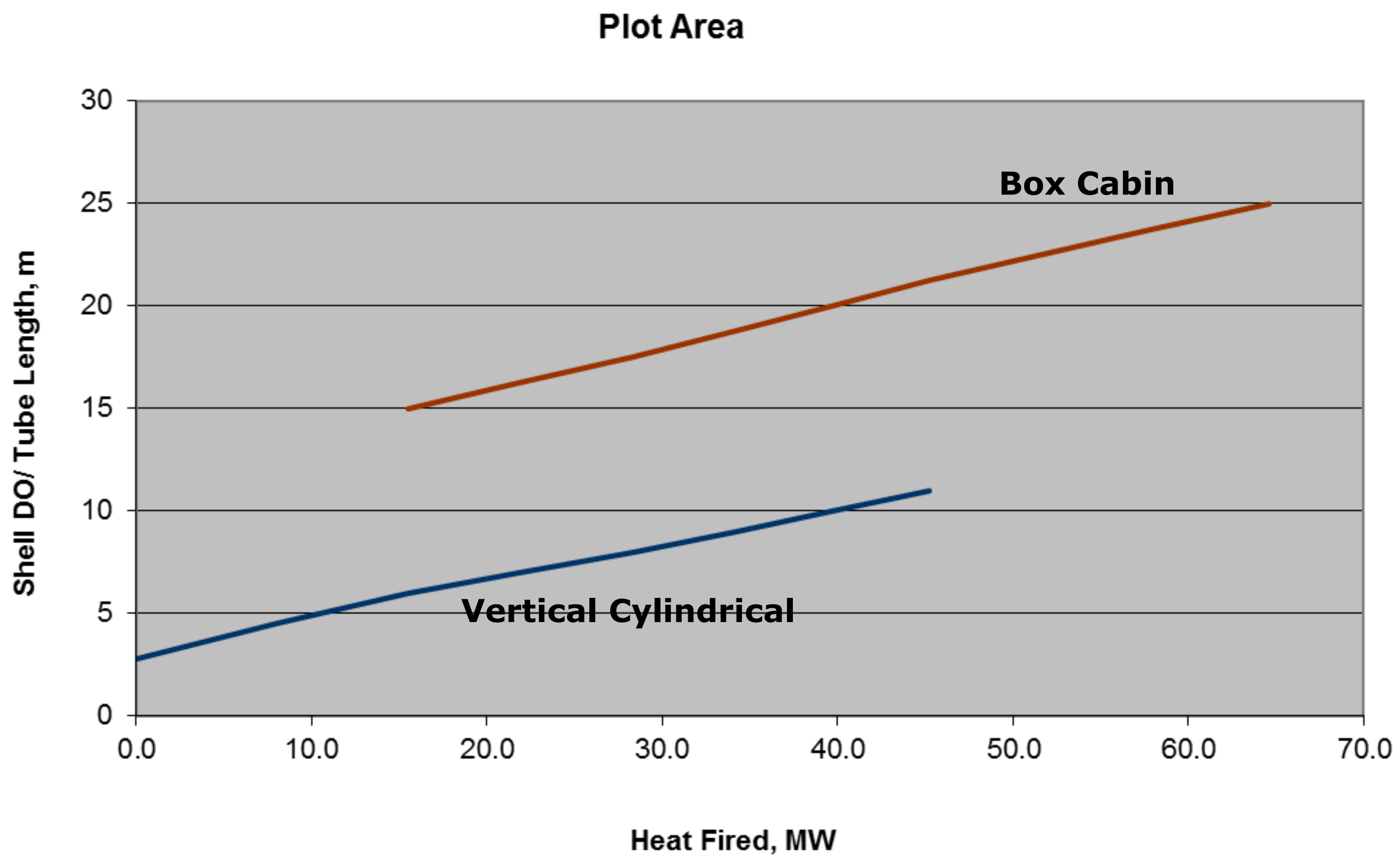
PLOT SIZE



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Refinery Fired Heater

Conditions	Crude	Vacuum	Visbreaker	Coker	FCC Charge
T in/ out, °C	270-380	350-400	350-400-500	350-500	270-370
ΔP, bar	10-12	6-8 mm HG	20-25	30-35	3
Vapor in/out, %	30-50	20-30	30-80	50-80	-
Flux, kW/m^2	40	25	25	32	32
Duty, MW/ TPA	60	40	44	40	32
Type	Box / Cabin	Box / Cabin	Twin Cell	Twin Cell	VC

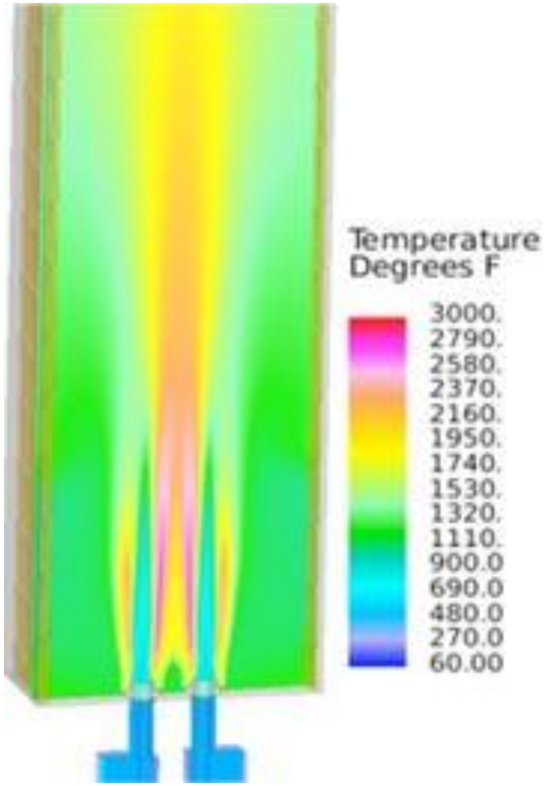
Reaction Fired Heaters

- Usually double fired, to ensure uniform heat transfer, minimum metal temperature and to avoid coking
- Multi-level burners to match firing rates to changing reaction demands
- **Visbreaker**: Mild cracking of heavy ends to produce light ends
- **Delayed Coker**: Severe cracking of heavy ends to produce light ends
- **EDC Cracker**: Severe cracking of feed
- **Naphtha Cracker**: Severe cracking of feed
- **Steam: Hydrocarbon Reformer**: Conversion of HC and steam to produce H2, CO2, CO in the presence of catalyst

FIRING MODES

Different Firing modes:

- Vertically upward floor firing is common
- End wall firing
- Side wall firing
- Top – vertically downward firing



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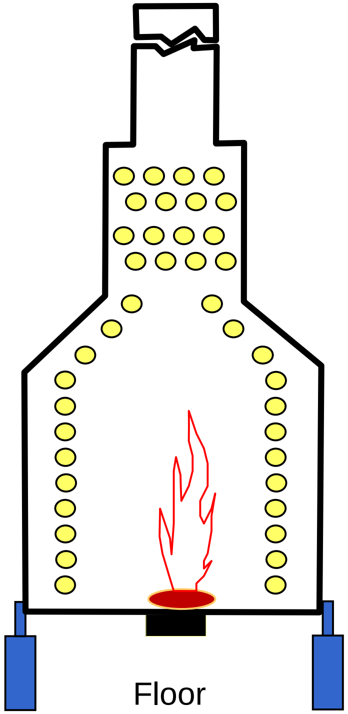
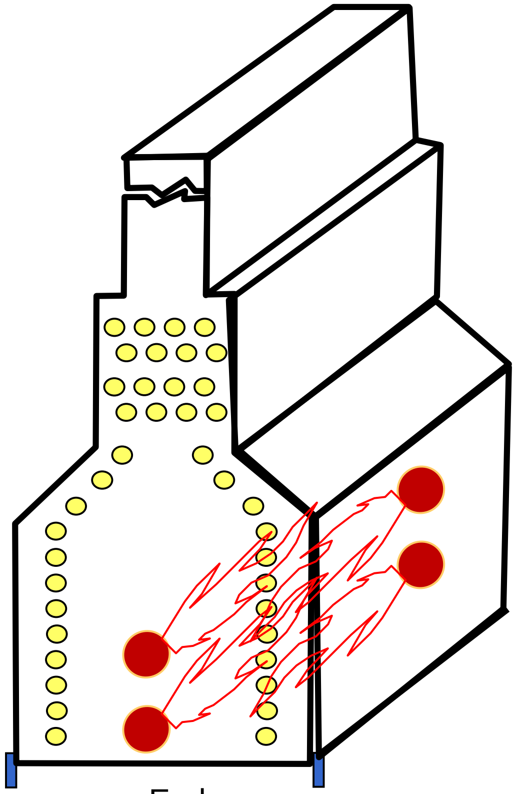
FIRING MODES

- Floor firing, vertically up is common
- End wall firing to have minimum number of burners with long flames. Eliminates elevated heater floor



Floor



End

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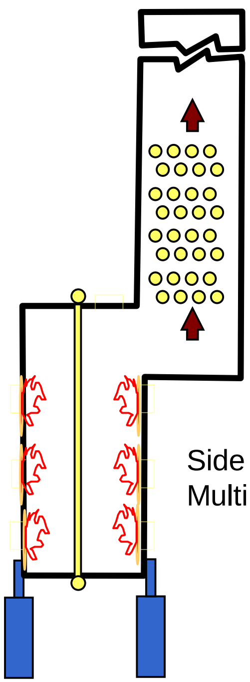
FIRING MODES

Vertically Upward Floor Firing

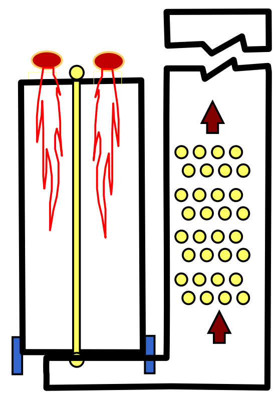
End Wall Firing

FIRING MODES

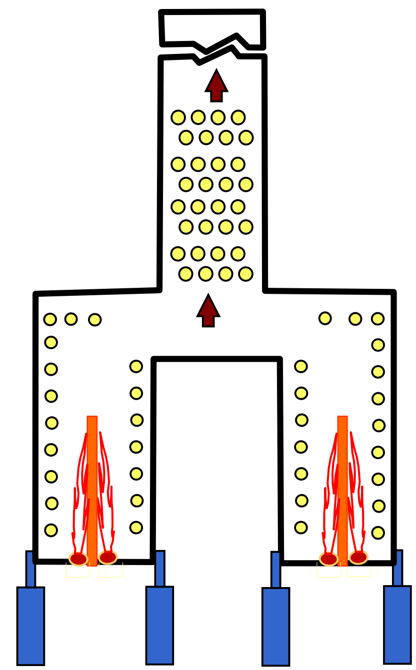
- Top-fired and side wall-fired as in reactor heaters
- Fire on a central wall (bridge wall) for more uniform heat in Delayed Coker / Visbreaker



Side double sided
Multi level



Top double-sided



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FIRING MODES

Side Wall Firing

Top Firing

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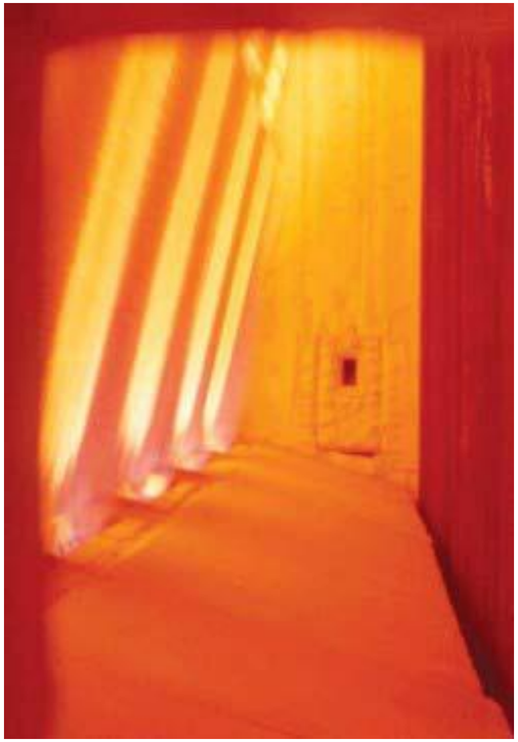
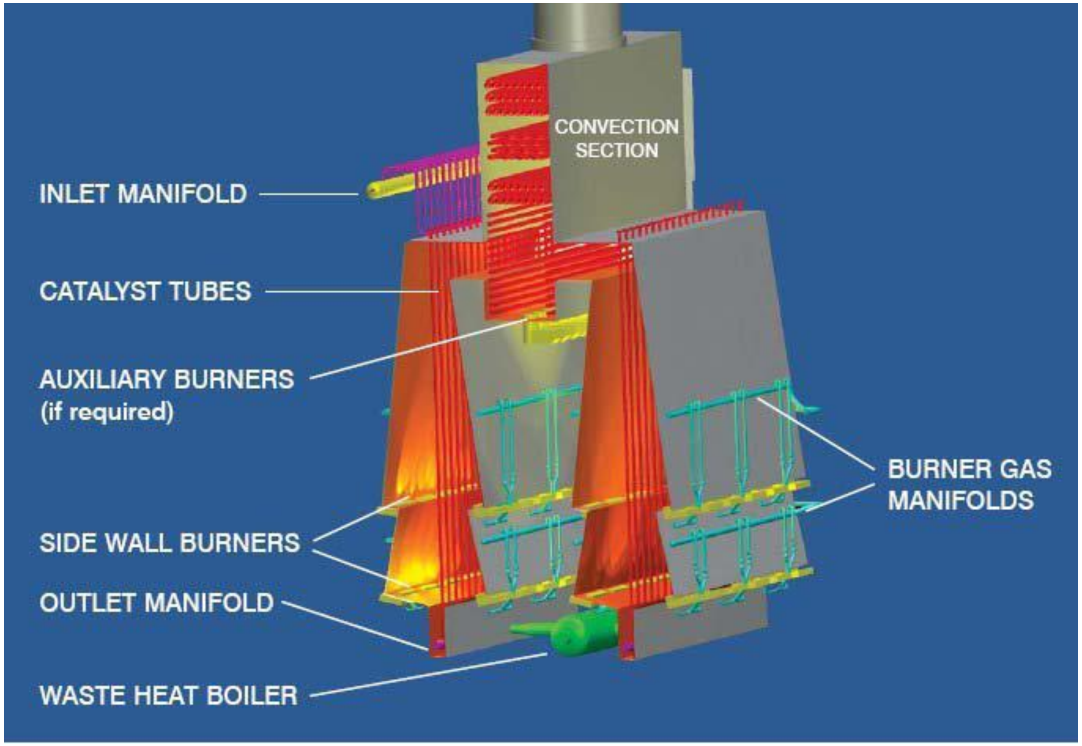
Multi level vertically upward firing



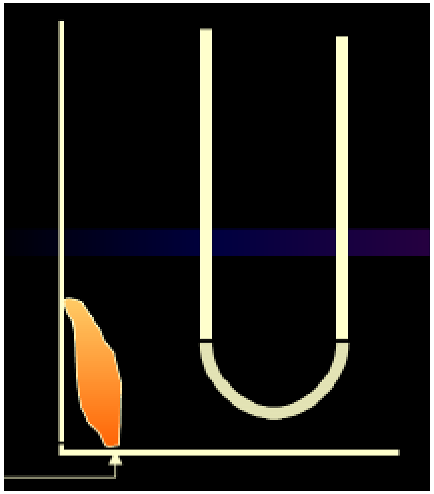


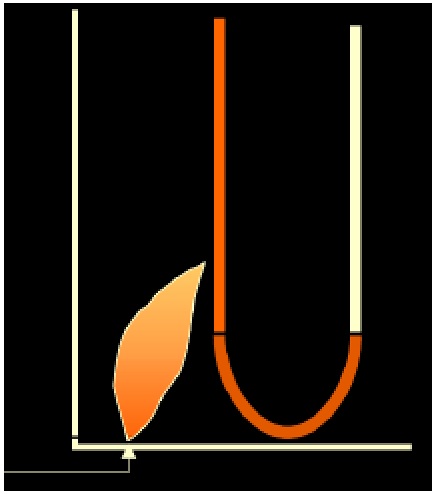
BURNERS

- Combustion in the firebox by mixing fuel and air
- Burners should be selected to provide stable combustion with the following characteristics:
  - Ability to handle wide range of fuels
  - Predictable flame patterns for all fuels and firing rates
  - Good turndown ratio between max & min firing rates
  - Low noise and NOx levels
  - Provision for safe ignition, easy maintenance
  - Low excess air operation
- Fuel gas pressure and air draft provide energy for mixing fuel gas and combustion air
- Mixing of fuel and combustion air occurs in the gas phase, all liquid-fuel burners use atomizing devices to break up the liquid mass into micron-size droplets

BURNERS

- Burner tiles provide a hot surface for stabilizing and sustaining ignition and provide a required shape flame
- Burners should be selected such that overall size of flame avoids flame impingement and local overheating of the tubes
- Uniform heat distribution within the firebox improves the performance of the fired heater
- Pilot burners provide a continuous ignition source
- Many installations use UV cells to monitor the failure of flame in pilot burners
- Large heaters have multiple burners





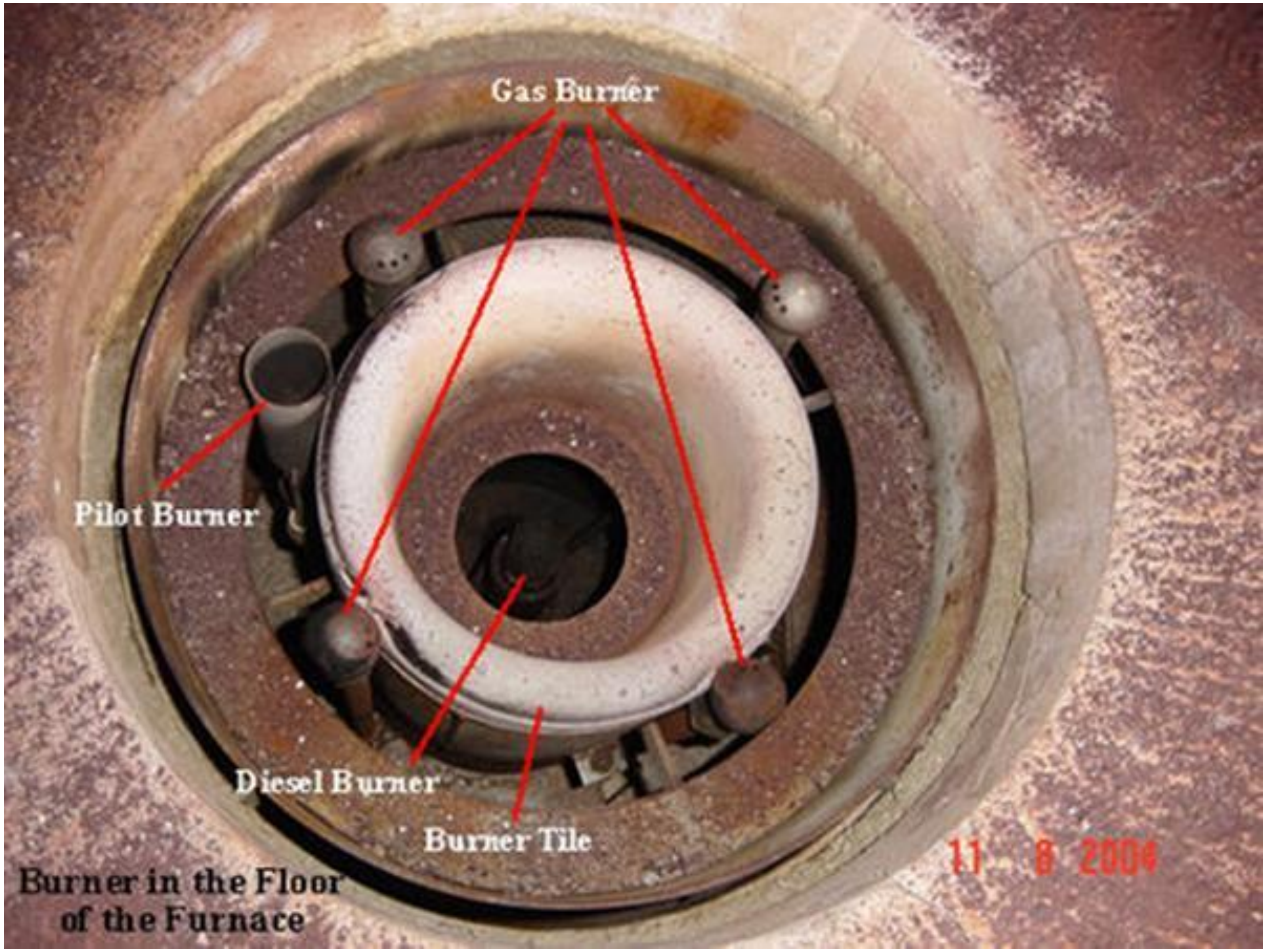
Burner Types & Accessories

- Gas - Raw Gas or Pre-mixed gas
- Inspirating pre-mix burners
  - Fuel gas flowing via a venturi pulls in the combustion air
  - Short dense flames that are not affected by wind gusts
- Raw gas burners
  - Part of combustion by a venturi. Rest via secondary air register
  - Larger turndown ratios, require lower gas pressures, and are also quieter
  - Most of the refinery burners are this type
- Oil
  - Mechanical spray for light oil
  - Steam atomization for heavy oil

BURNERS

- Low NOx burners
  - 0.05 Vs. 0.13 (conventional burners) lb NOx /MMBtu
  - Fuel and air are staged to reduce the flame temperature and excess air
- Radiant Wall burners
  - Flame spreads across the burner tile and the furnace wall refractory without any forward projection into the firebox.
- Combination gas and oil burners
- Burners with Pilot for 50 to 100,000 Btu/hr
- Draft
  - Natural or Forced or Induced or Balanced Draft
- With or without Air preheating
- Generally Noise: 100 to 110 dBA. Require noise attenuation plenums and orifice mufflers for 85 or 90 dBA levels

