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of Process Equipment Design

REFINERY FURNACE
SELECTION, SIZING
AND TROUBLESHOOTING

(ENGINEERING DESIGN GUIDELINES)</td><td>Co Authors

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INTRODUCTION

Scope

This guideline provides knowledge on designing, operating and troubleshooting a refinery heater. This design guideline can assist in understanding the basic design of refinery heaters with suitable size, materials of construction and heat of combustion. A refinery heater is one of the most important pieces of equipment in a refinery processing plant. Refinery heater's firing provides a large part of the heat for the process. This heat for the process comes from the combustion of fuels.

Fired heaters and boilers are essential components of most refineries, chemical plants and power generation facilities. Process heaters are widely used in petroleum refineries, where they are called refinery heaters. Process heaters are used to transfer heat generated by the combustion of fuels to a fluid other than water contained in tubes. This fluid may either be process fluid or a heat transfer fluid. They are used for pre-heating crude oil and other feed stocks for many refinery processes where the use of steam from boilers may not be practical.

One of the problems encountered in refinery fired heater is an imbalance in the heat flux in the individual heater passes. This imbalance may cause high coke formation rates and high tube metal temperatures, which reduce a unit's capacity and can cause premature failures. Coke formation on the inside of heater tubes reduces the heat transfer through the tubes, which leads to the reduced capacity.

The choice of refinery heater style and design is crucial for the best performance of furnace. Factors affecting the performance of refinery heater are influenced by the maximum amount of the heat absorbed, the capacity of burners, process requirements, economics and safety.

The theory section explains the selection of the refinery heater type, calculation of sizing, heat transfer concepts and combustion basics. The application of the refinery heater theory with the examples assists the user to study the refinery heater concepts and be prepared to perform the actual design of the refinery heater.

General Design Consideration

Heat is one of most important things in the process plant industry. Equipment that produces and supplies the heat requirement to process plant is called a furnace. Furnaces have high temperatures, open flames, oxygen and fuel; all the components of combustion. The term furnace can also refer to a direct fired heater. They expose hydrocarbon stream to heat that drives a distillation tower, a reactor, and in some cases, change the stream's molecular structure through cracking.

Fired heaters and boilers are essential components of most refineries, chemical plants and power generation facilities. Process heaters are used to transfer heat generated by the combustion of fuels to a fluid other than water contained in tubes. This fluid may either be process fluid or a heat transfer fluid. They are used for pre-heating crude oil and other feed stocks for many refinery processes where the use of steam from boilers may not be practical.

Process heaters are useful where a temperature higher than that easily obtainable with steam is necessary. Process heaters bum a variety of fuels, including natural gas, refinery and process gas and distillate and residual oils. Process heaters are widely used in petroleum refineries, where they are called refinery heaters. Applications include

- preheating crude oil and other feeds for distillation,
- hydrotreating,
- reforming and
- coking.

In some operations, such as thermal cracking, chemical reactions occur in the process heater tubes. Total annual process heater energy consumption in refineries is approximately 2.3 quadrillion Btu, equivalent to a mean of 260,000 MMBtu/hr (on a three-shift, 365-day basis).

Typical process heaters can be summarized as follows:

- Start-Up Heater — Starts-up a process unit where it is required to heat up a fluidized bed of catalyst before adding the charge.
- Fired Reboiler — Provides heat input to a distillation column by heating the column bottoms and vaporizing a portion of it. Used where heat requirement is greater than can be obtained from steam.
- Cracking Furnace — Converts larger molecules into smaller molecules, usually with a catalyst (pyrolysis furnace).
- Process Heater — Brings feed to the required temperature for the next reaction stage.
- Process Heater Vaporizer — Used to heat and partially vaporize a charge prior to distillation.
- Crude Oil Heater — Heats crude oil prior to distillation.
- Reformer Furnace — Chemical conversion by adding steam and feed with catalyst.

Basically, a furnace has four basic components, consisting of box, burner, coil, and stack. The burner will produce the heat then the heat liberated by the combustion of fuel is transfer to a process fluid flowing through tubular coils. Figure 1 show the components of fired heater.