BURNERS



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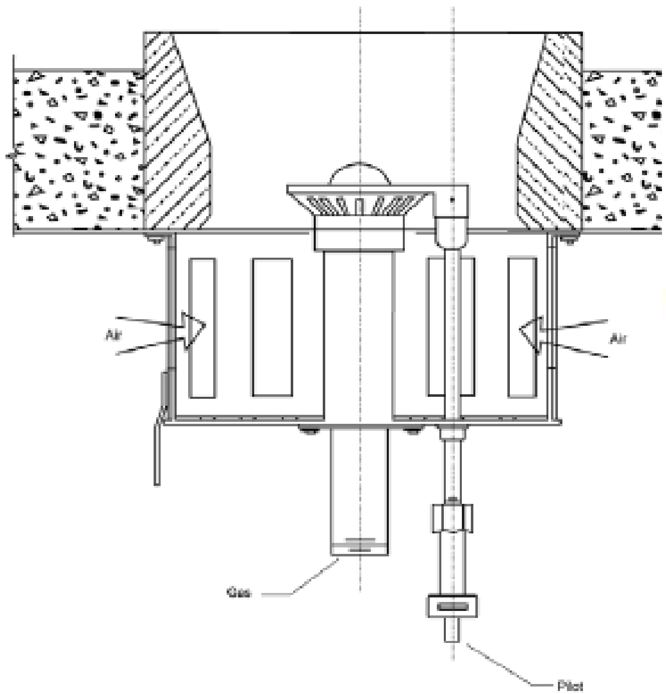
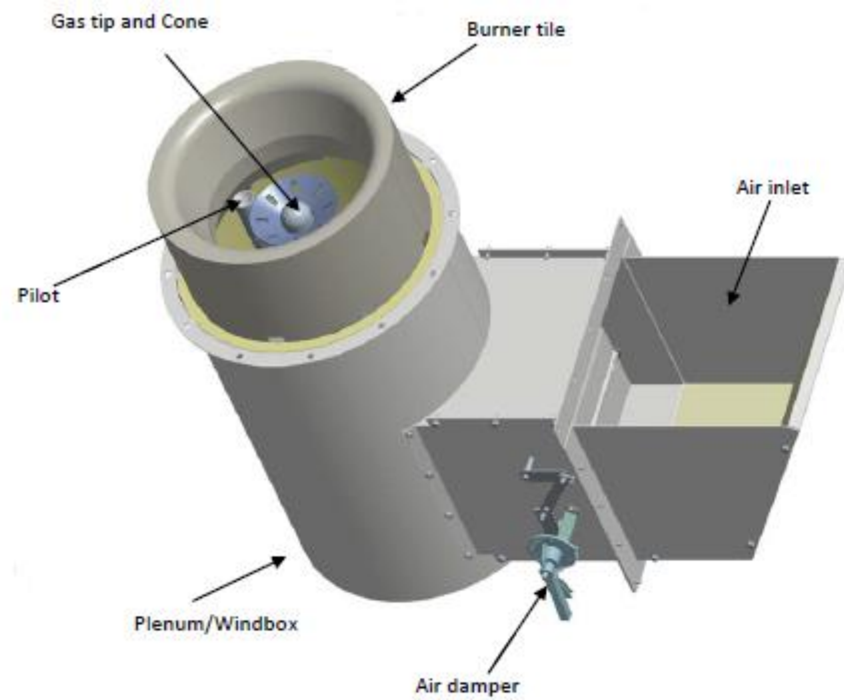
Raw Gas Burners





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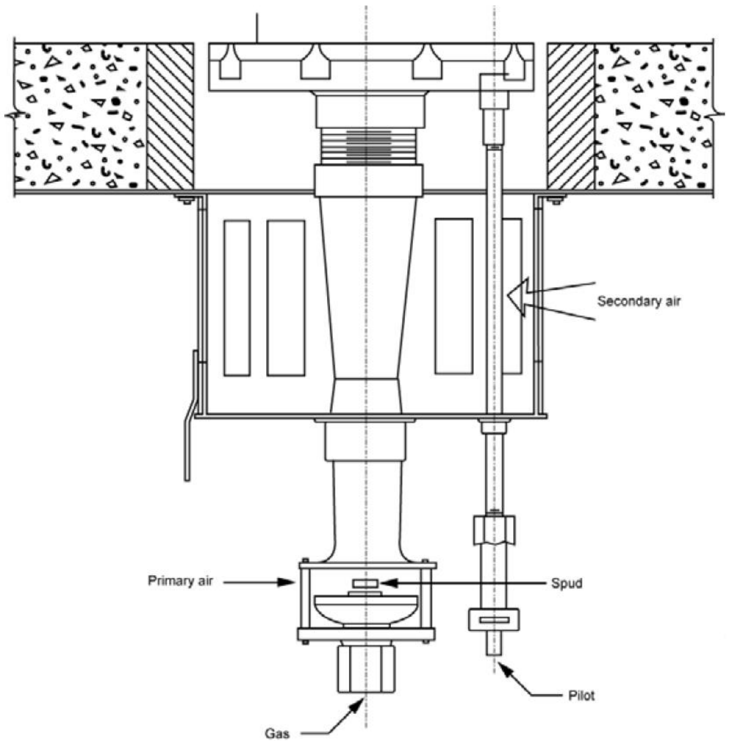
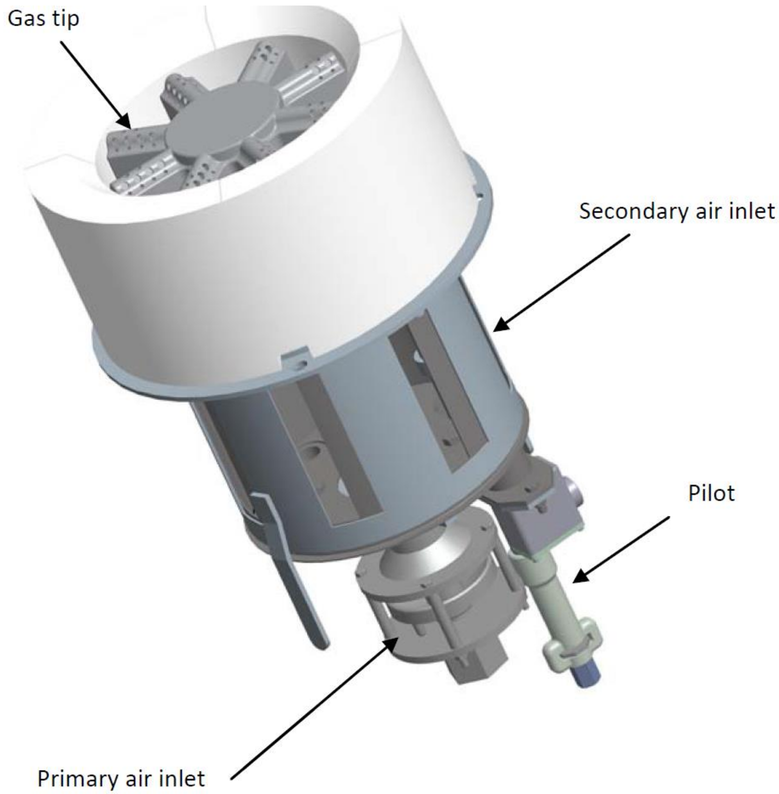
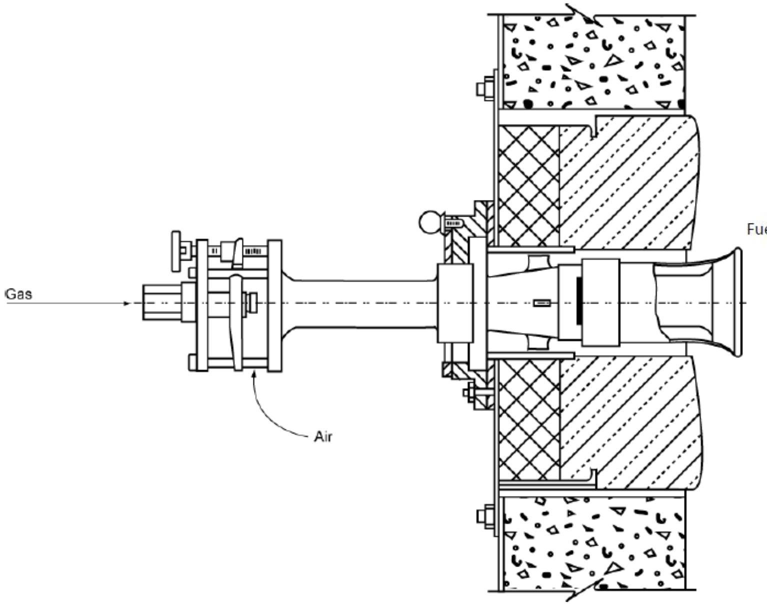
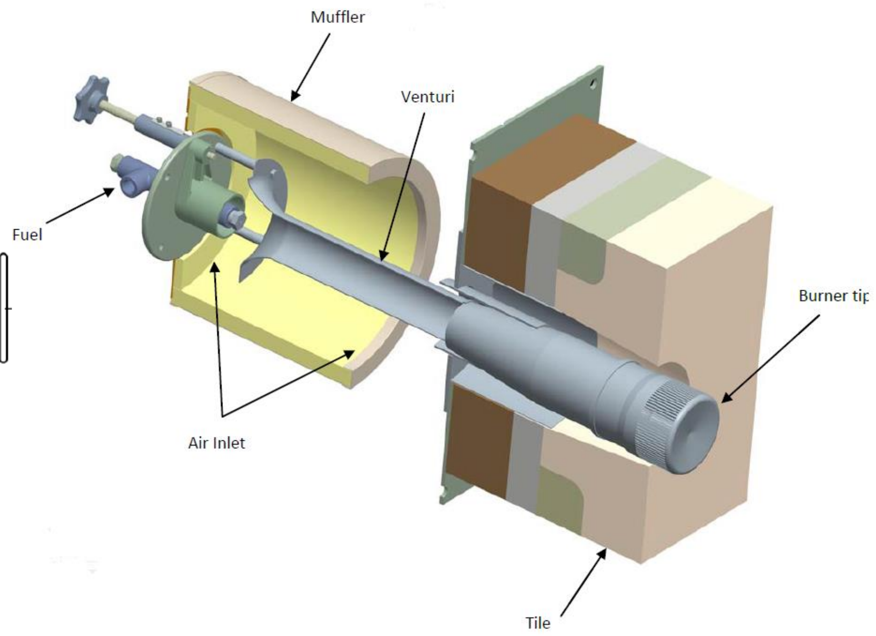
Premix Gas Burners





Radiant Wall Burners





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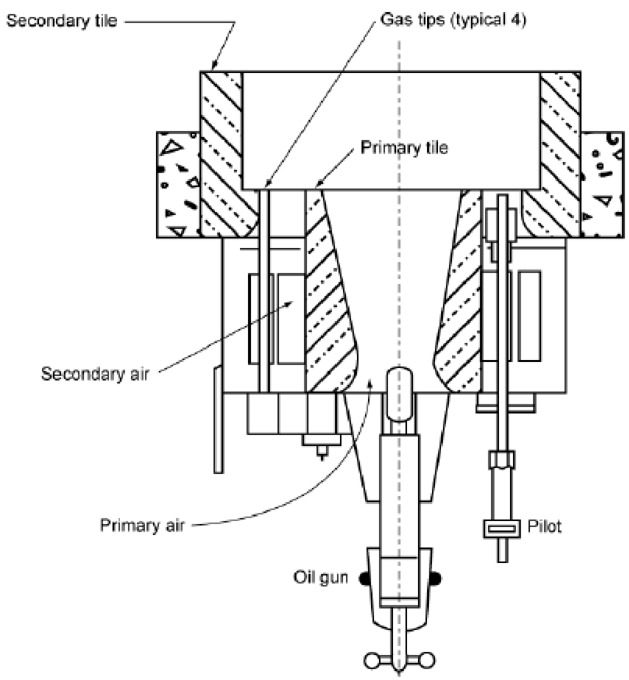
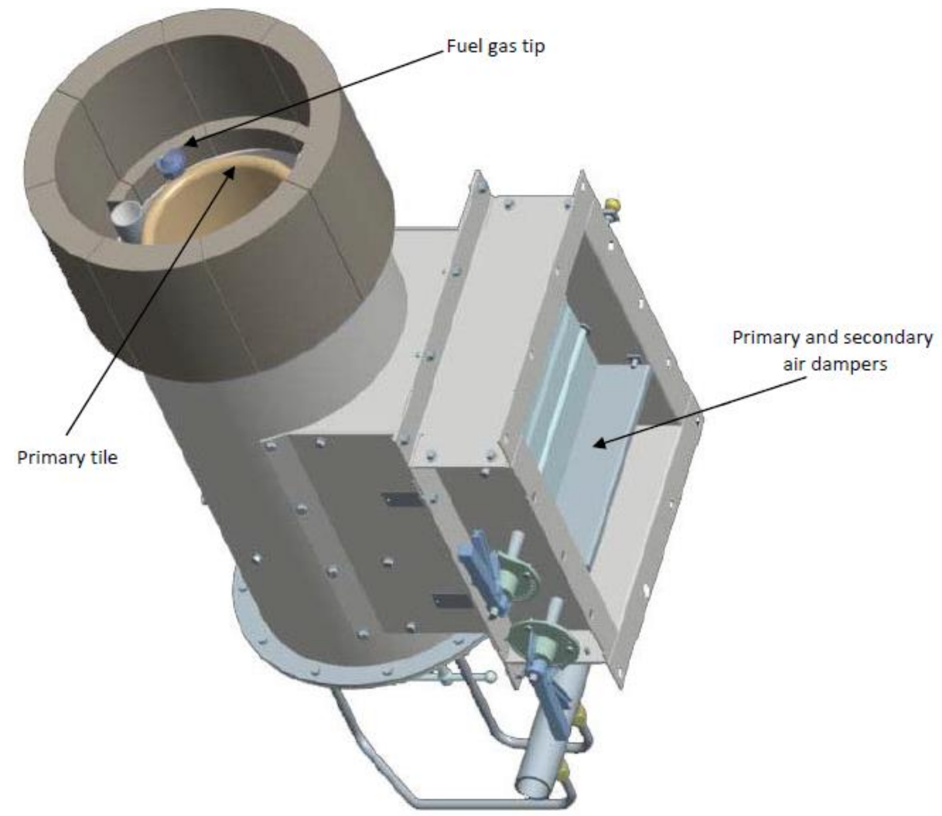
Combination Oil & Gas Burners





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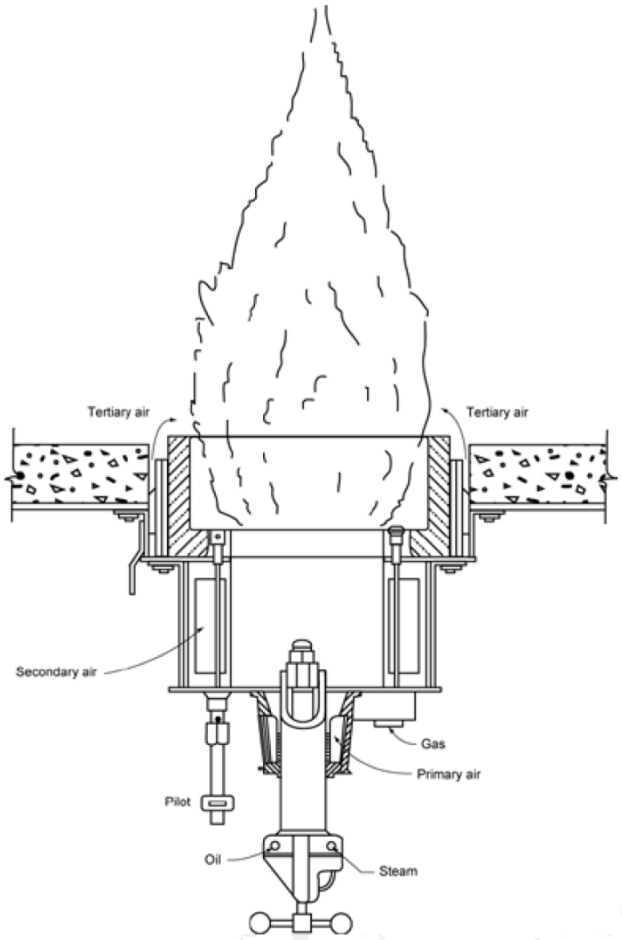
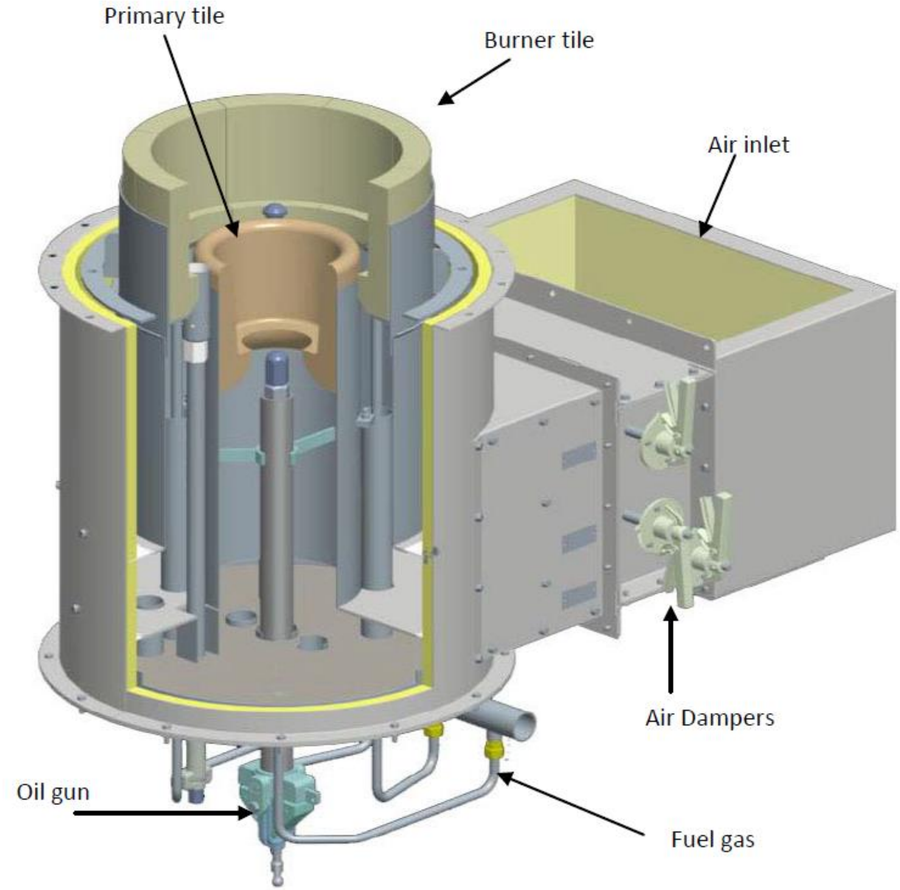
Low NOx Combination Oil & Gas Staged Burners





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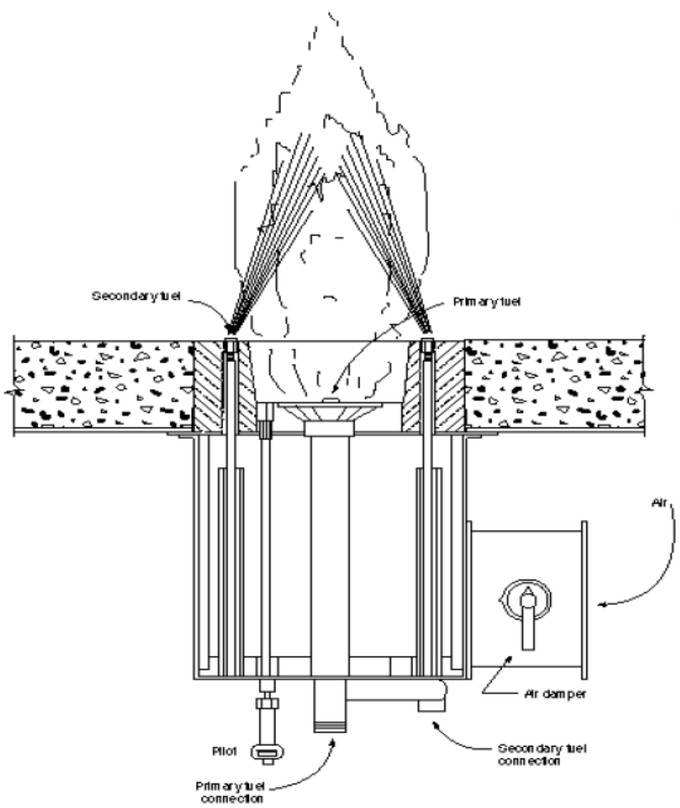
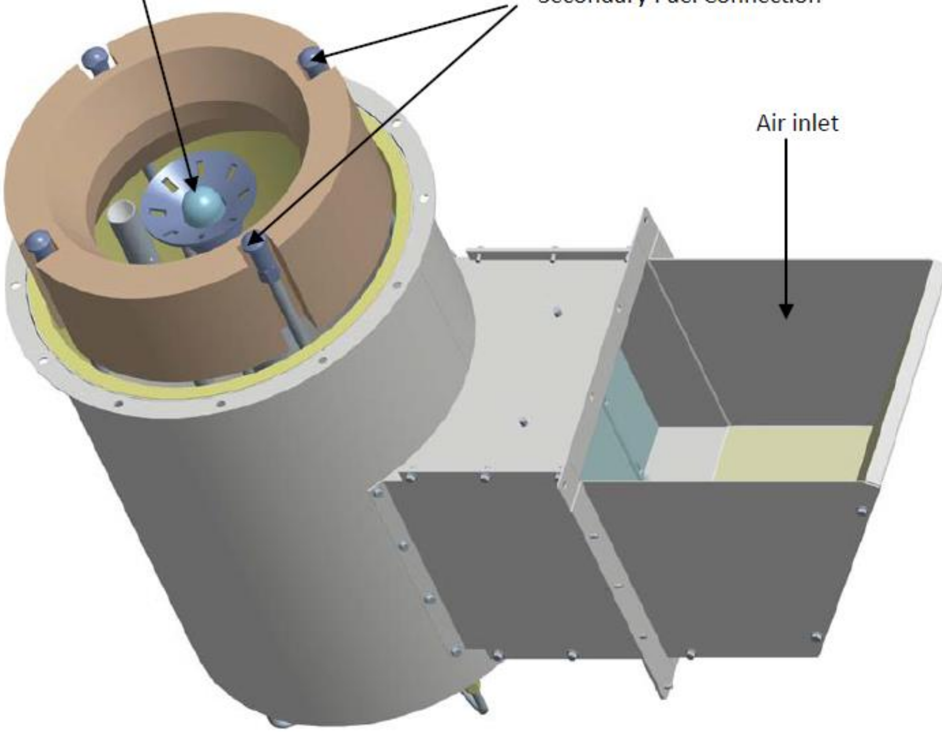
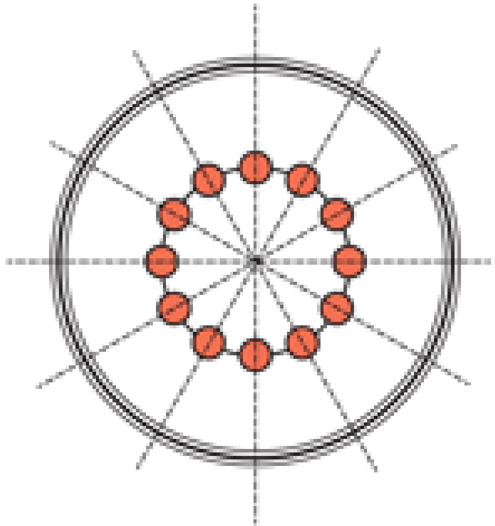
Low NOx Gas Staged Burners