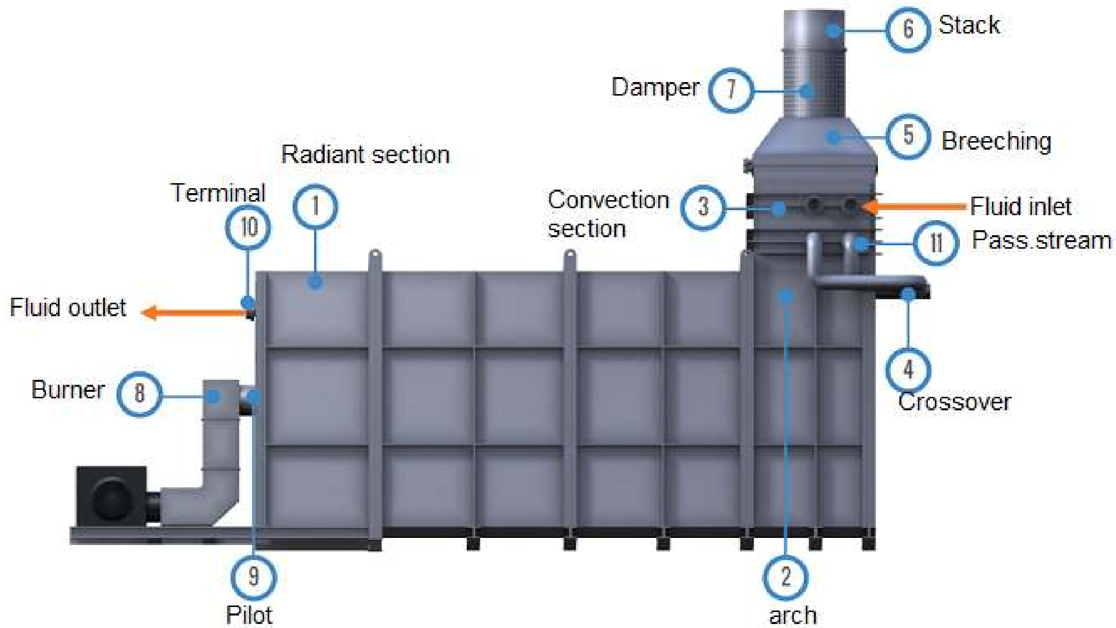


Figure 1: Heater components (THM)

1. radiant section –portion of the heater in which heat is transferred to the tubes primarily by radiation
2. arch–flat or sloped portion of the heater radiant section opposite the floor
3. convection section –portion of the heater in which the heat is transferred to the tubes primarily by convection
4. crossover–inter-connecting piping between any two heater-coil sections
5. breeching–heater section where flue gases are collected after the last convection coil for transmission to the stack or the outlet ductwork
6. stack–vertical conduit used to discharge flue gas to the atmosphere
7. damper–device for introducing a variable resistance in order to regulate the flow of flue gas or air

Note: In some cases, like smaller forced-draft systems, a damper is not used.

8. burner–device that introduces fuel and air into a heater at the desired velocities, turbulence and concentration to establish and maintain proper ignition and combustion

   Note: Burners are classified by the type of fuel fired, such as oil, gas, or combination (also called dual fuel).

9. pilot–small burner that provides ignition energy to light the main burner
10. terminal–flanged or welded connection to or from the coil providing for inlet and outlet of fluids
11. pass/stream–flow circuit consisting of one or more tubes in series

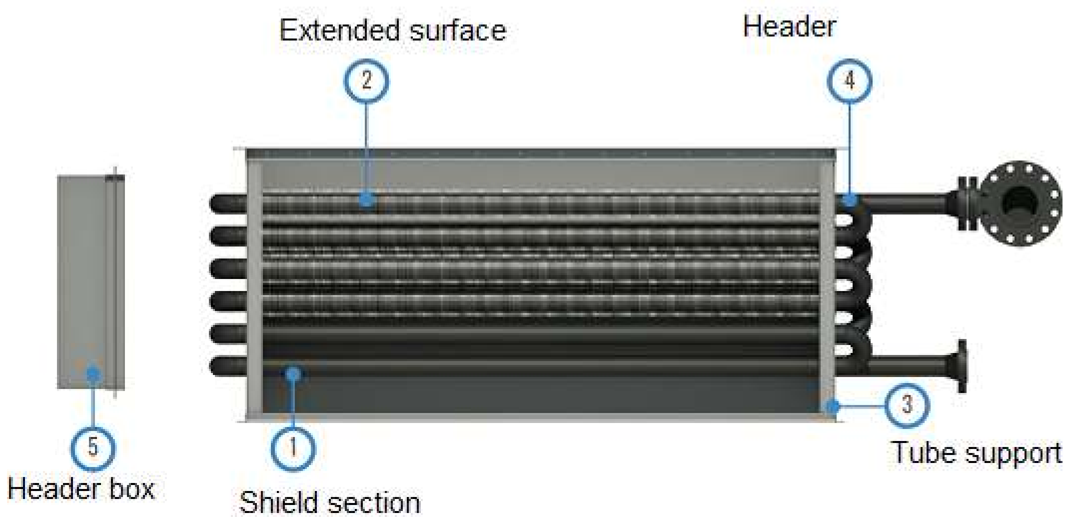


Figure 2: Convection Section (THM)

1. shield section/shock section–tubes that shield the remaining convection-section tubes from direct radiation

2. extended surface–heat-transfer surface in the form of fins or studs attached to the heat-absorbing surface
3. tube support/tube sheet–device used to support tubes
4. header (return bend)–cast or wrought fitting shaped in a 180°bend and used to connect two or more tubes
5. header box–internally insulated structural compartment, separated from the flue-gas stream, which is used to enclose a number of headers or manifolds

Below are several types of furnace:

1. Vertical cylindrical fired heater

This furnace is commonly used in hot oil service and other processes where the duties are usually small. These heaters are probably the most common in use today and are used for heat duties up to about 150 MBtu/hr. This type of cylindrical upright, tube in the radiant section mounted vertically in a circle round of the burner. The burner is located on the bottom floor, so that the flame is parallel with the tube. Fire heater of this type can be design without or with convection section. Below is kinds of the cross section of vertical-cylindrical fired heater.

a. **Vertical cylindrical all radiant**:

The all-radiant heater is inexpensive, but since the temperature of flue gases leaving the heater is high, 1500 – 1800°F . Heater of this type does not have convection section. Usually this type have low efficiency and heat duty ranges from 3-7 million kcal/hour.

b. **Vertical cylindrical helical coil**:

The coil is arranged helically along the cylindrical wall of the combustion chamber. Its primary use is to heat thermal fluids and natural gas. Capacities range from 1 to 30 million Btu/hour.

c. **Vertical cylindrical with crossflow convection section**:

The convection section is installed above the combustion chamber. Mostly, air preheater are added to increase the efficiency. Heat duty of this type from 5-35 million kcal/hour.

d. **Vertical cylindrical with integral convection**:

The distinguishing feature of this type is the use of added surface area on the upper part of the radiant coil to promote convection heating. This type is added surface area on the upper part of the radiant coil to promote convection heating. Duties are from 2.5 – 25 million kcal /hr.