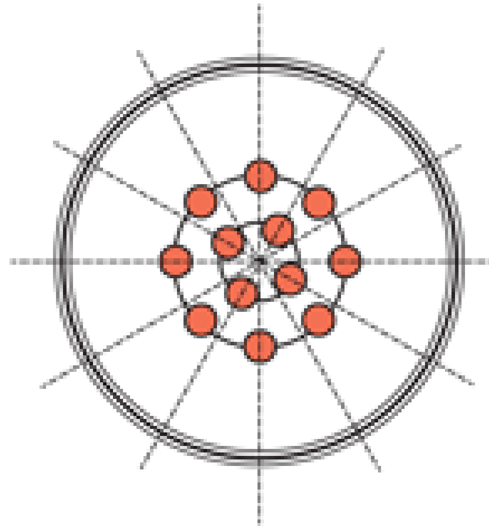




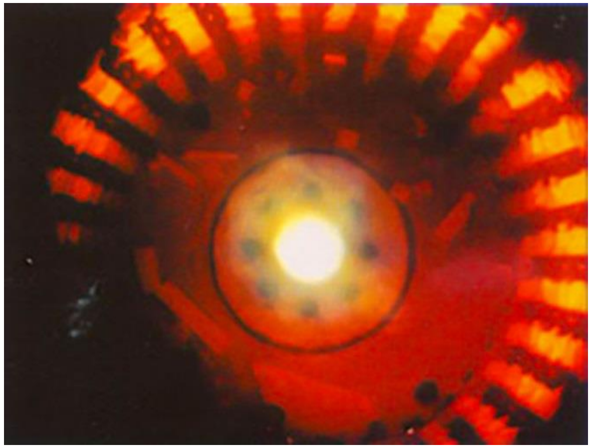
BURNERS



Burners in one circle

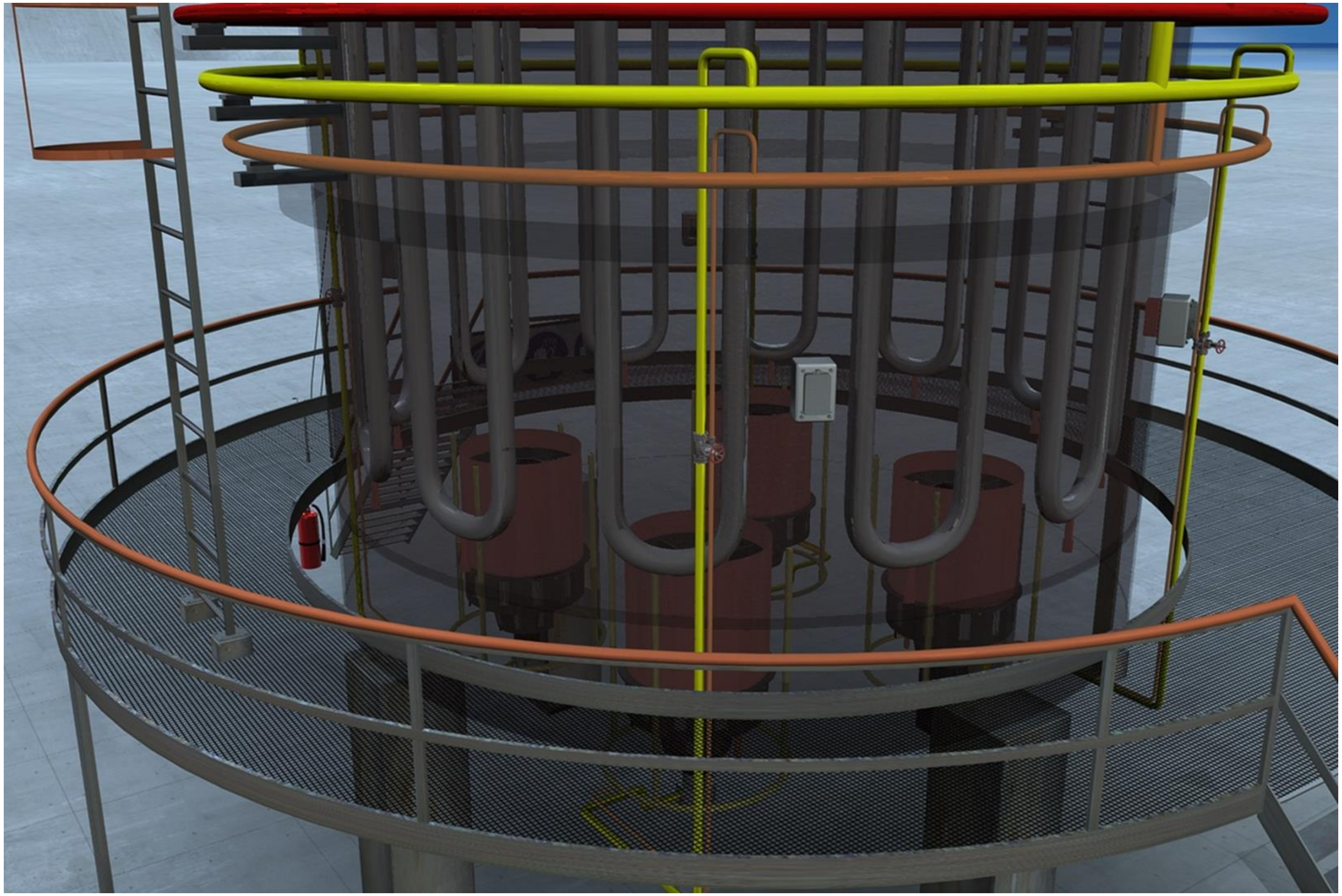


Burners in two circles

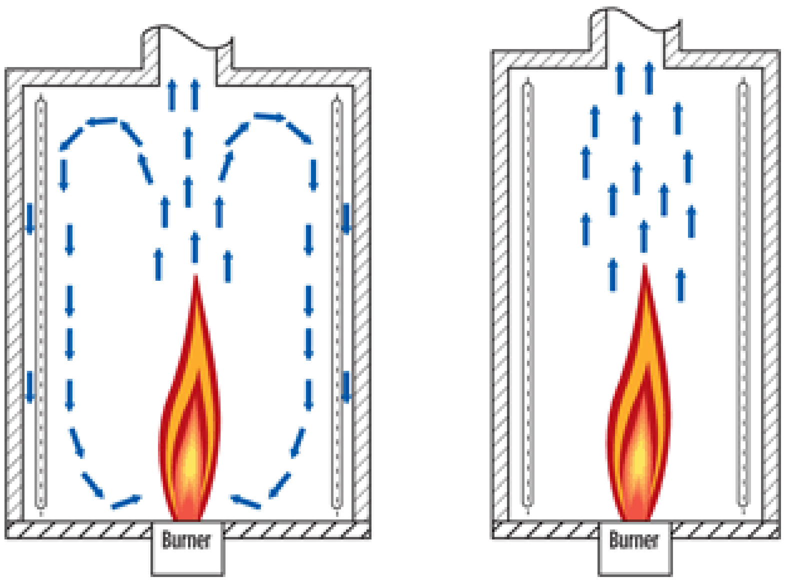


BURNERS

BURNERS

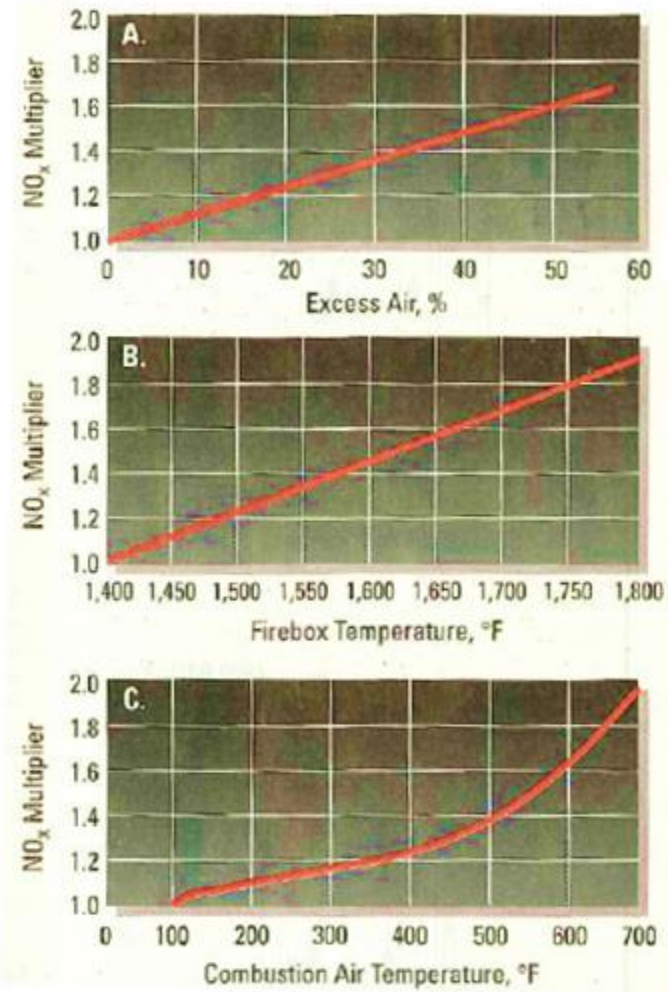


BURNERS



Normal firebox
(flue gas recirculation)

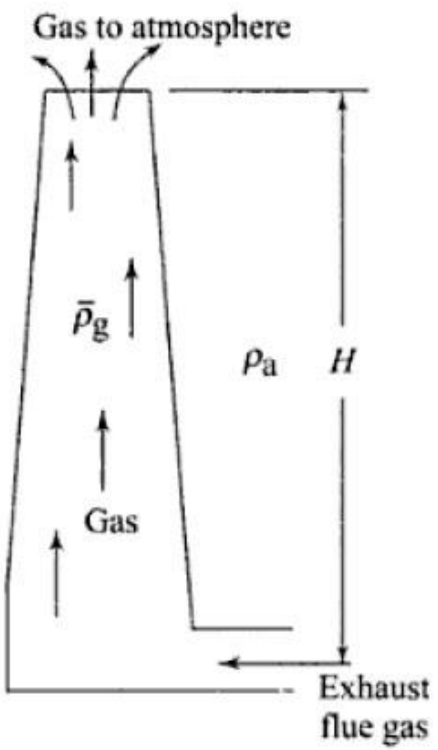
Tight firebox
(no or low flue gas recirculation)



INGENERO

DRAFT

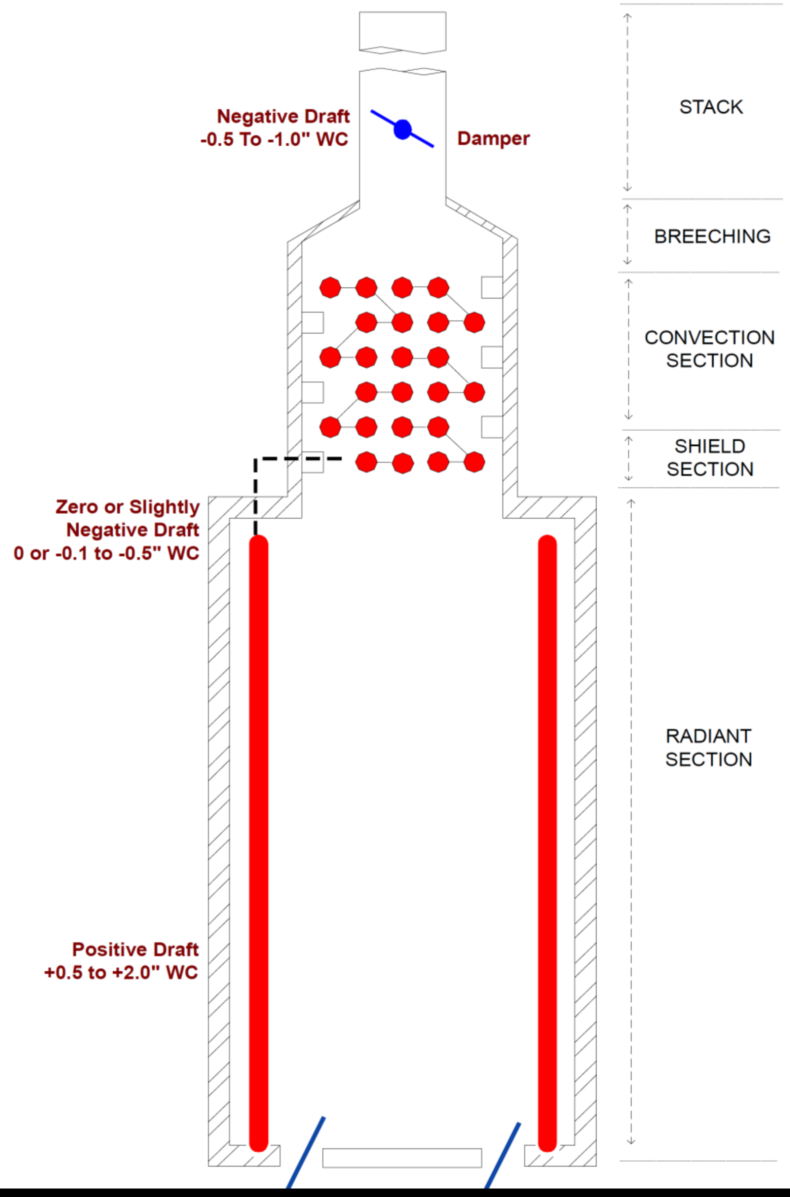
- For optimum operation
  - Minimum excess oxygen in the flue gas entering the convection section
  - Very small negative pressure at the convection section inlet
- Stack dampers and secondary air registers affect the draft
- The hot gas pushes so that the pressure is always greatest at the firewall
- The stack draft pulls and when correctly balanced the pressure at the bridgewall should be close to zero or very slightly negative
- Excessive draft, either positive pressure or negative pressure, can lead to severe problems in the convection section



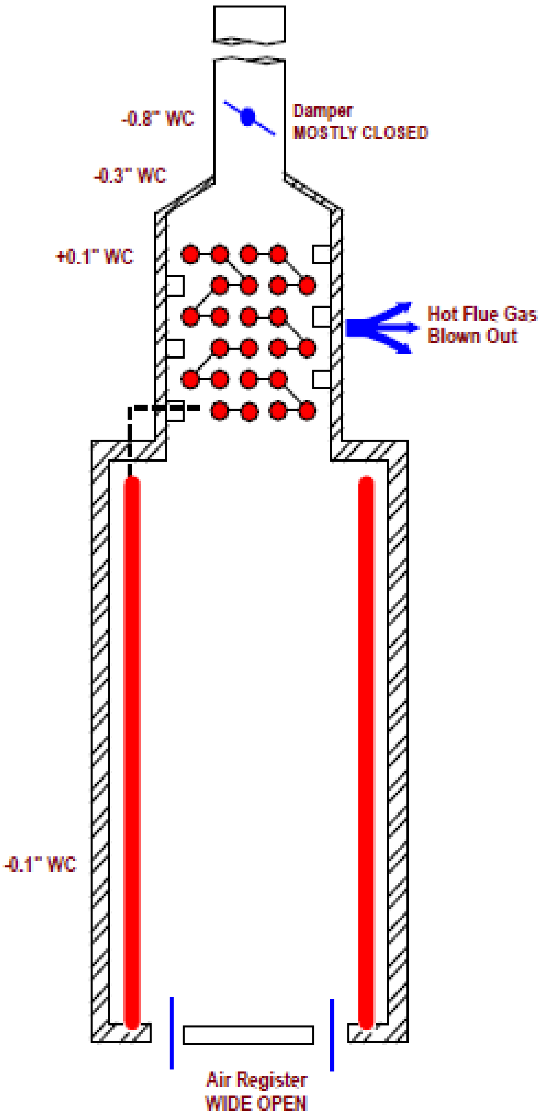
$$\Delta p = gH(\rho_a - \bar{\rho}_g)$$

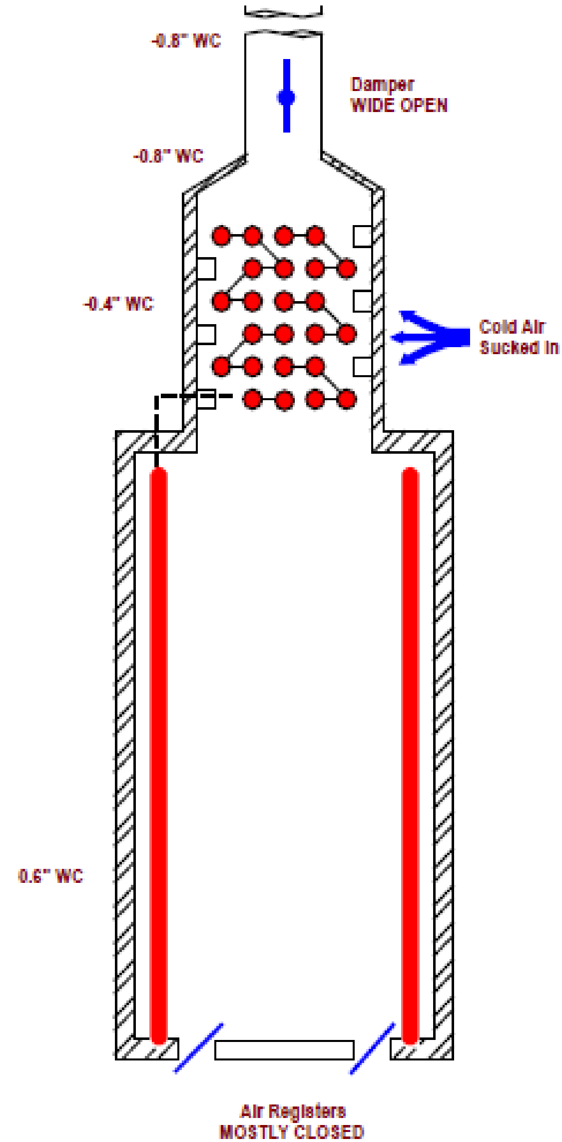
INGENERO

CORRECT DRAFT



EXCESSIVE DRAFT





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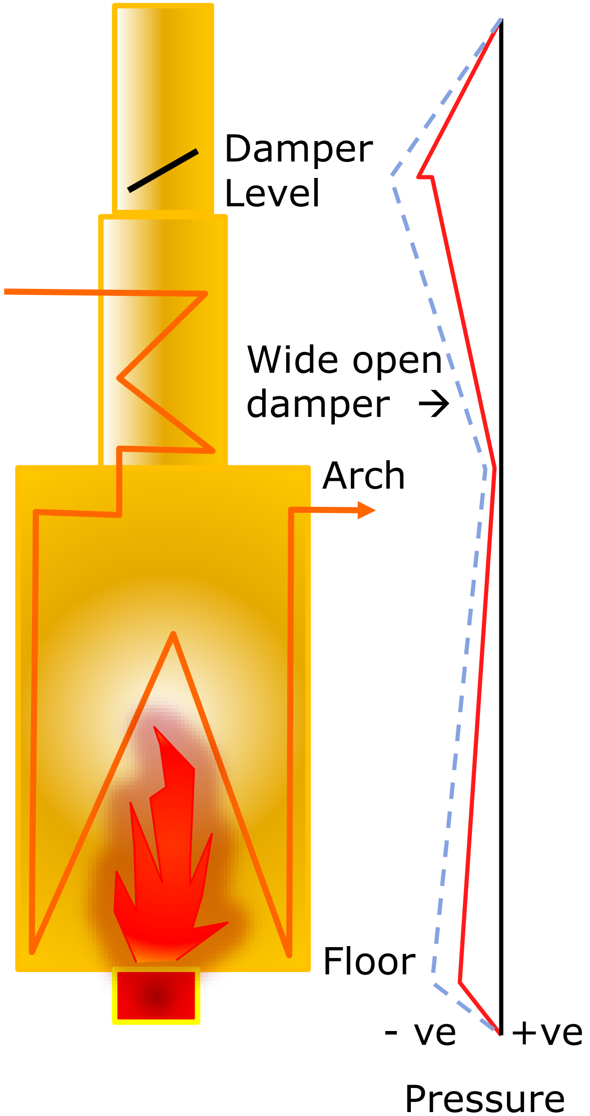
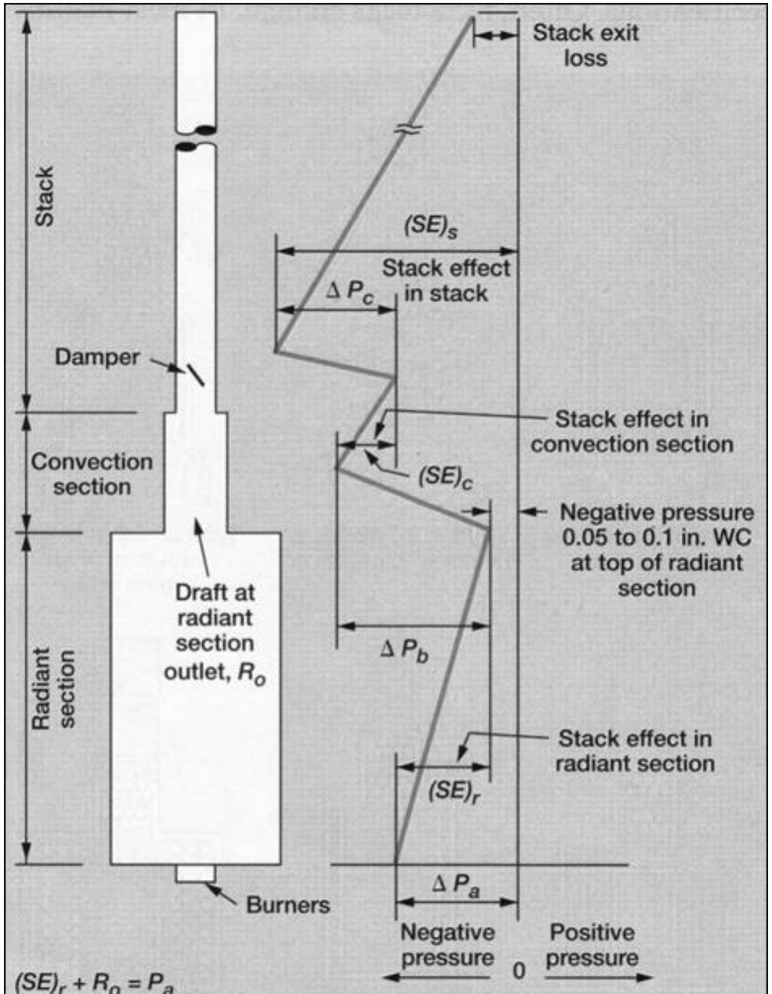
Natural Draft