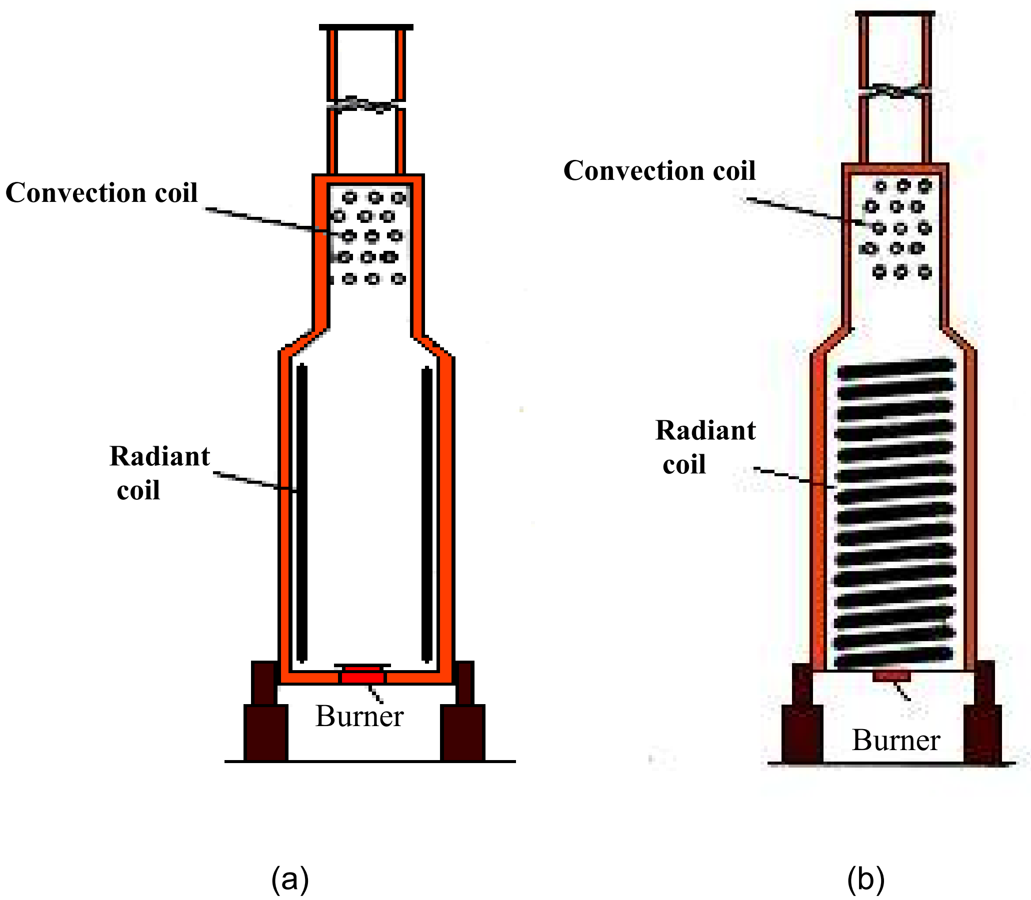


Figure 3: Vertical cylindrical fired heater: (a) all radiant and (b) helical coil

2. Horizontal tube cabin fired heaters

This cabin has room type consists of the radiation and convection. Tube-tube mounted horizontally while the burner is located on the floor furnace, so that the flame is not straight and parallel to the wall heater. The first layer of tubes in the convection section directly facing into combustion chamber or the radiant fire box called shield tubes. The burner mounted on the floor of the cabin and fire is directed vertically.

Cabin fired heater have some variation in the application. It is like cabin furnace with a centre wall. In the figure below the fire heater usually can be used for the large fired heater and has two separate heating zones are required in the radiant section. This design is economical, high efficiency duties are from 20 - 50 million kcal/hour. In many operations, about 75% of the heat is absorbed in the radiant zone of a fired heater.