- Chimney Effect
  - Fire box provides draft to suck in ambient air through burners. About 5-8 mm (0.2-0.3”) WC
  - Stack meets pressure drop across convection tubes and damper. About 10-12 mm (0.4-0.5”) WC
- Residual draft at arch level is (-)2.5 mm (-0.1”) WC
- Easy to operate and maintain



Typical Natural Draft



$(SE)_r + R_o = P_a$

$(SE)_c + (SE)_s = P_b + P_c$ + Stack exist loss + R_o

ΔP_a = Pressure drop across burners (draft available at burner level)

ΔP_b = Flue gas pressure drop across convection section

ΔP_c = Losses due to damper, stack friction, stack entrance

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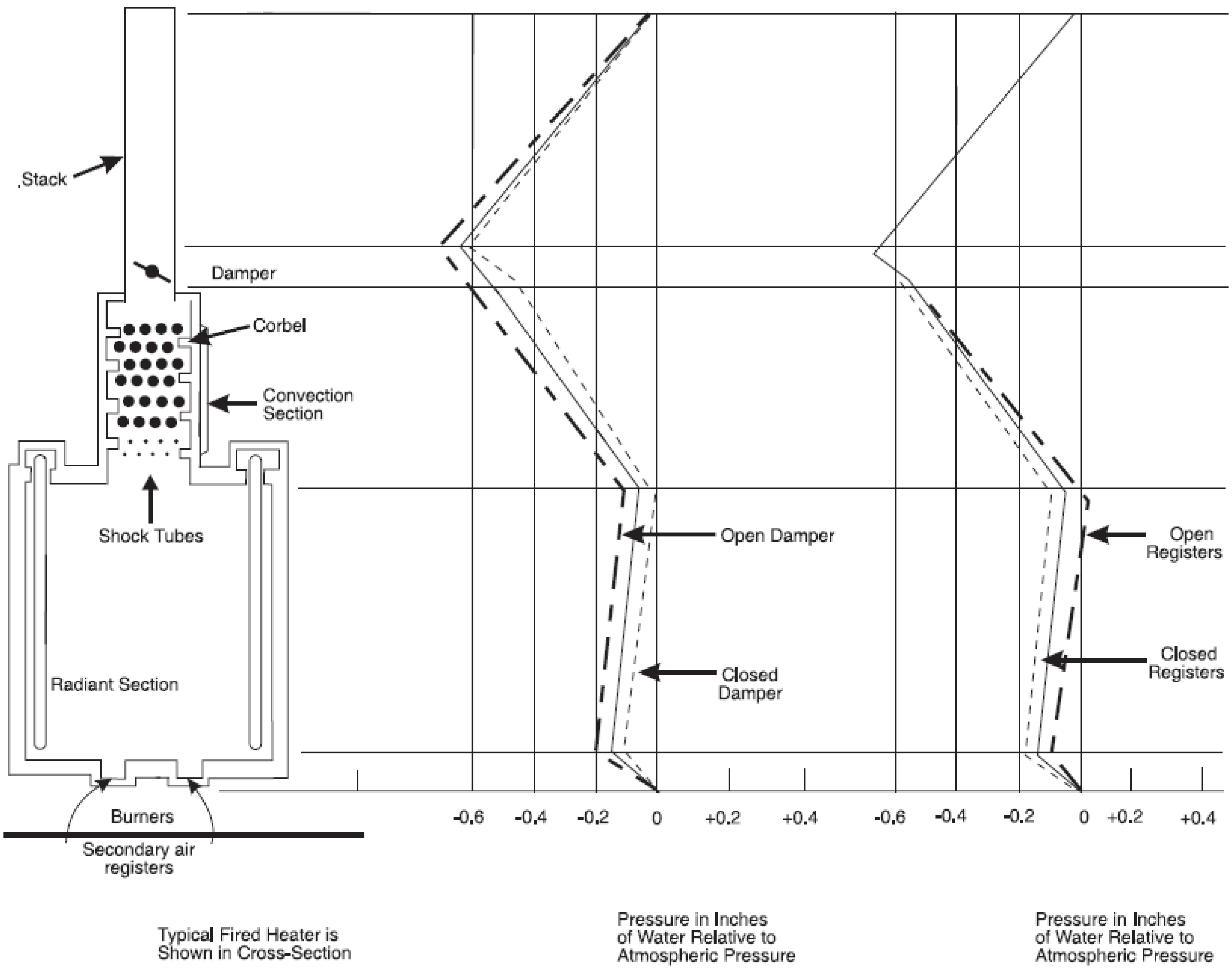
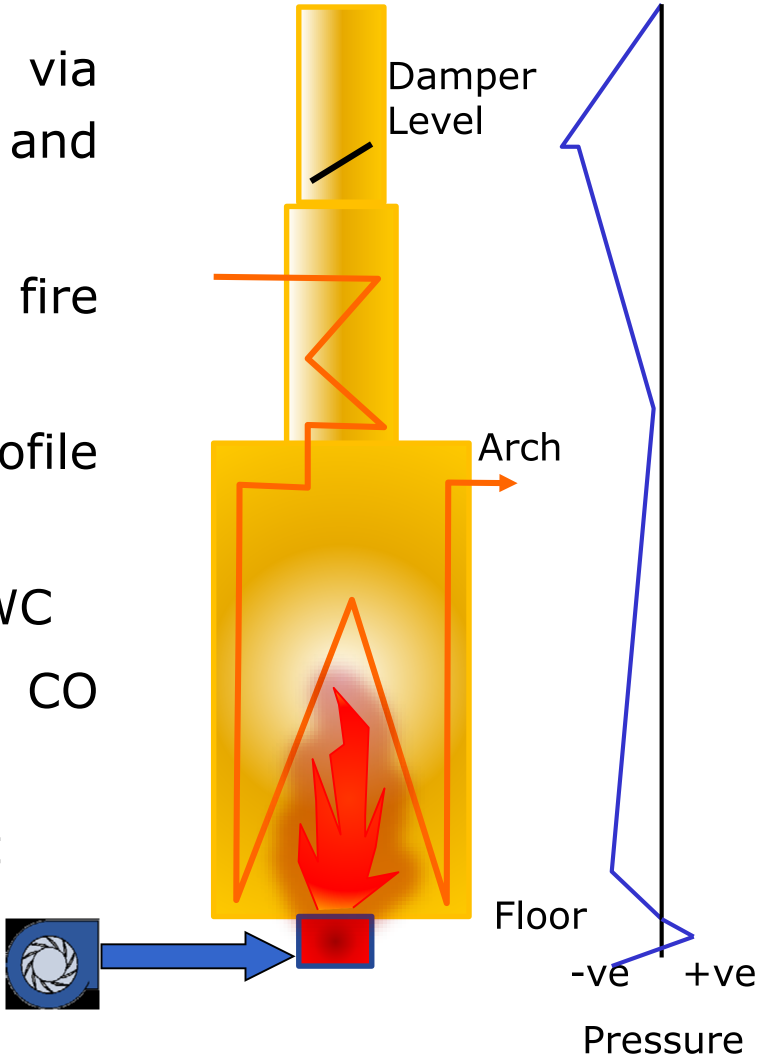


Typical Natural Draft Profile

Forced Draft

- Combustion air through FD fan via ducts, air pre-heater, if any and burner
- It adds to the chimney effect of fire box
- Fire box inside pressure profile remains the same
- Fan Head = 150-200 mm (6-8”) WC
- Air flow controlled by O2 or CO analyzer
- Rest, the same as in Natural Draft



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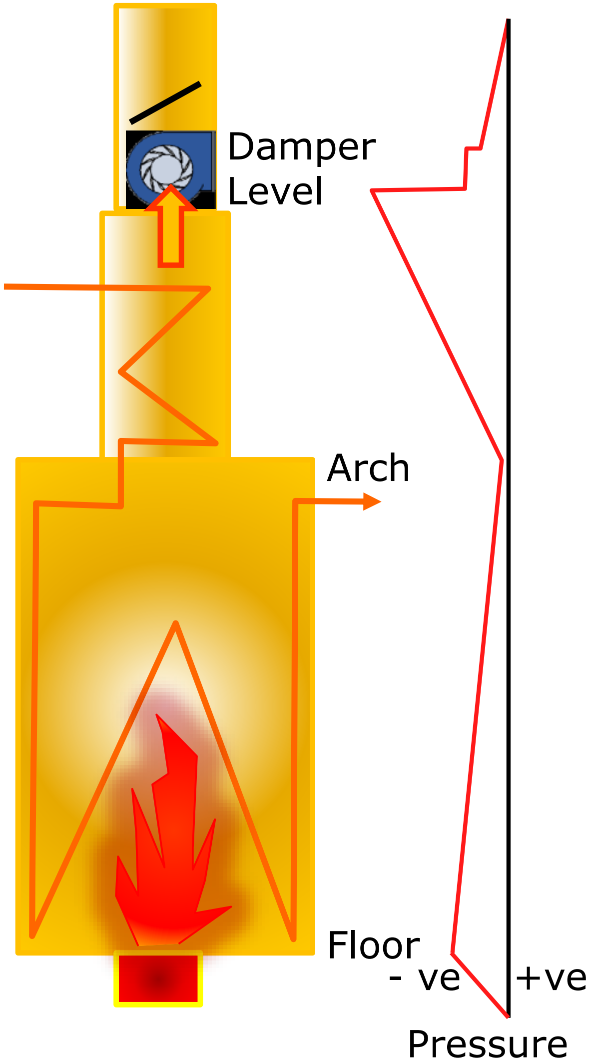
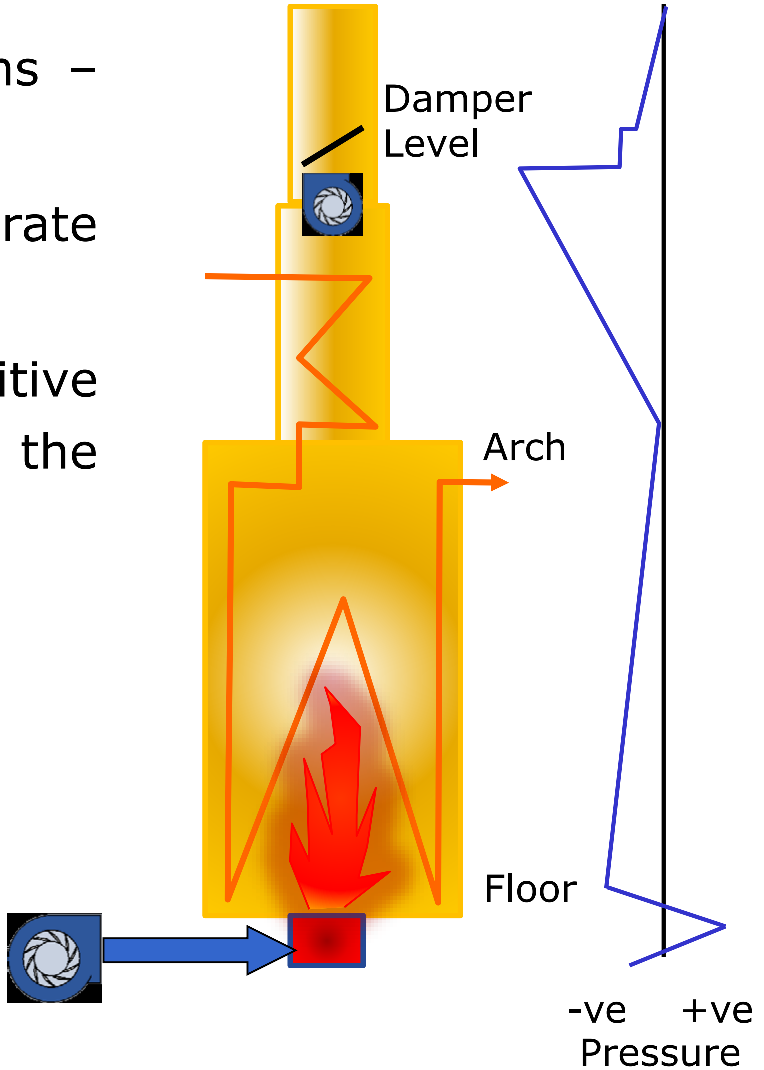
Induced Draft

- Fire Box: Same as in Natural Draft
- ID Fan adds to the chimney effect of stack to meet pressure drop across convection tubes and damper
- Fan Head = 50-75 mm (2-3”) WC
- Usually in a high efficiency heater with cooler flue gas, which is unable to provide good chimney effect
- Draft at arch level: Same as in Natural Draft, controls ID Fan



Balanced Draft

- A combination of FD and ID Fans – usually with air pre-heater
- All process fired heaters operate under slight vacuum at arch level
- If, fire box is operated under positive pressure, the arch refractory is the first to crack and fall



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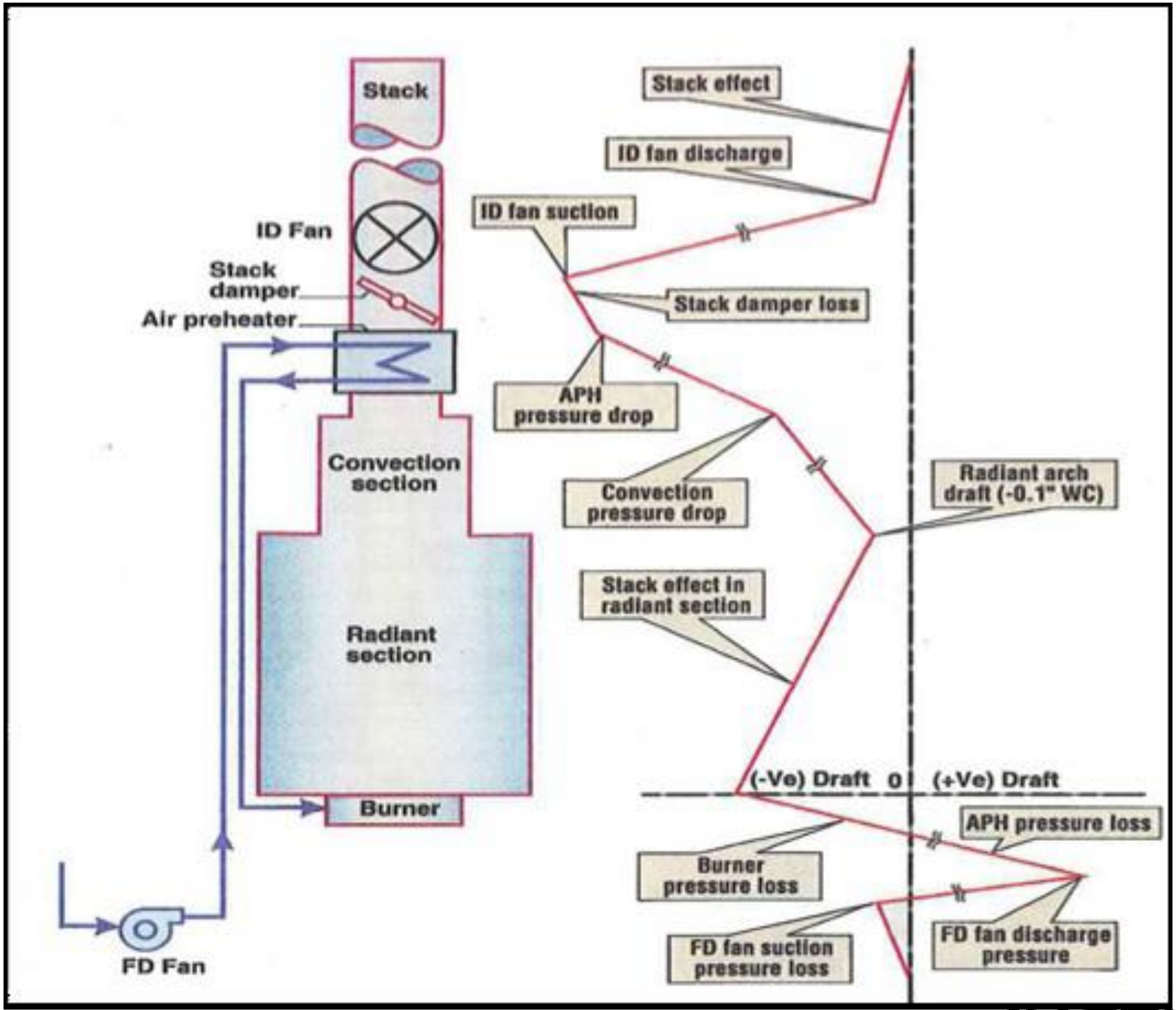
DRAFT



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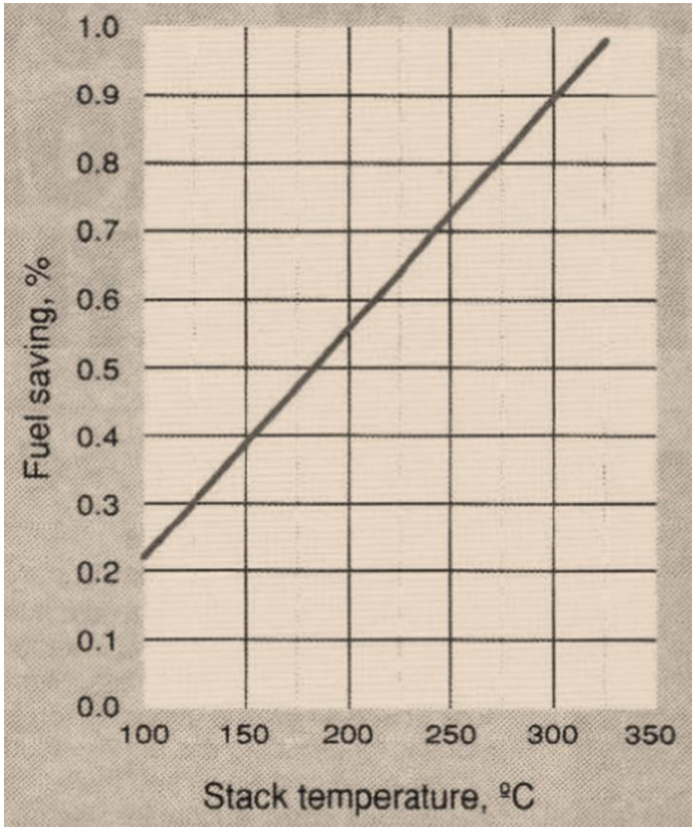
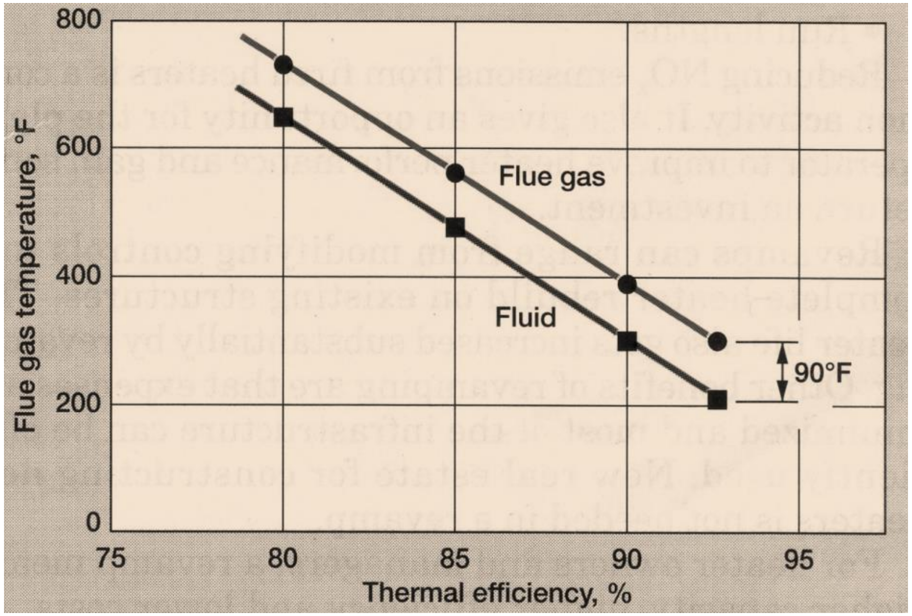
ID Fan

FD Fan

WASTE HEAT RECOVERY

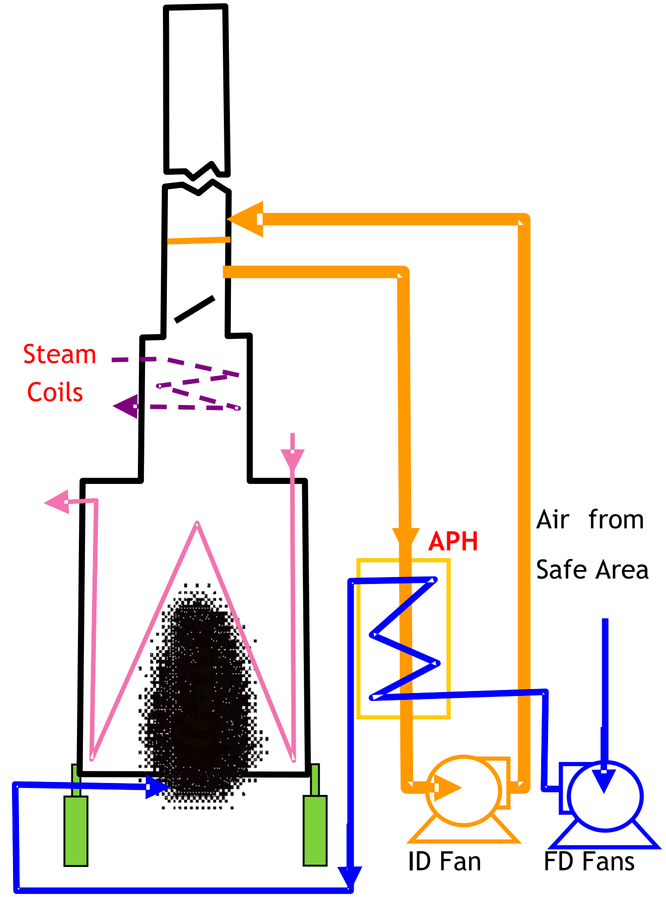
- Typically every 25°C drop in flue gas temperature results in 1% efficiency improvement
- Waste heat is recovered by,
  - Process preheat, saves fuel
  - BFW preheat, steam generation and superheating, does not reduce fuel demand
  - Combustion air preheat through Air pre-heater (APH), saves fuel
- This helps to minimize process energy demand, saving energy
- In convection section, steam generation location needs to be on balance location as during turndown of the main service, secondary fluids may not get their heat demand
- Provide auxiliary firing in ducts/ convection base for secondary fluid heating in convection section


Fuel saving, %
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
100
150
200
250
300
350
Stack temperature, ºC


Flue gas temperature, °F
800
600
400
200
0
75
80
85
90
95
Thermal efficiency, %
Flue gas
Fluid
90°F

AIR PREHEATER (APH)

- Air pre heater tubes can be part of convection bank or mounted on grade
- Require FD and ID fans
- Viable with high flue gas temperature, high heat duty and high fuel cost
- Better flame control
- Used when high radiant duty and high flue gas temp
- Also used when low convection duty, may under perform in retrofit
- May employ water, process or heat transfer fluid in a coupled system. Water or heat transfer fluid requires a circulating loop
- Air pre-heat may also be achieved with waste low temperature streams such as excess LP steam



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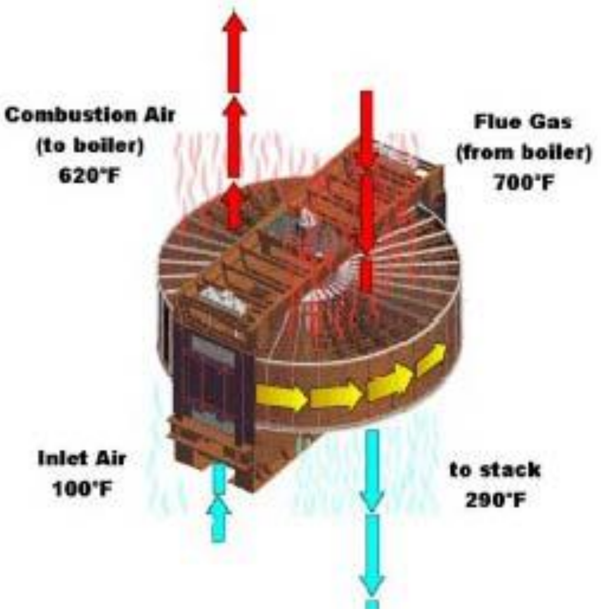
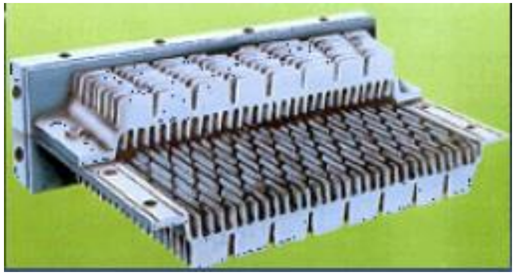
AIR PREHEATER (APH)

- Air pre-heaters requires large surfaces as gas and air side HTC are low
- Air preheater are made of tubes, extended surfaces or light metal elements packed in high density baskets
- If flue gas is cooled below its acid dew point, may require glass tubes to with stand acid corrosion. This situation is generally avoided in process heaters
- Air pre-heater may employ heat pipes (sealed pipes with heat transfer fluids that vaporizes on the flue gas side and condenses on air side)





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AIR PREHEATER (APH)

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AIR PREHEATER (APH)

- Air pre-heaters require extensive duct work for air and flue gas; FD and ID Fans
- Also requires duct work to revert to natural draft operation under part load
- High air pressure drop burners minimize the required number of burners and provides better air distribution but unable to revert to natural draft operation

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AIR PREHEATER (APH)

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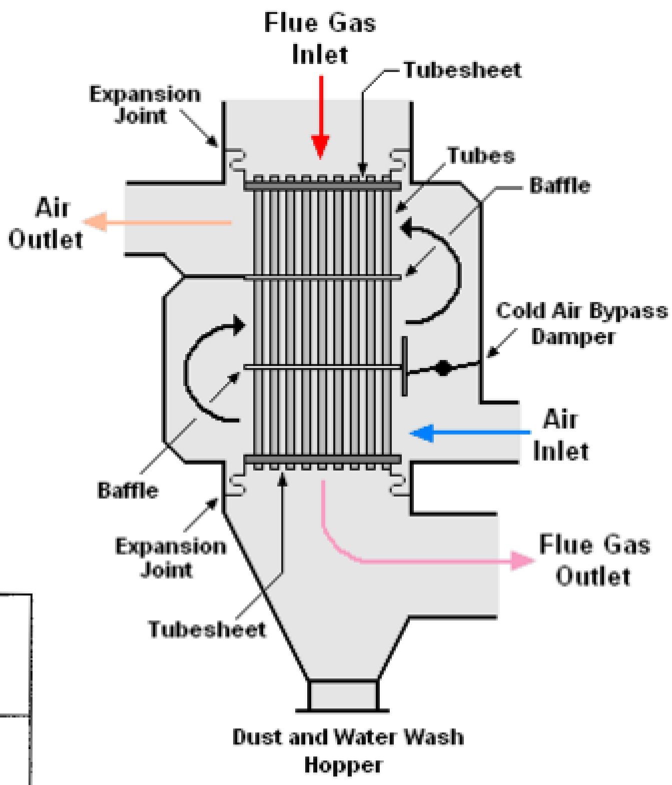
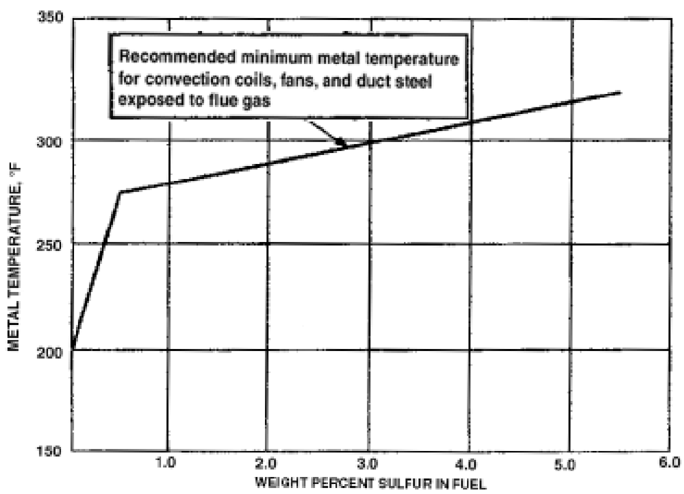
AIR PREHEATER (APH)

- Maintain Cold End Metal Temperature to avoid high corrosion of tubes, ducts and fans due to acid-mist
- Flue Gas Temperature may fall during part load operation or low air temperature or changes in excess air or fuel composition
- Cold End Temperature is maintained by Cold air bypass in air pre-heater or External preheat of cold air





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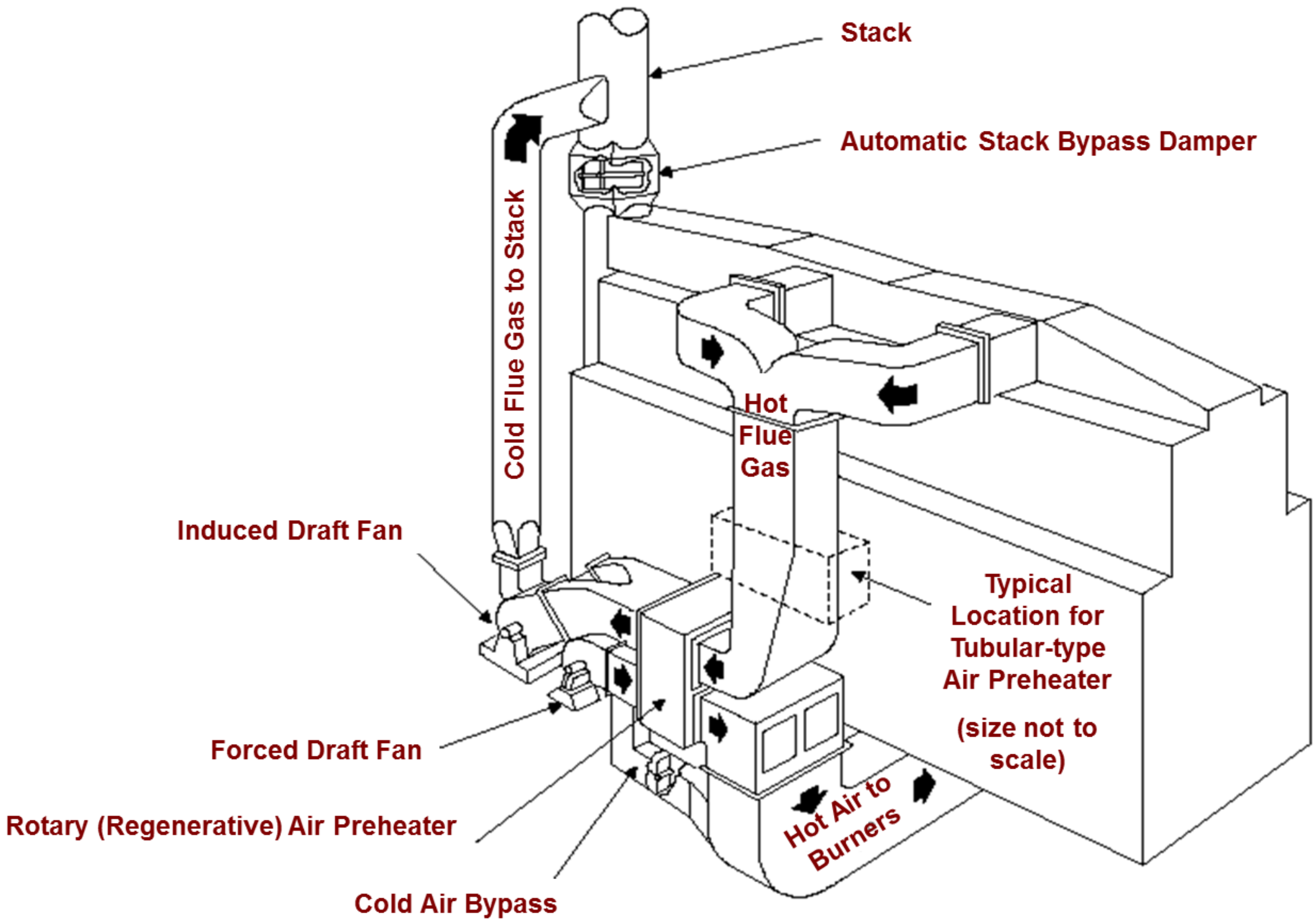
AIR PREHEATER (APH)

TYPICAL AIR PREHEATER INSTALLATION



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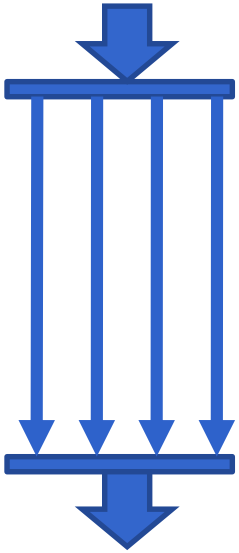
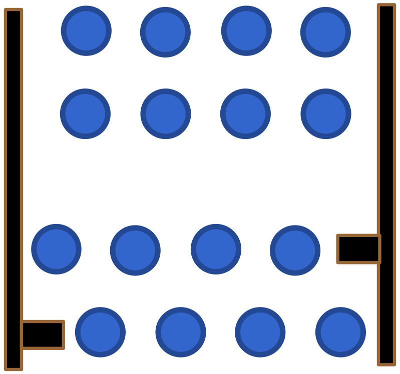
COILS

- Radiant coils:
  – Vertical or horizontal hairpins, arranged along the wall, in a row
  – Helical coils
- Convection coils:
  – In a rectangular bank
  – Square or Triangular pitch
- Tubes:
  – Usually 4” to 6”
  – Smaller tubes in steam / water service
  – Bigger tubes in vacuum service
- Tubes arranged in passes “parallel flow paths” to meet pressure drop available
  – Note: In heat exchangers, number of passes reduce ““parallel flow paths” and add to frictional length, increasing pressure drop

4 Passes



Square Pitch



Triangular Pitch

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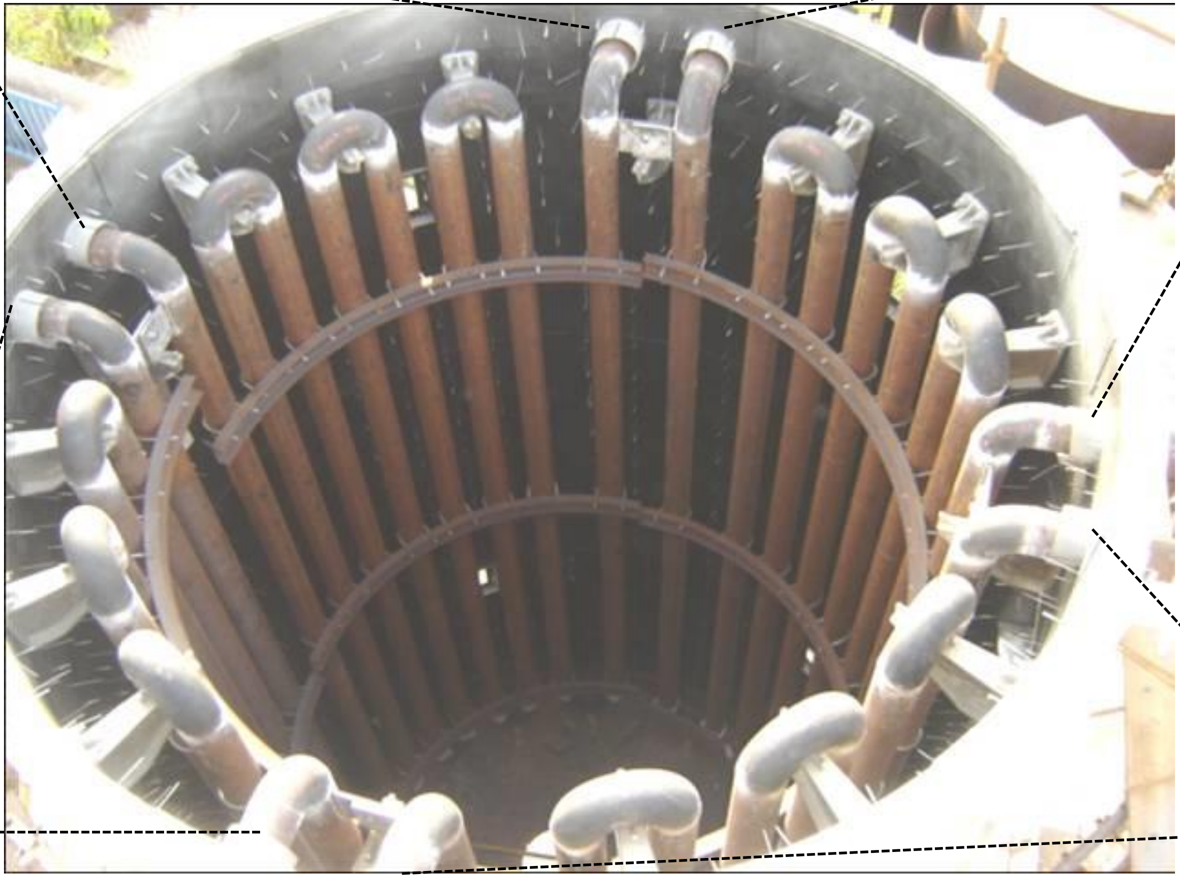
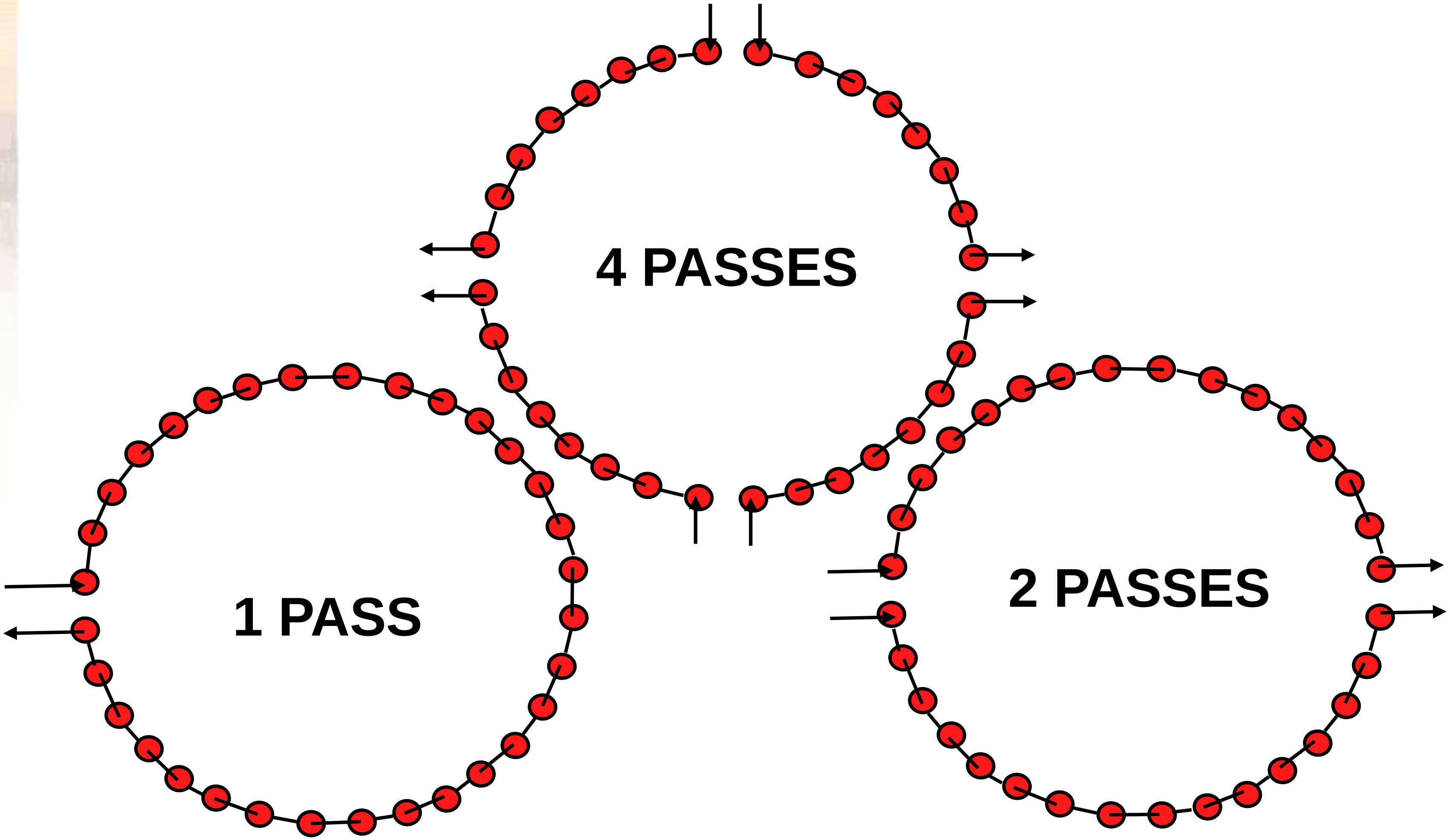
Vertical Cylindrical with Vertical Hairpin Tubes




4 PASSES
1 PASS
2 PASSES

COILS

- Arranged for easy removal; all free to expand
- Material selection based on:
  - Internal and external oxidation
  - Max TMT that decides creep-rupture life
  - Carbon Steel, Low/high Chrome Alloy, SS, 25 Cr-20Ni

- Manifolds – provided when there is more than 1 pass, to ensure equal flow to all passes

- Tube-end fittings has same material as tubes
- Usually 180°return bends. Welded between two adjacent tubes and can be housed in fire box
- In severe coking services, mule ear plug headers are provided
- Plugs are removed for mechanical "turbining" -cleaning of tubes with air operated tools