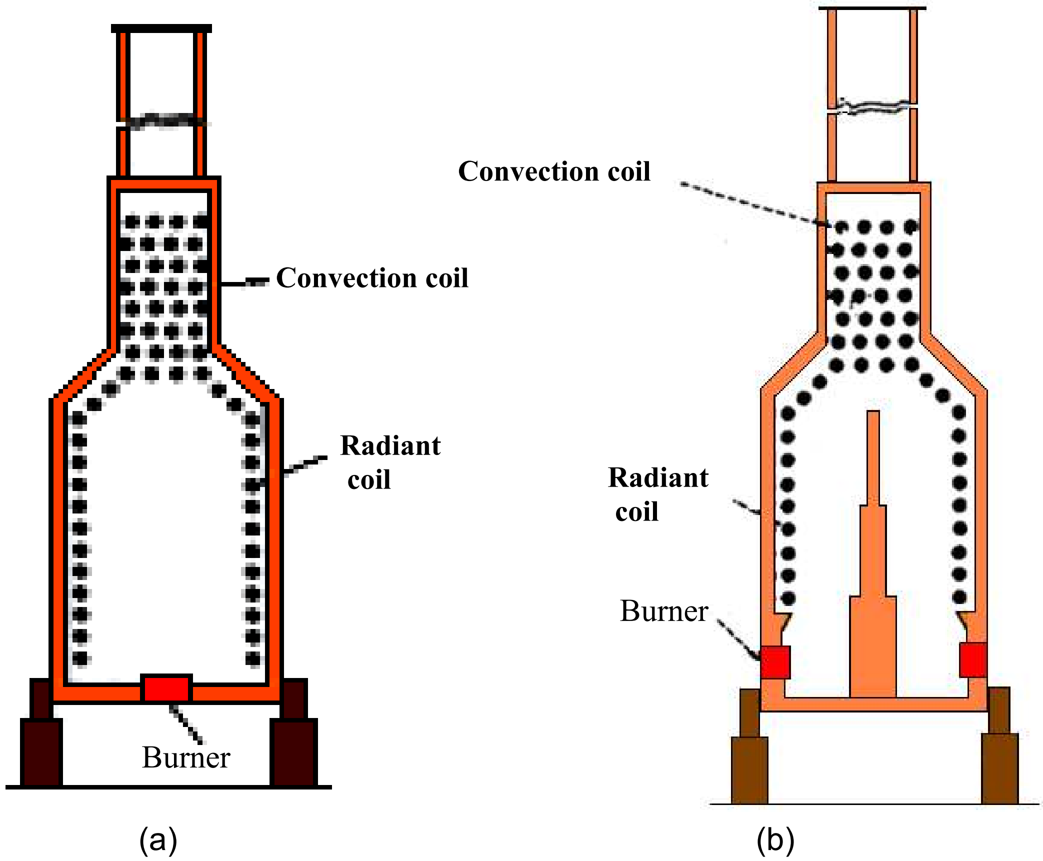


Figure 4: Horizontal tube cabin fired heaters: (a) cabin with convection section and (b) cabin with dividing bridge wall

3. Hoop-tube fired heater

This fire heater has tube bent like U-type with vertically oriented. In all-vapor flow, non-coking services where low coil pressure drop is desired. This design is used where the pressure drop must be very low since the path through each tube provides a design with many passes. Application of this type is in the catalytic reformers charge heater. Duties are from 13-25 million kcal/hr.

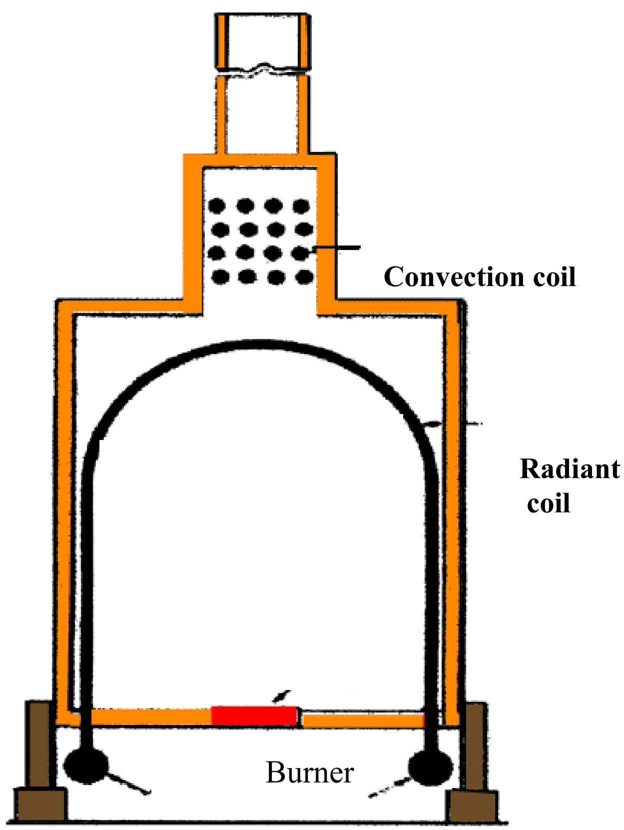


Figure 5: Hoop-tube fired heater

4. Vertical tube box fired heaters

In this fire heater, tubes stand vertically along wall in the radiant section. Vertical radiant tubes are arranged in a single row in each combustion cell (there are often two cells) and are fired from both sides of the row. Such an arrangement yields a uniform distribution of heat-transfer rates about the tube circumference. This heater is suitable for the large forced-draft burners. Requirement of heat input to each cell provided by burner.