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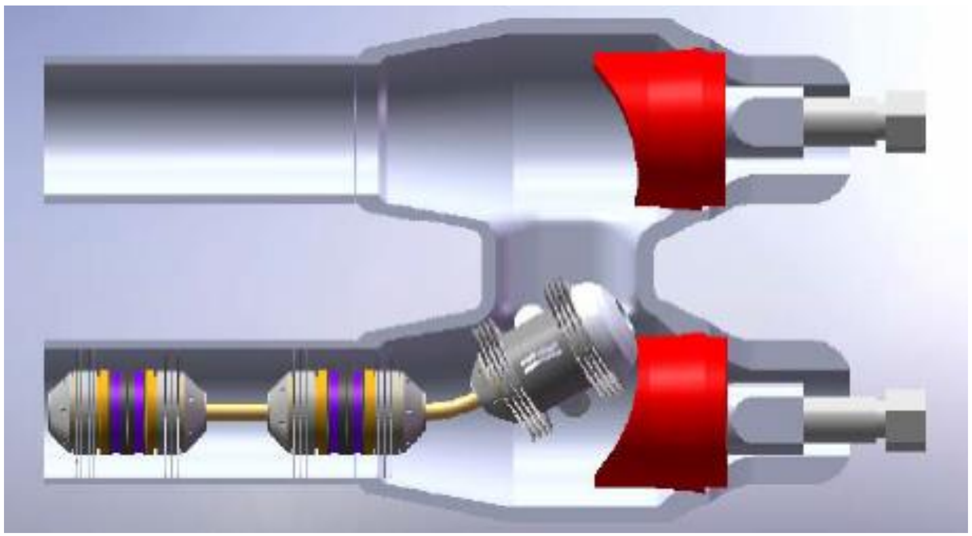
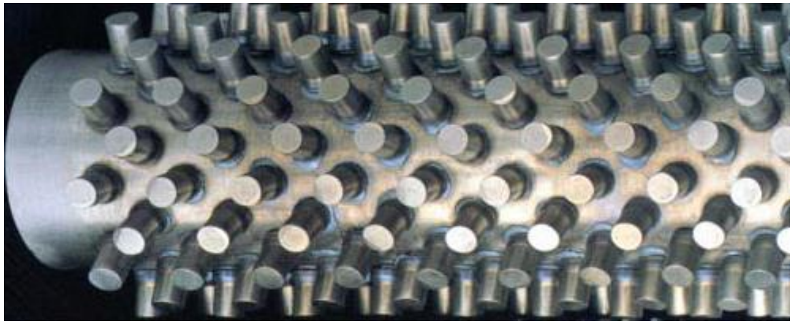
COILS



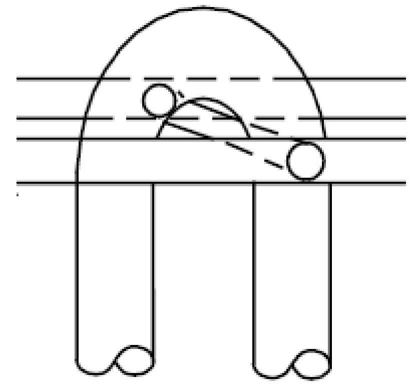
Extended Surface Tubes

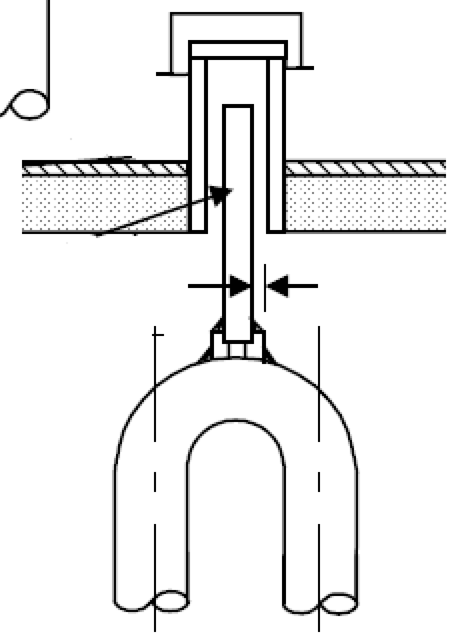
- As flue gas side heat transfer coefficient is low, extended surface tubes are used in the convection section
- Finned tubes with gas and light oil firing
- Studded tubes with heavy oil firing
- Bottom two rows of convection tubes ("shock tubes") are bare, as they receive fire box radiation



TUBE SUPPORTS

- Vertical radiant tubes are guided in the top and supported at the bottom, if outlet is at bottom
  - Bottom U clamp support, buried in floor refractory can be of a less expensive material
  - Usually the outlet side is supported ("anchored") to minimize forces to external piping
  - Top outlets preferred to go straight into column/ reactor





TUBE SUPPORTS

- Horizontal radiant tubes are supported along the length and in tube sheets in the ends
- Design horizontal radiant-section intermediate tube supports and top supports for vertical radiant tubes to permit their replacement without tube removal and with minimum refractory repair
- The unsupported length of horizontal tubes shall not exceed 35 times the outside diameter or 6 m, whichever is less

TUBE SUPPORTS

- Convection tubes are supported by intermediate and end tube sheets
- Intermediate supports are usually 25Cr-20Ni, 25Cr-12Ni, SS or CS;
- High vanadium + sodium in fuel oil may call for 50Cr-50Ni, expensive
- End tube sheets are castable lined CS
- Supporting of extended-surface tubes.
  - Designed to prevent mechanical damage to the extended surface
  - Permit easy removal and insertion of the tubes
  - For studded tubes, a minimum of three rows of studs shall rest on each support
  - For finned tubes, at least five fins shall rest on each support

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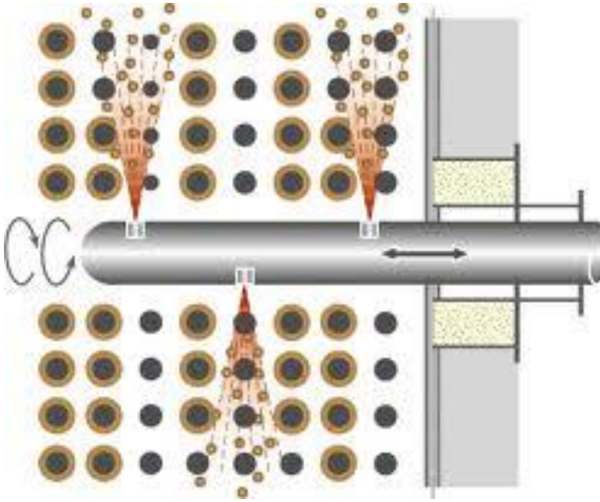
SOOT BLOWERS

- Soot blowers are used to blow away any external deposits on extended surface tubes
- One at a time. Multiple blowers can be sequenced for grade or control room operation
- Fixed soot blower with multi-nozzles are used with clean fuel. Retractable blower with a two nozzles are used in dirty service
- Soot blowers are automatic, sequential and/or fully retractable
- Normally steam is used, but other types are available e.g. air and acoustic devices



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SOOT BLOWERS

- Retractable soot blower lances have two nozzles, an air bleed and a check valve to stop flue gas entering
- Retractable soot blowers are spaced upon a maximum horizontal or vertical coverage of 1.2 m (4 ft) from the lance centre-line, or five tube rows, whichever is less
- Tube supports are considered as a limit to individual soot blower coverage
- Erosion protection shall be provided for convection-section walls located within the soot-blowing zones, using castable refractory with a minimum density of 2000 kg/m3

RETRACTABLE SOOT BLOWER

ROTARY SOOT BLOWER

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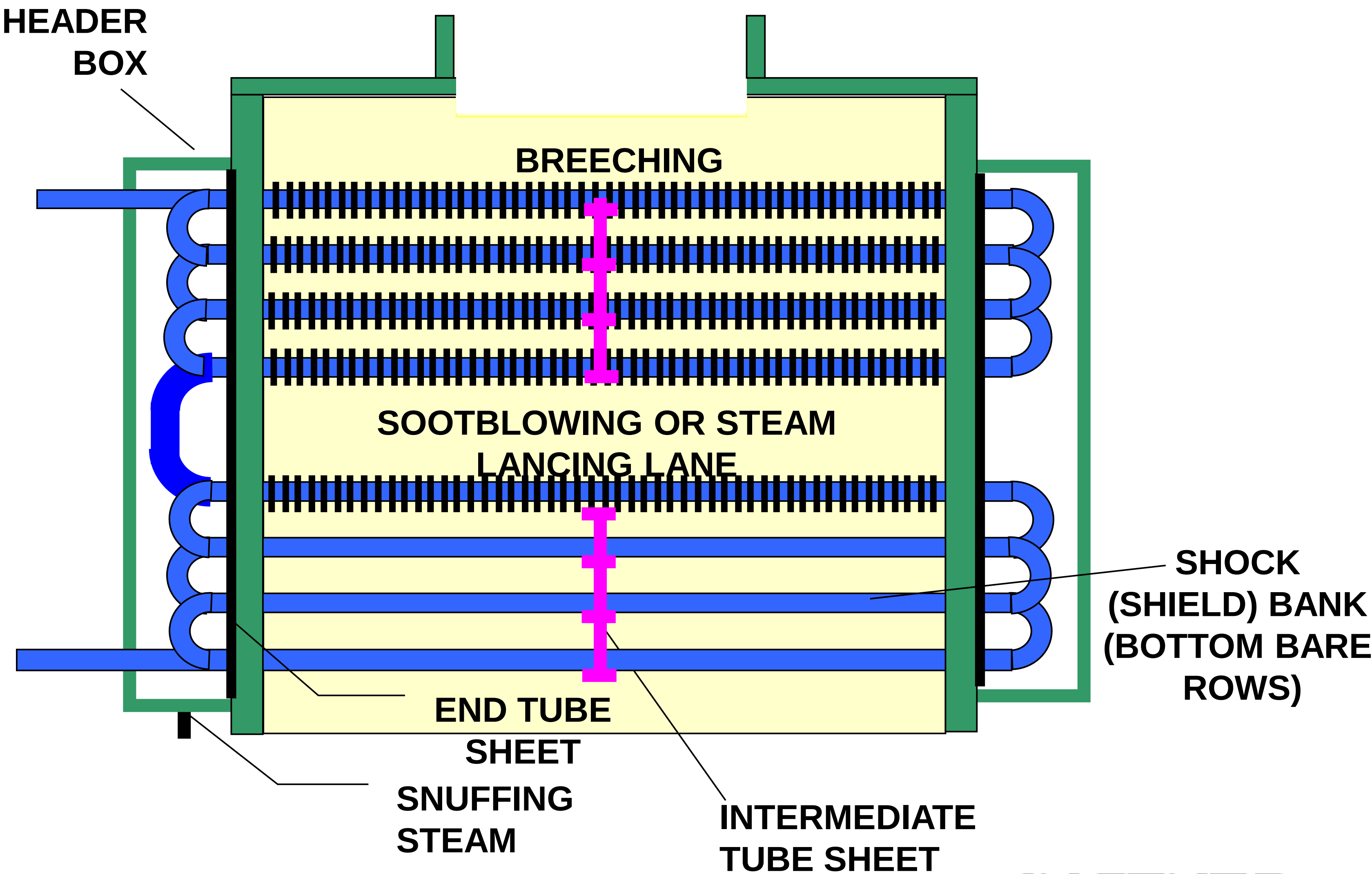
SOOT BLOWERS



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REFRACTORIES & INSULATION

- Refractory protects external steel casing from hot gases. In fire box, they help in re-radiation to the back of the tubes
- Usually reduces the heat losses to less than 2% of the heat release.

Three common types of insulation are:

- **LHV Castable Refractory** —Mixture of cement, aggregate, and insulation in 1:2:6 proportions
- Low cost, concrete-type insulation has a density of 55 lb/ft3, a low coefficient of expansion, and negligible shrinkage
- LHV castable withstands high (150-200 ft/sec) gas face velocities
- Before start-up, cure and dry out the refractory to avoid "spalling" or flaking caused by unequal thermal expansion

REFRACTORIES & INSULATION

- **Ceramic Fiber** — A sandwich construction of this material in two densities is sometimes used
- Extra protective coating normally applied first to the steel casing for protection against sulfur oxides in the flue gas because ceramic fiber is porous
- Much lighter than LHV and is suitable for convection sections
- Ease of application in freezing weather, when water in refractory is a problem; and no need to dry out or cure the ceramic fiber when it is first applied
- For cyclic operations, less heat is stored in the fiber which reduces warm-up time
- Rain or snow entering the heater during shutdown may drench the fiber, causing it to tear away from the studs on a vertical wall

REFRACTORIES & INSULATION

- Ceramic fiber cannot withstand gas face velocities above 50 ft/sec
- If soot blowing or steam lancing of finned tubes is required, LHV castable refractory must be used or the fiber must be covered with an 1/8 in stainless steel erosion
- **Insulating Firebricks** — These are used for bridgewalls and floors
- Quite dense, 150 lb/ft3, are shipped loose, and field installed
- Must be dried out slowly
- After proper installation, firebricks are sturdy and resist deterioration from weather and high gas velocities.
- **External Insulation** — In sulfur plants and in cold climates, external insulation is frequently used to maintain a minimum stack temperature to prevent condensation within the stack

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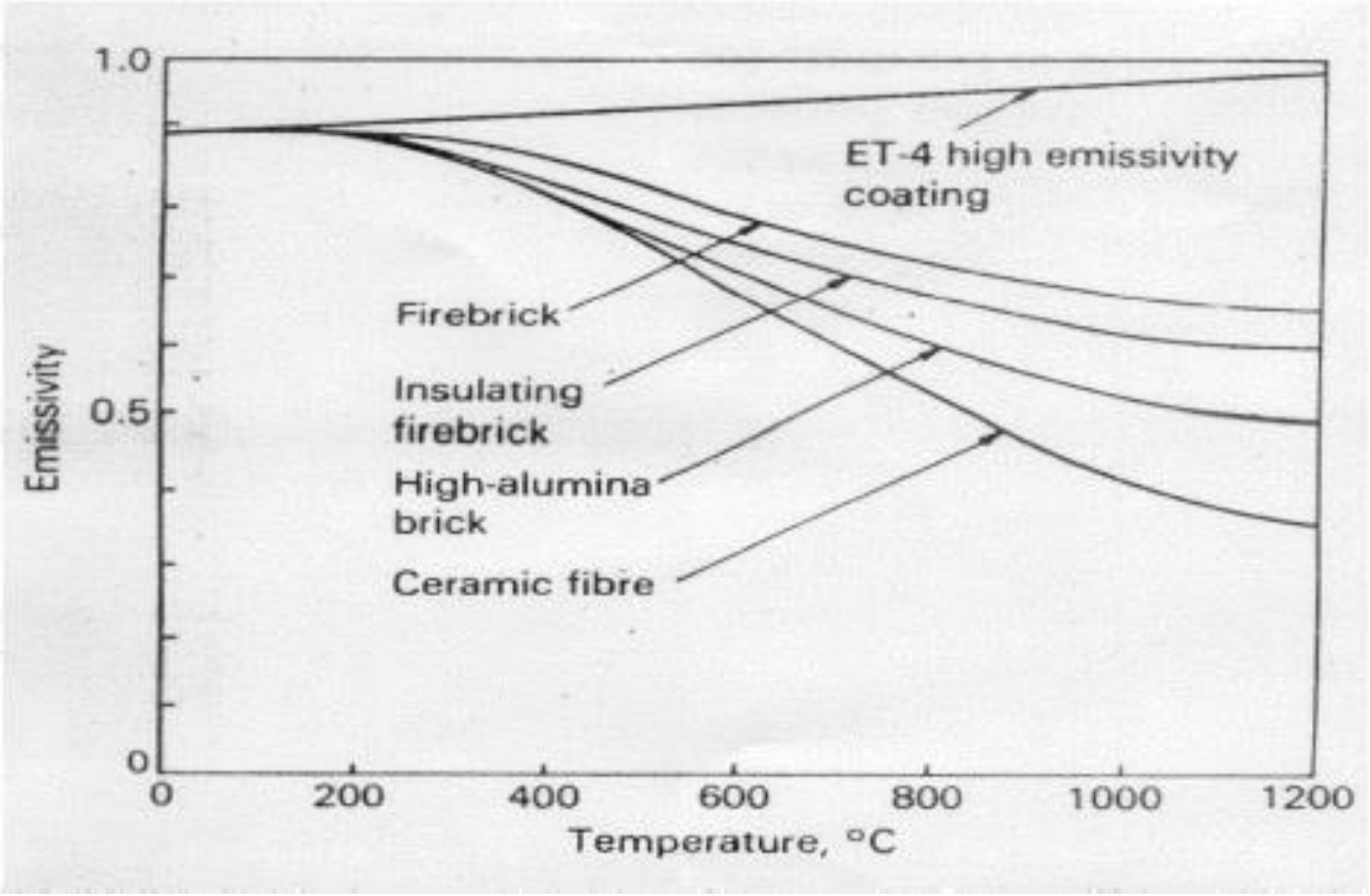

1.0
0.5
0
Emissivity
0
200
400
600
800
1000
1200
Temperature, °C
ET-4 high emissivity
coating
Firebrick
Insulating
firebrick
High-alumina
brick
Ceramic fibre

Heat transfer modes in heater

- Radiation
- Convection
- Conduction

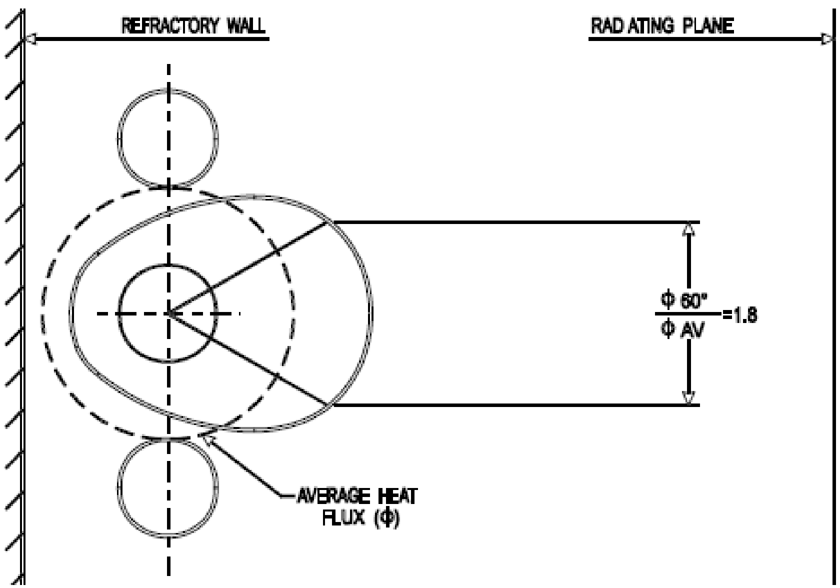
Typical Heat distribution in a heater

Sr. No.	Heat Transfer Modes	Typical Heat Transfer
1	Direct heat transfer through flame radiation	14%
2	Direct heat transfer through gas radiation	28%
3	Direct heat transfer through gas convection	6%
4	Indirect heat transfer through refractory reflection	12%
	Total heat transfer in radiant section	**60%**
5	Direct heat transfer through convection in convection bank	25%
	Total useful heat	**85%**
6	Flue gas loss	13%
7	Radiation loss	2%
	Total	**100%**

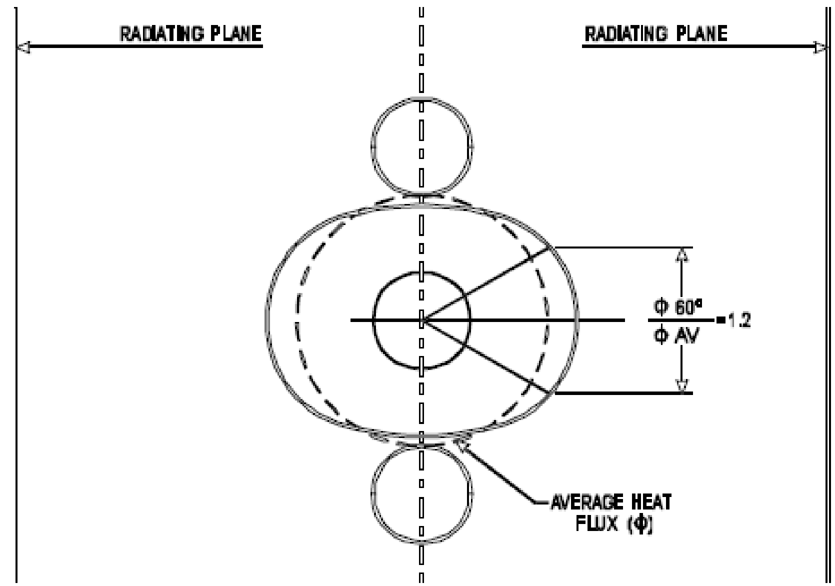
Firing Modes

- Single
- Double

Circumferential Radiant Heat Flux Distribution



Single Firing



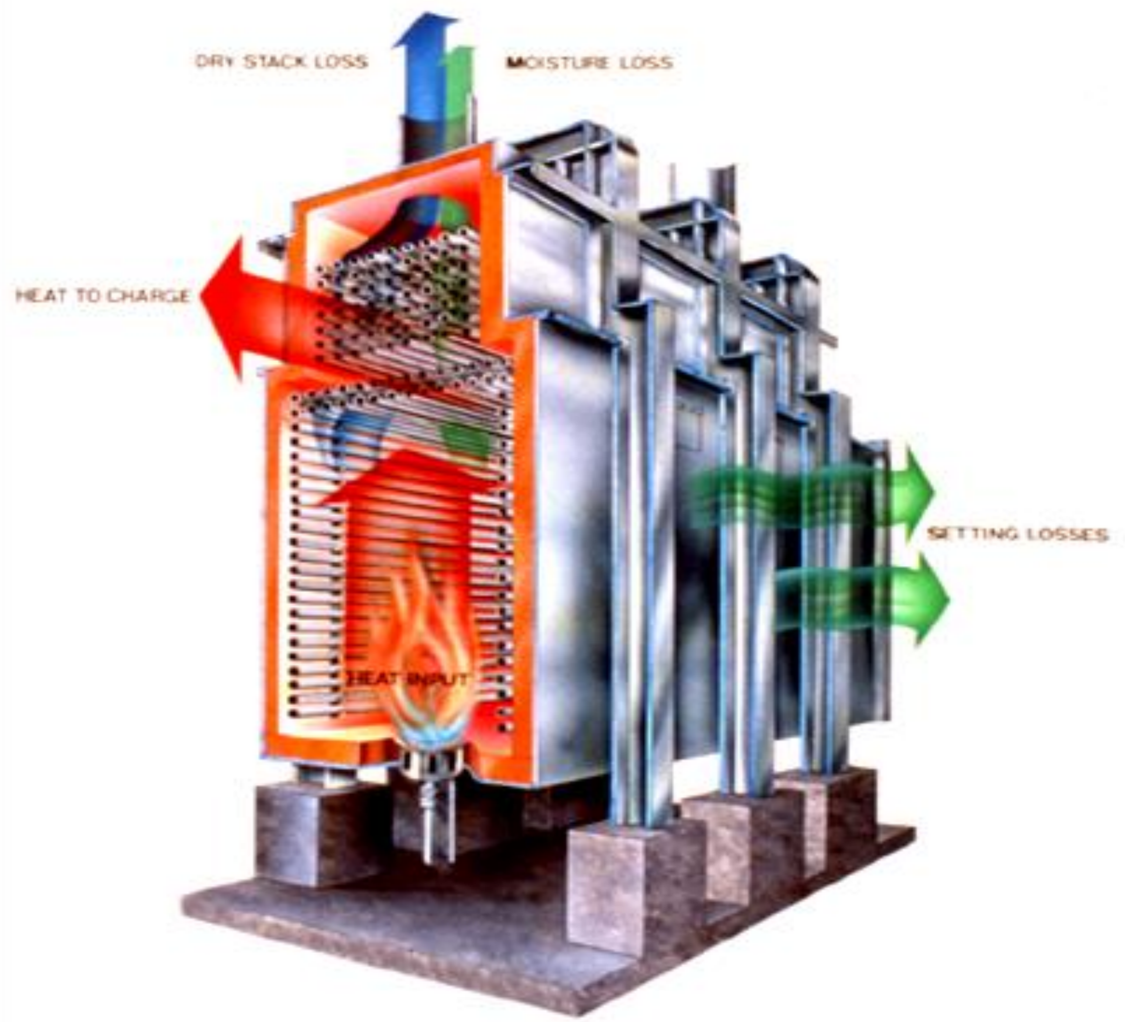
Double Firing

- Single fired is the most common firing for all heaters
- Single firing means that the tubes 'see' flames on one side only
- Double firing means that the tubes 'see' flames on both sides
- Double firing reduces the coil length or surface area for the same maximum tube metal temperature
- Double firing also means more burners are required as well as more radiant box volume
- Single verses double firing is usually selected based on the severity of the process fluid and operating conditions