5. Horizontal tube box fired heaters

The radiant and convection section in a typical of horizontal tube box in the Figure 5 are separate by a wall called bridge wall. Function of bridge wall is to create a good direction of flame and to stream the smoke in to flue stack. Burners are firing from the floor along both sides of the bridge wall. Duties are from 30 to 8 million kcal /hour.

6. Multiple cell heaters

For two-cell horizontal tube box have high efficiency, duties from 25-65 million kcal/hour.

7. Helical coil fired heater

This heater configuration is commonly used where the duties are small. Since each pass consists of a separate winding of the coil, pressure drop options are limited. Many of these only have a radiant section, since efficiency is often not that critical, especially in intermittent services like for a regeneration heater.

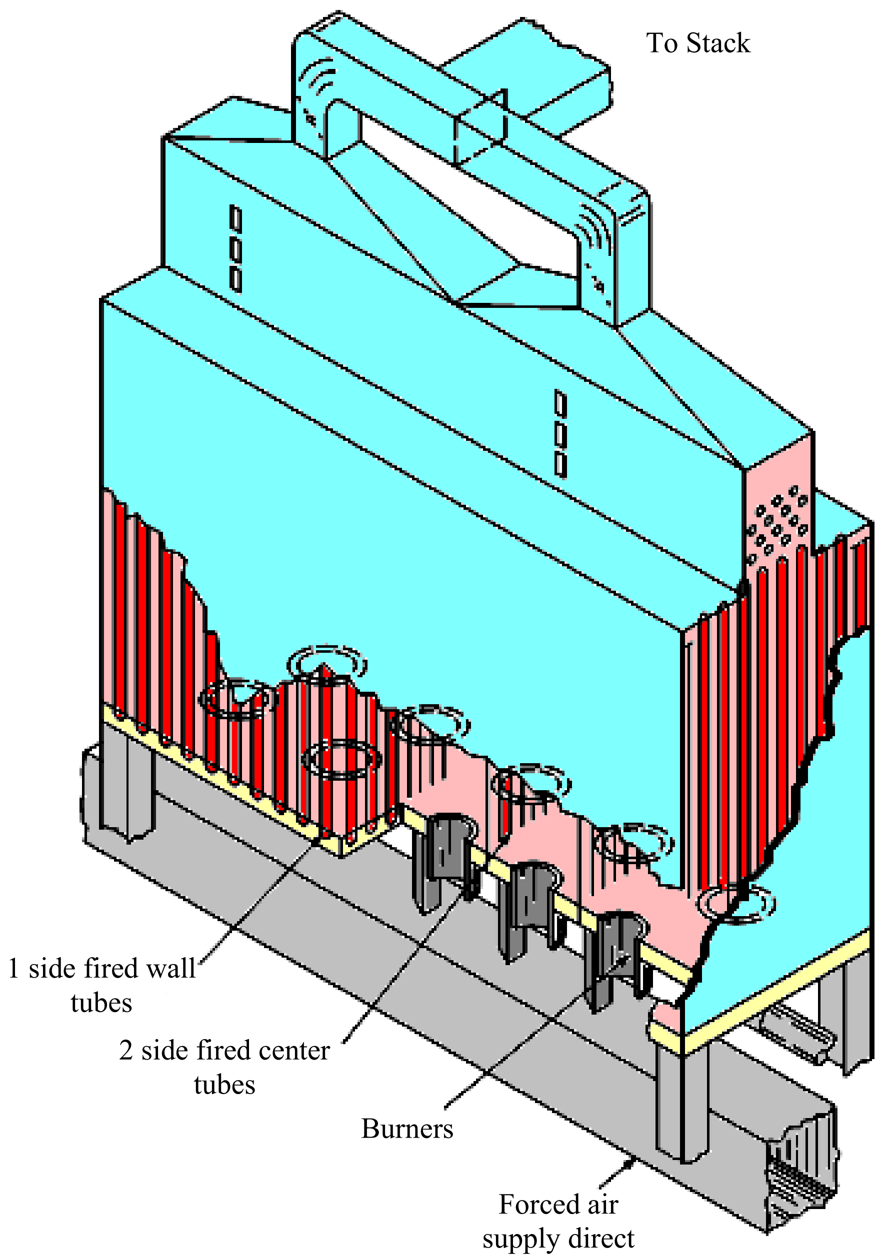
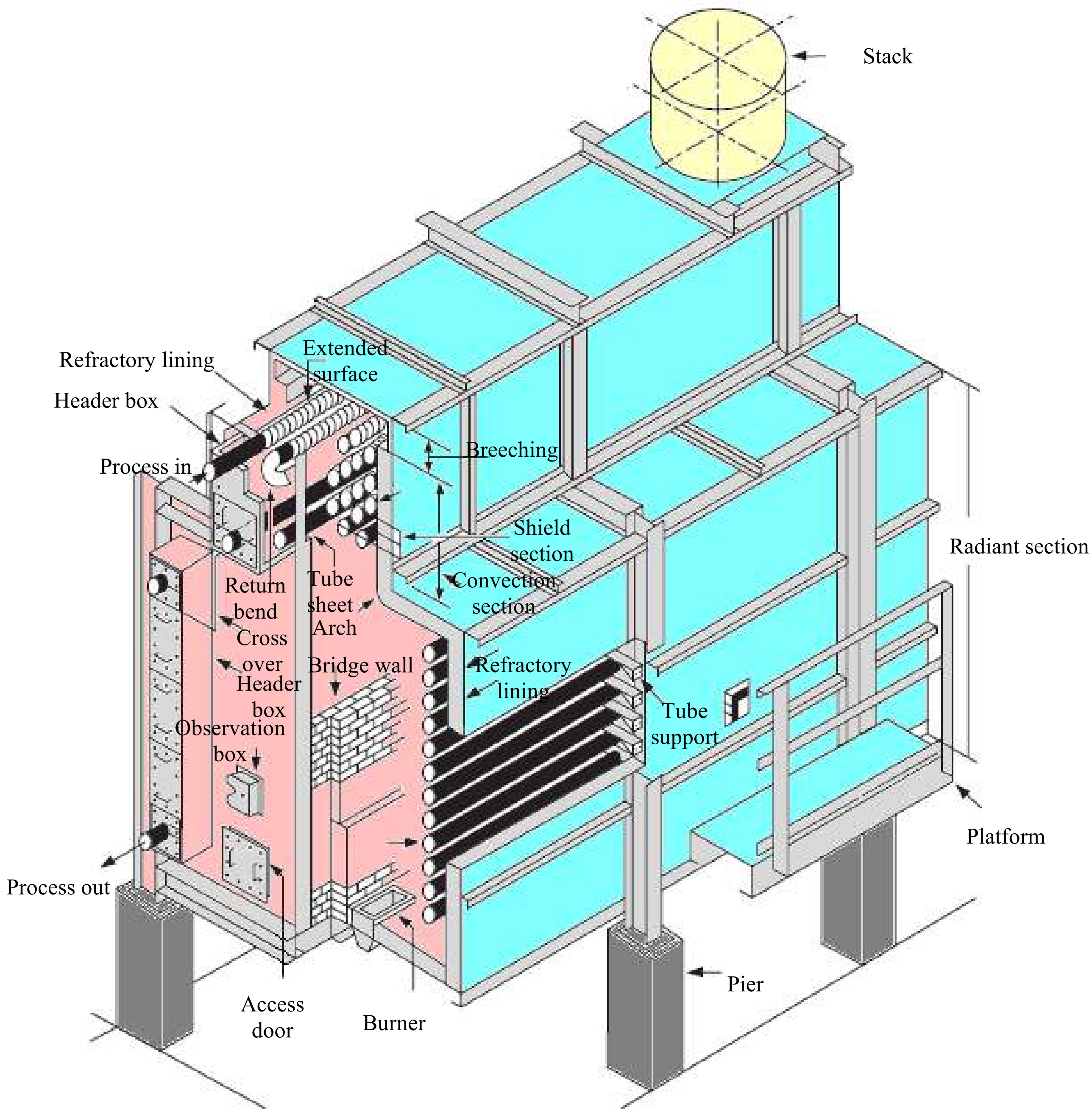