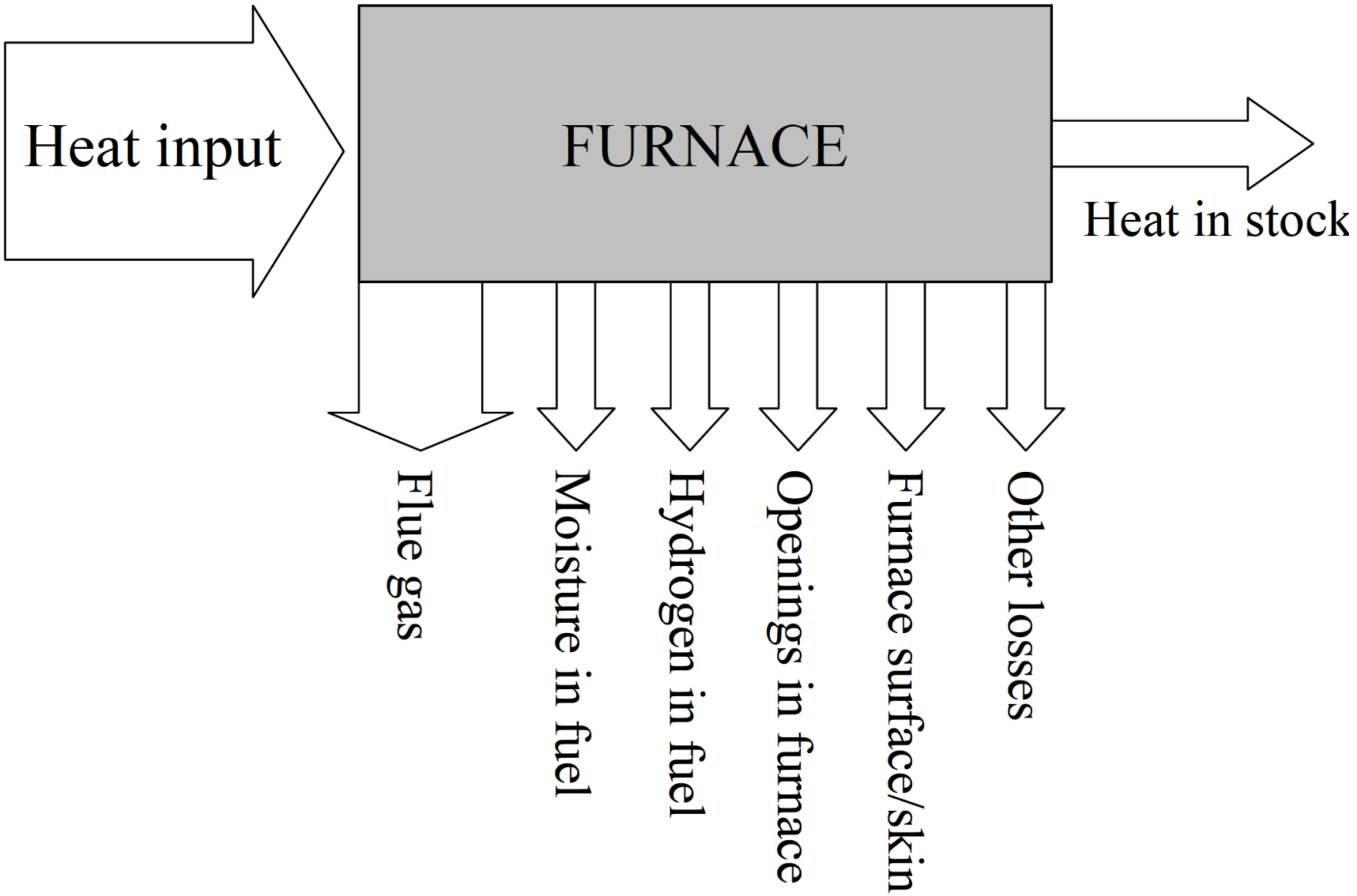
HEAT TRANSFER

- Higher the heat flux, lower is radiant section size and overall heater cost
- Heat flux is decided by coking and product discoloration which can lower its value
- Maximum Average Heat Flux
  - Single side firing : 12000 Btu/ft2.hr (32500 kcal/m2.hr)
  - Double side firing: 22000 Btu/ft2.hr (60500 kcal/m2.hr)

Furnace Heat Losses



Furnace Heat Losses



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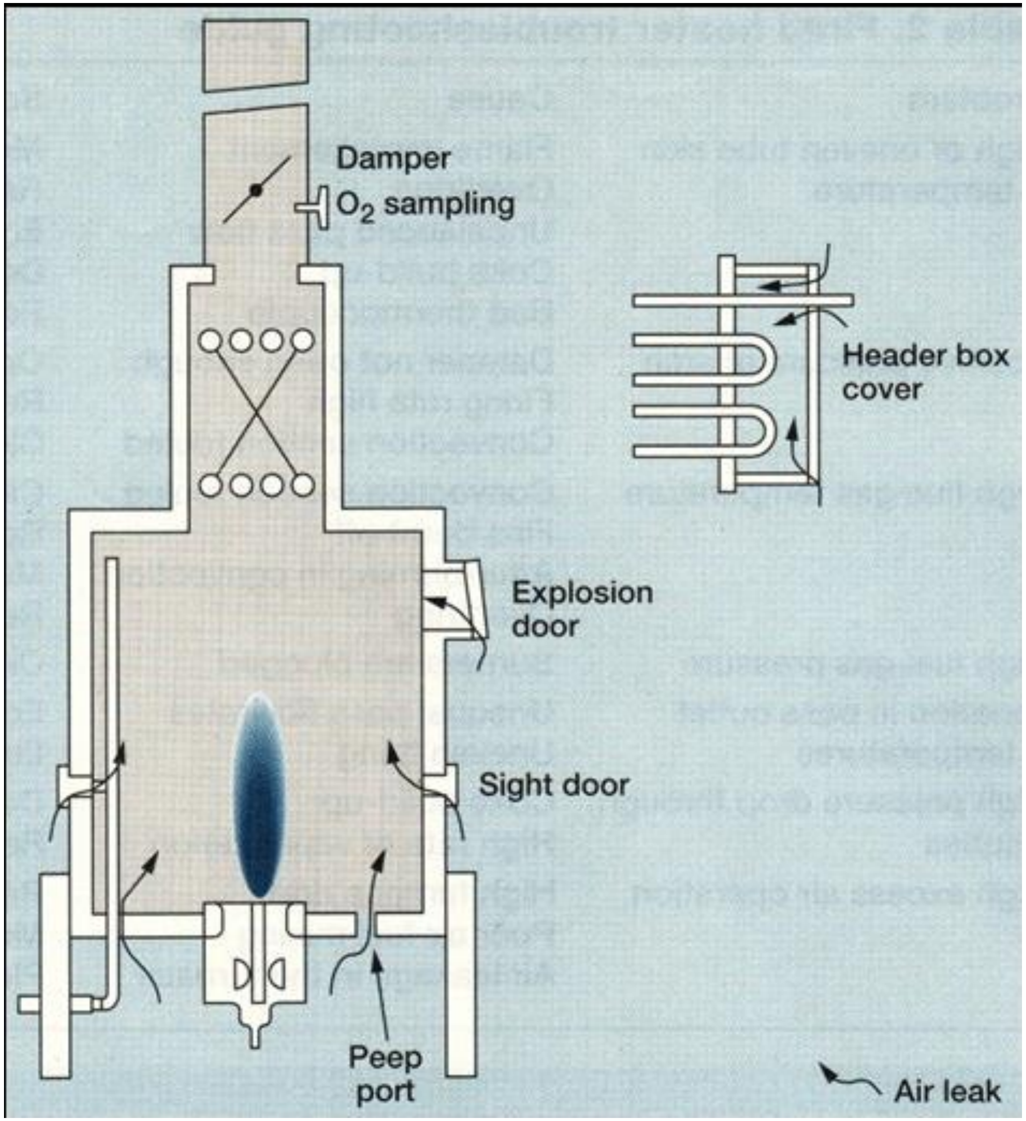
Furnace Heat Losses

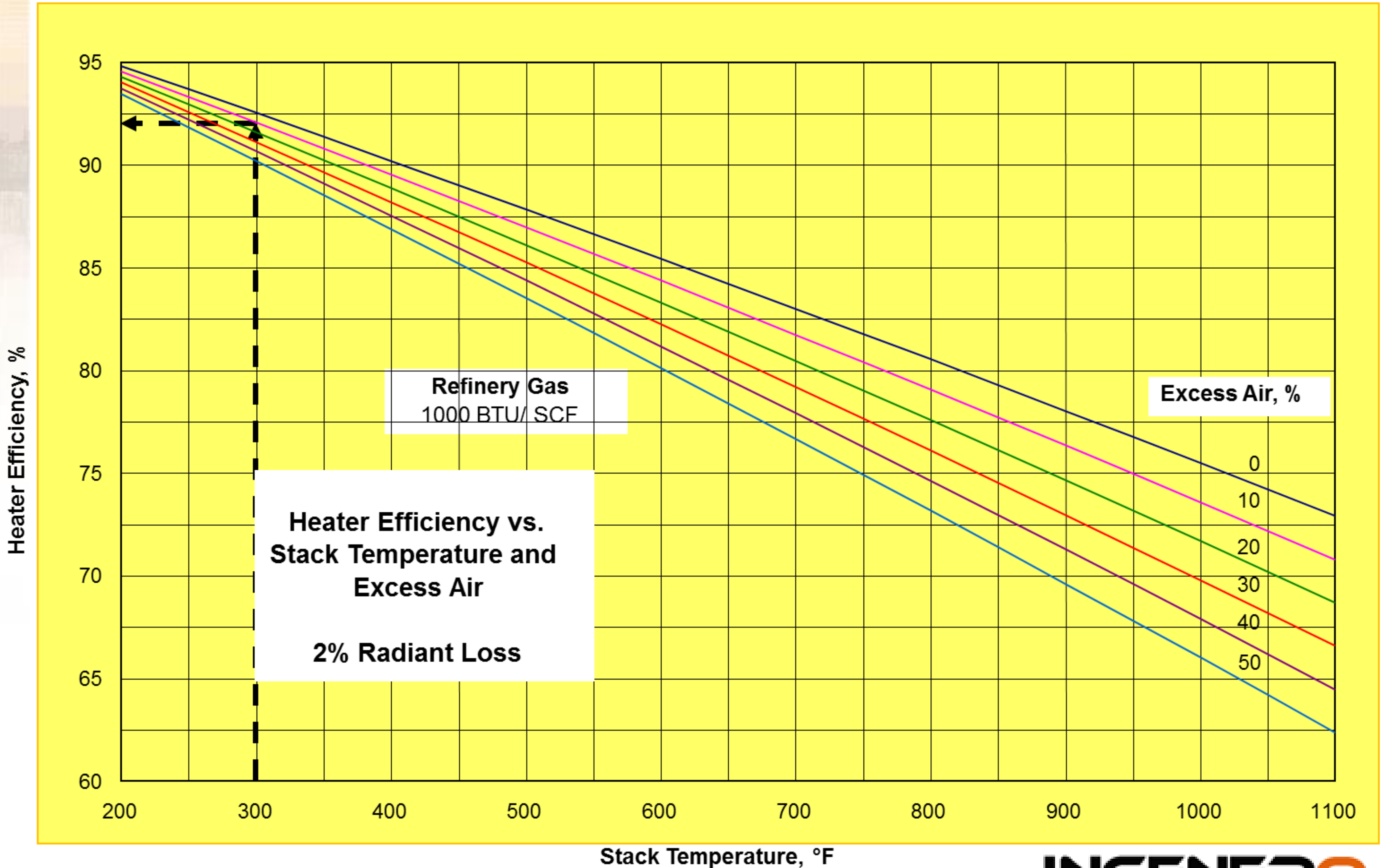
- **Flue gas losses**: part of the heat remains in the combustion gases inside the furnace. This loss is also called waste-gas loss or stack loss.
- **Loss from moisture in fuel**: fuel usually contains some moisture and some of the heat is used to evaporate the moisture inside the furnace
- **Loss due to hydrogen in fuel** which results in the formation of water
- **Loss through openings in the furnace**: radiation loss occurs when there are openings in the furnace enclosure and these losses can be significant, especially for furnaces operating at temperatures above 540°C. A second loss is through air infiltration because the draft of furnace stacks/chimneys cause a negative pressure inside the furnace, drawing in air through leaks or cracks or when ever the furnace doors are opened.

Furnace Heat Losses

- **Furnace skin / surface losses, also called wall losses**: while temperatures inside the furnace are high, heat is conducted through the roof, floor and walls and emitted to the ambient air once it reaches the furnace skin or surface.
- **Other losses**: there are several other ways in which heat is lost from a furnace, although quantifying these is often difficult. Some of these include
  - **Stored heat losses**: when the furnace is started the furnace structure and insulation is also heated, and this heat only leaves the structure again when the furnace shuts down. Therefore this type of heat loss increases with the number of times the furnace is turned on and off
  - **Incomplete combustion losses**: heat is lost if combustion is incomplete because un-burnt fuel or particles have absorbed heat but this heat has not been put to use
  - **Loss due to formation of scales**


Damper
O_2 sampling
Header box
cover
Explosion
door
Sight door
Peep
port
Air leak

Furnace Efficiency



Furnace Efficiency

- **Fuel Efficiency**

  = (Fuel fired + Sensible heat of Fuel + Sensible heat of air – Stack loss – Radiation loss) / (Fuel Fired)

  $= (LHV + \Delta Hf + \Delta Ha - \Delta Hs - \Delta Hr) / (LHV)$

- **Thermal Efficiency**

  = (Fuel fired + Sensible heat of Fuel + Sensible heat of air – Stack loss – Radiation loss) / (Fuel Fired + Sensible heat of Fuel + Sensible heat of air)

  $= (LHV + \Delta Hf + \Delta Ha - \Delta Hs - \Delta Hr) / (LHV + \Delta Hf + \Delta Ha)$

Step By Step Procedure For Thermal Design of Fired Heaters

- Input absorbed duty (MMkcal/hr)
- Select heater type based on heater service and duty
- Assume radiant-convection split as 70-30%
  - (if convection-radiation type heater)
- Input radiant average heat flux
- Input or assume radiant coil diameter and number of passes
- Preliminary estimation of radiant coils surface area, coil length and fire box dimensions (Tube circle diameter, length, width, height as applicable)

- Input or assume convection section tube diameter, length and number of passes (same as radiant, if convection-radiation type heater)
- Preliminary estimation of tube surface area, number of rows and pressure drop
- Prepare Simulation model (Fired Heater Design Software):
  - Input process stream properties, parameters and fuel properties
  - Input fired heater type, dimension, radiant coils geometry and convection tubes geometry, Air preheater (if applicable) etc.
  - Input excess air requirement and percent radiant losses

HEAT TRANSFER

- Fine tune radiant coil and convection geometry to match heater absorbed duty and process parameters by adjusting fuel flow rate

- Estimate following by using Software Model:
  - Firing duty
  - Process side pressure drop
  - Bridge wall temperature, flue gas temperature profile, stack temperature, etc.
  - Average and peak heat fluxes
  - Tube Metal Temperature (TMT) of radiant coils and convection section tubes, fin tip temperature of convection tubes

HEAT TRANSFER

  - Flue gas velocities in convection section
  - Stack Height & Stack losses

- Estimate heater fuel efficiency and net thermal efficiency
- Prepare API 560 fired heater data sheet

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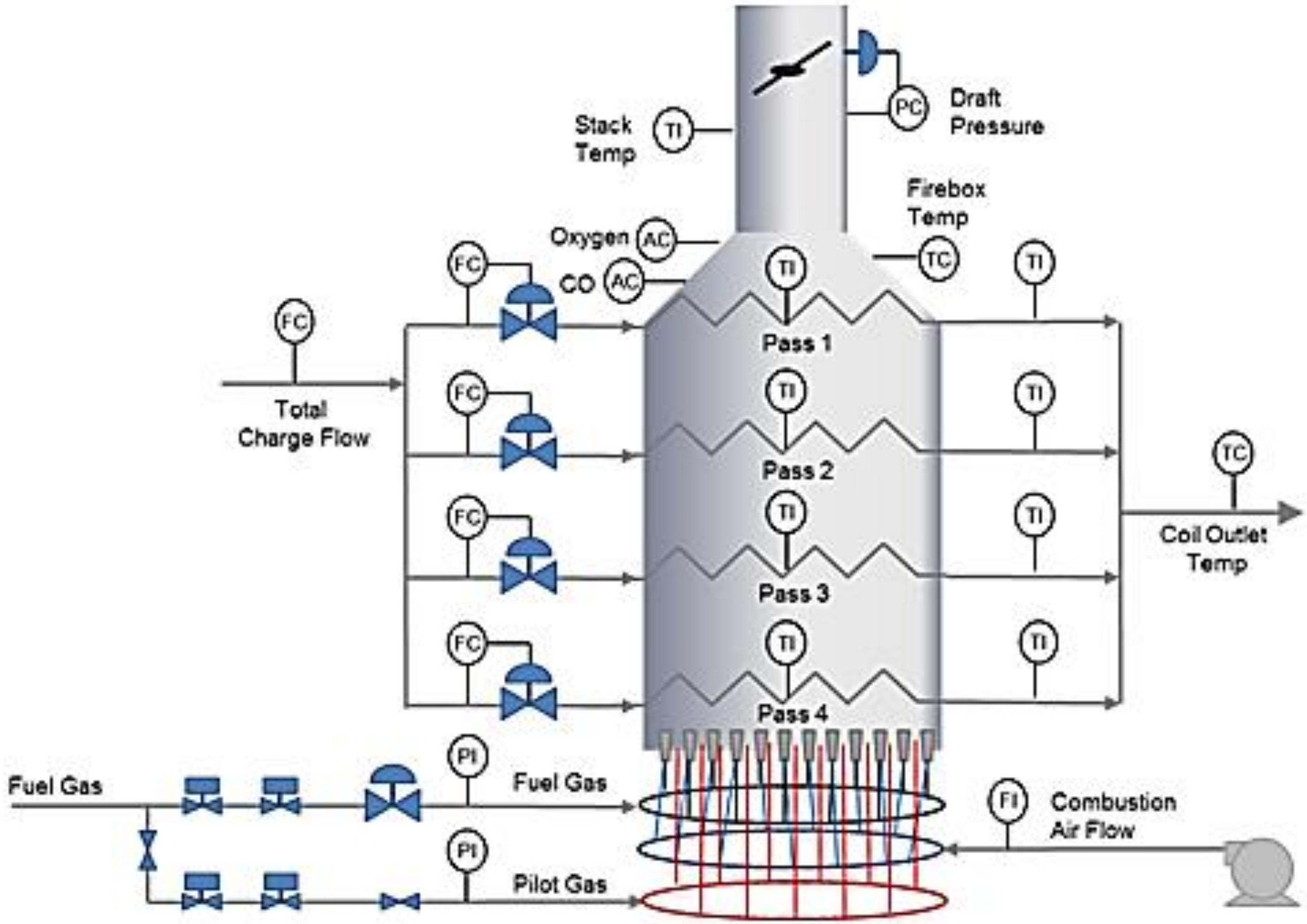
CONTROLS - INSTRUMENTATION

- **Coil**
  - TI at Inlet/ Outlet of each pass, TIC, TAH, TAHH at outlet
- **Coil Skin**
  - Skin Point TI for each pass
- **Fire Box Instruments**
  - TI and Draft Gauge in fire box, arch and stack, TAH, TAHH, O2-CO2 analyzer tapping in stack
- **Flame**
  - Flame monitors
- **Fuel Oil**
  - Steam tracing, cross-over purging and fuel oil return line. PG, PAL, PALL, TG, TAL

- Steam Line

- **Fuel Gas/ Pilot Gas**
  - Heat tracing; PG, PAL, PALL
- **Air Lead Lag Control**
  - With FD fan system, care is taken to reduce fuel first, before reducing air first and vice versa while increasing firing. This is to ensure that adequate excess air is always available to avoid a fire box explosion


Stack
Temp
TI
PC
Draft
Pressure
Firebox
Temp
TC
Oxygen
AC
CO
AC
FC
Total
Charge Flow
FC
FC
FC
FC
TI
Pass 1
TI
Pass 2
TI
Pass 3
TI
Pass 4
TI
TI
TI
TI
TC
Coil Outlet
Temp
Fuel Gas
PI
Fuel Gas
PI
Pilot Gas
FI
Combustion
Air Flow

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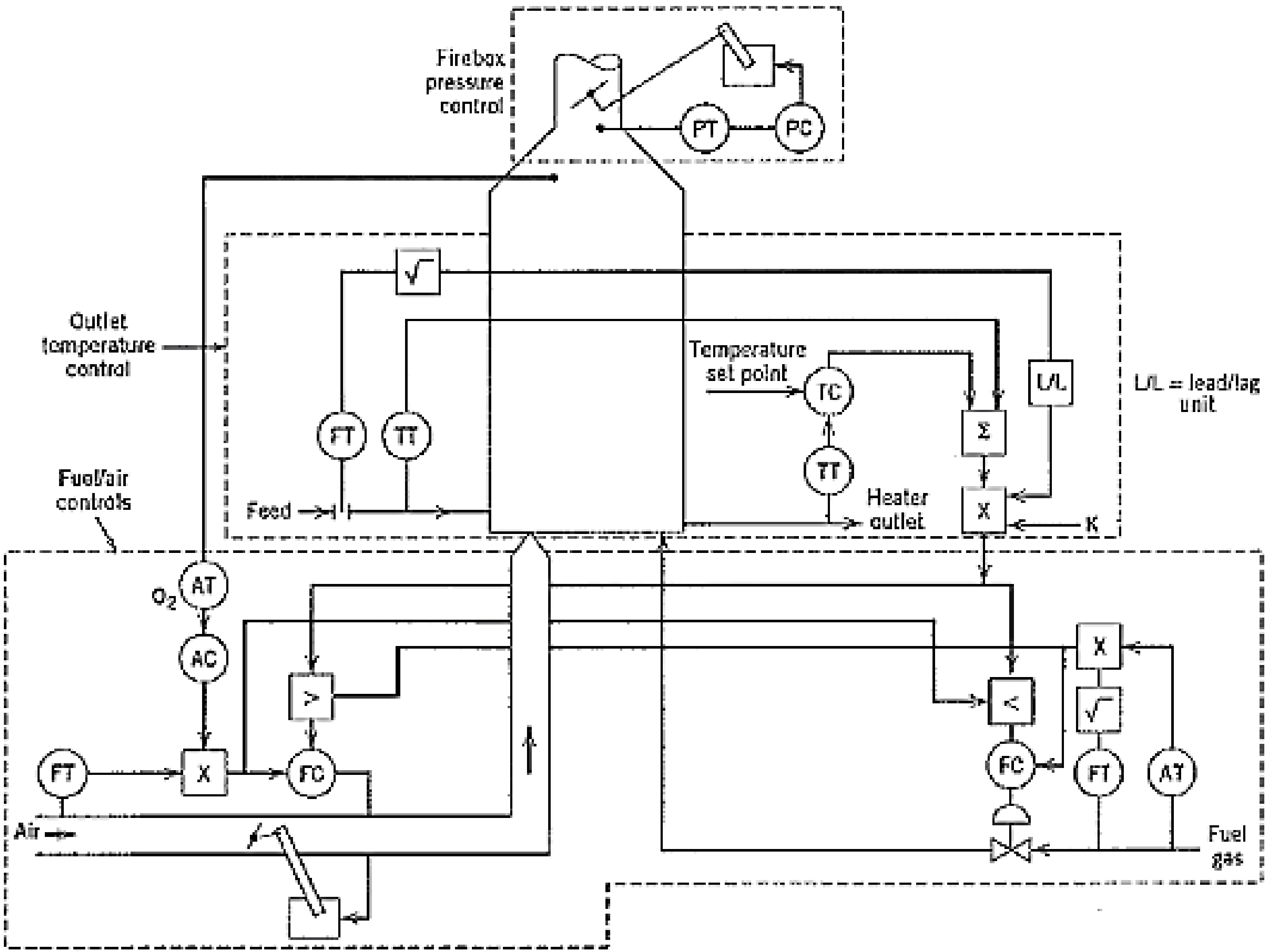

Firebox pressure control
PT
PC
Outlet temperature control
FT
TT
Temperature set point
TC
TT
Heater outlet
Feed
L/L
L/L = lead/lag unit
Σ
X
K
Fuel/air controls
O_2
AT
AC
FT
X
>
FC
<
FC
X
FT
AT
Air
Fuel gas

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GOOD PRACTICES

- Generally the flame length should be 60% of the firebox length
- The clearance between the flame and tubes at least 1.5 ft
- For small cylindrical heaters, the tube circle should be equal to the length of the firebox. For small cabin heaters, the width, height, and tube length should be equal
- For large heaters the height of a cylindrical heater is twice the tube circle, and for cabins a good ratio of width to height to length is 1:2:4
- The firebox shell is reinforced steel plate. The insulation behind the tubes is usually 5 in. of 1:2:6 lumnite (cement), haydite (aggregate), vermiculite (insulation) castable.

GOOD PRACTICES

– The floor is at least 6 in. of 1:2:6 castable, often with a firebrick surface. The bridge wall is always firebrick
– By far the most common tube material is A-106B carbon steel
– The nominal size range is 2 to 8 inch with 3 and 4 inch the most prevalent
– Short radius return bends are standard and the tubes are usually 1.5 nominal diameters from the refractory wall
– Tubes are typically spaced at two pipe nominal sizes
– Typical Recommended excess air levels

	Natural draft	Forced draft
Fuel Gas	15-20%	10-15%
Light Fuel Oil	20-25%	15-20%
Heavy Fuel Oil	25-30%	20-25%

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GOOD PRACTICES

– The floor is at least 6 in. of 1:2:6 castable, often with a firebrick surface. The bridge wall is always firebrick
– The first two rows of the convection section are called shock tubes and they “see” the firebox flame
– The first row receives the full radiant heat flux and also some convective heat transfer. It has the highest heat transfer flux in the heater and is always bare tubes
– The second shock row receives about one third of the radiant flux as well as convective heat transfer from the flue gas. It is also bare tubes
– Typically when natural gas is the fuel, the convection section fins are 1 in. high, 0.06 in. thick and up to 72 fins per linear ft

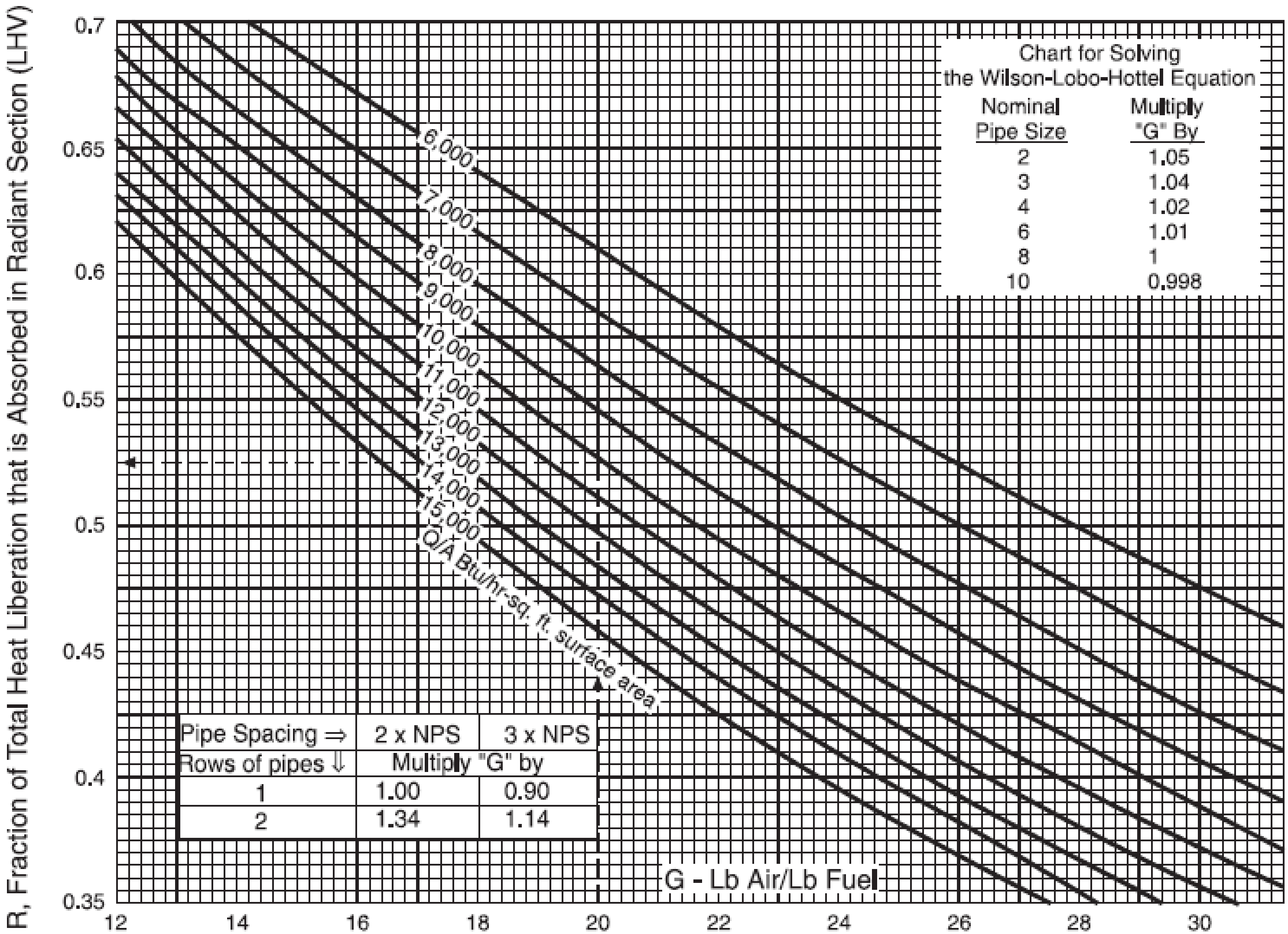
GOOD PRACTICES

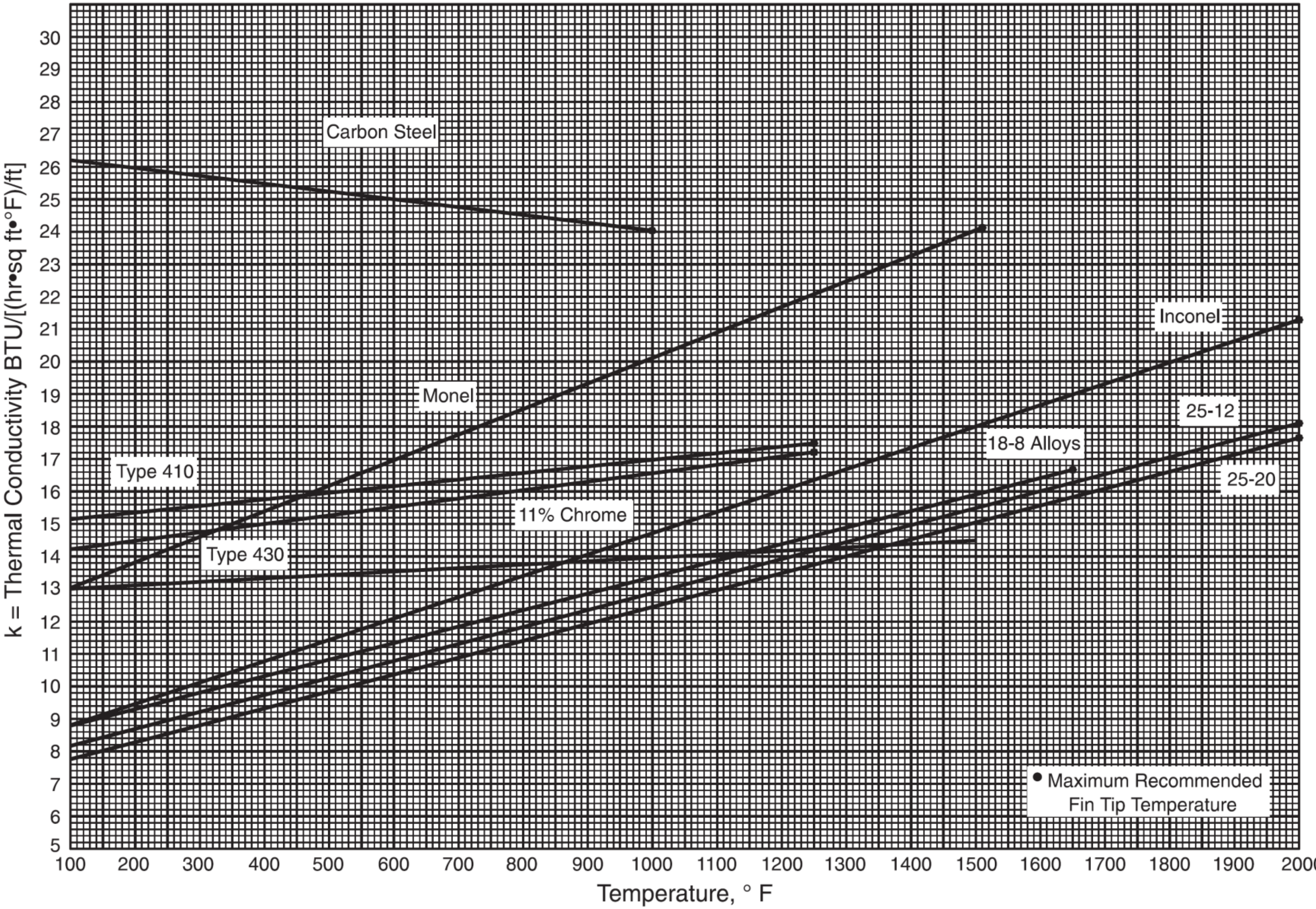
- For oil fired heaters where soot deposition is possible, the fins are 1 in. high, 0.105 in. thick and not more than 36 fins per ft
- Generally the first finned row has fewer, shorter, and thicker fins to reduce the fin tip temperature.
- Where ash and soot fouling are expected, a lane is left every four or five rows for soot blowers.
- The fins compensate for the low flue gas heat transfer coefficient.
- Typically, the heat flux in the convection section is 2000–4000 Btu/(hr·sq ft) of finned surface or 12,000–24,000 Btu/(hr·sq ft) on a bare tube basis

GOOD PRACTICES

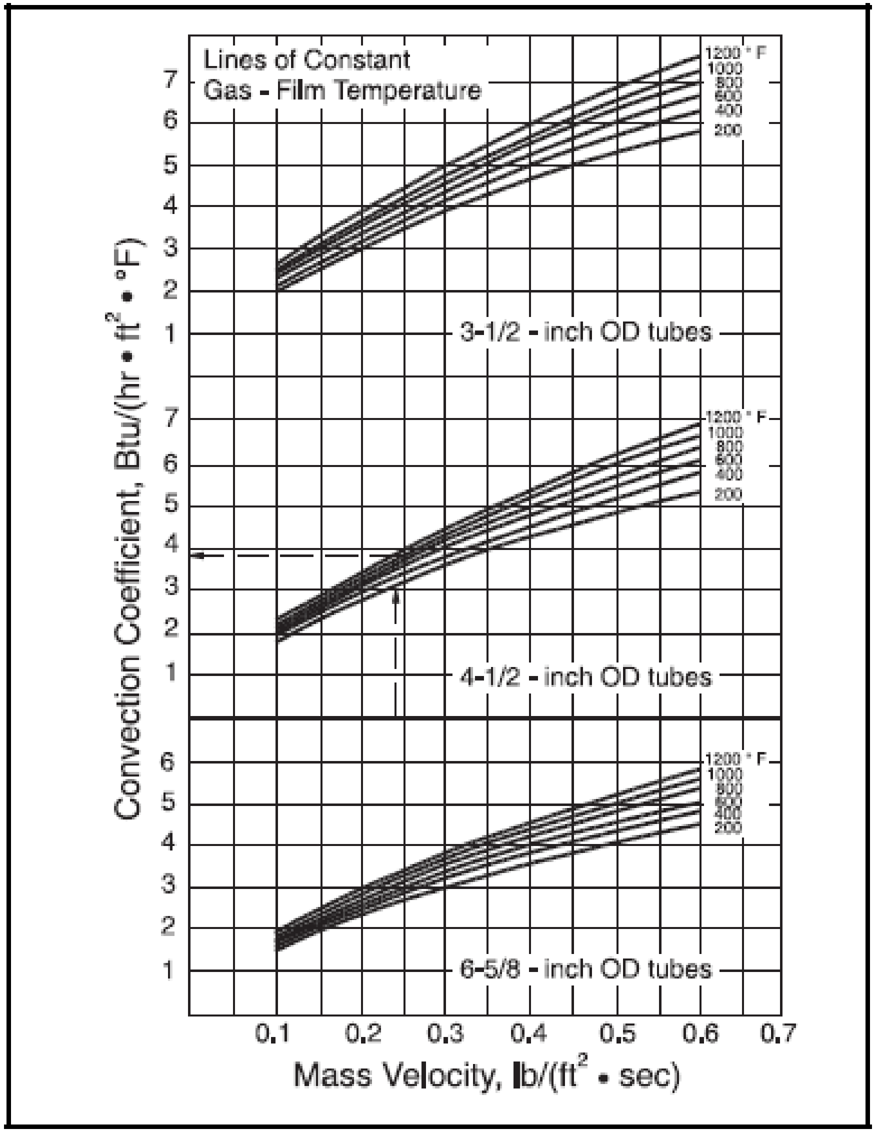
- Cast iron tube supports can be used below 800°F and 25%Cr–12%Ni is good up to 2000°F.
- With high vanadium or sodium levels in the fuel oil, 50%Cr–50%Ni must be used
- The distance between supports for horizontal tubes should be the lesser of 35 outside tube diameters or 20 ft
- The distance between supports on vertical tubes should not exceed either 70 tube diameters or 40 ft
- The stack diameter is generally sized for 15 to 20 ft/sec stack gas velocity
- The stack is normally bare carbon steel but must be lined if the flue gas temperature exceeds 750°F or if the fuel has high sulfur content

GOOD PRACTICES





k = Thermal Conductivity BTU/[(hr•sq ft•°F)/ft]
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
Carbon Steel
Inconel
Monel
25-12
18-8 Alloys
Type 410
25-20
11% Chrome
Type 430
• Maximum Recommended Fin Tip Temperature
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000
Temperature, ° F


Lines of Constant
Gas - Film Temperature
1200 ° F
1000
800
600
400
200
3-1/2 - inch OD tubes
4-1/2 - inch OD tubes
6-5/8 - inch OD tubes
Convection Coefficient, Btu/(hr • ft² • °F)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Mass Velocity, lb/(ft² • sec)

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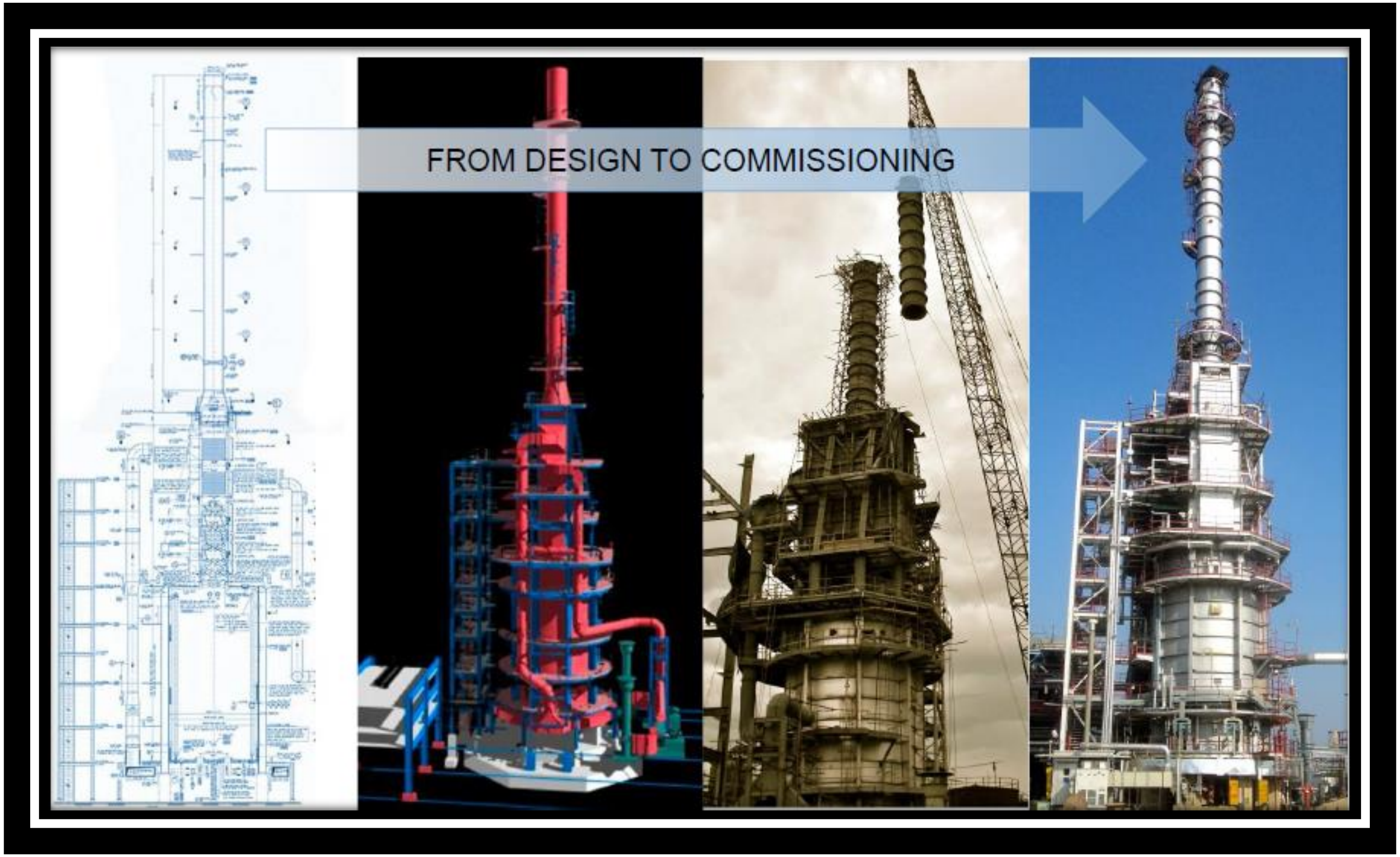
OVERVIEW



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QUERIES

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Thank you