Figure 6: Vertical tube box fired heaters


Stack
Extended surface
Refractory lining
Header box
Process in
Breeching
Shield section
Radiant section
Convection section
Return bend
Tube sheet
Arch
Cross over
Header box
Bridge wall
Refractory lining
Tube support
Observation box
Platform
Process out
Pier
Access door
Burner

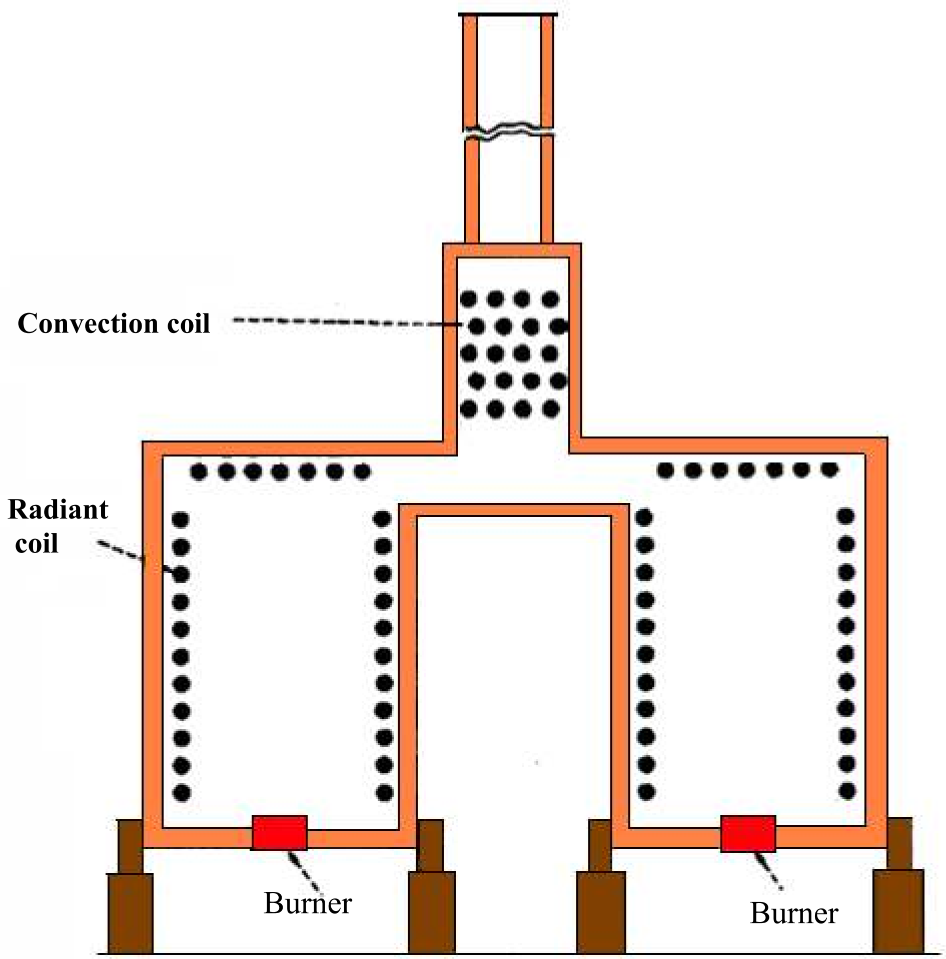


Figure 8: Multiple cell heaters

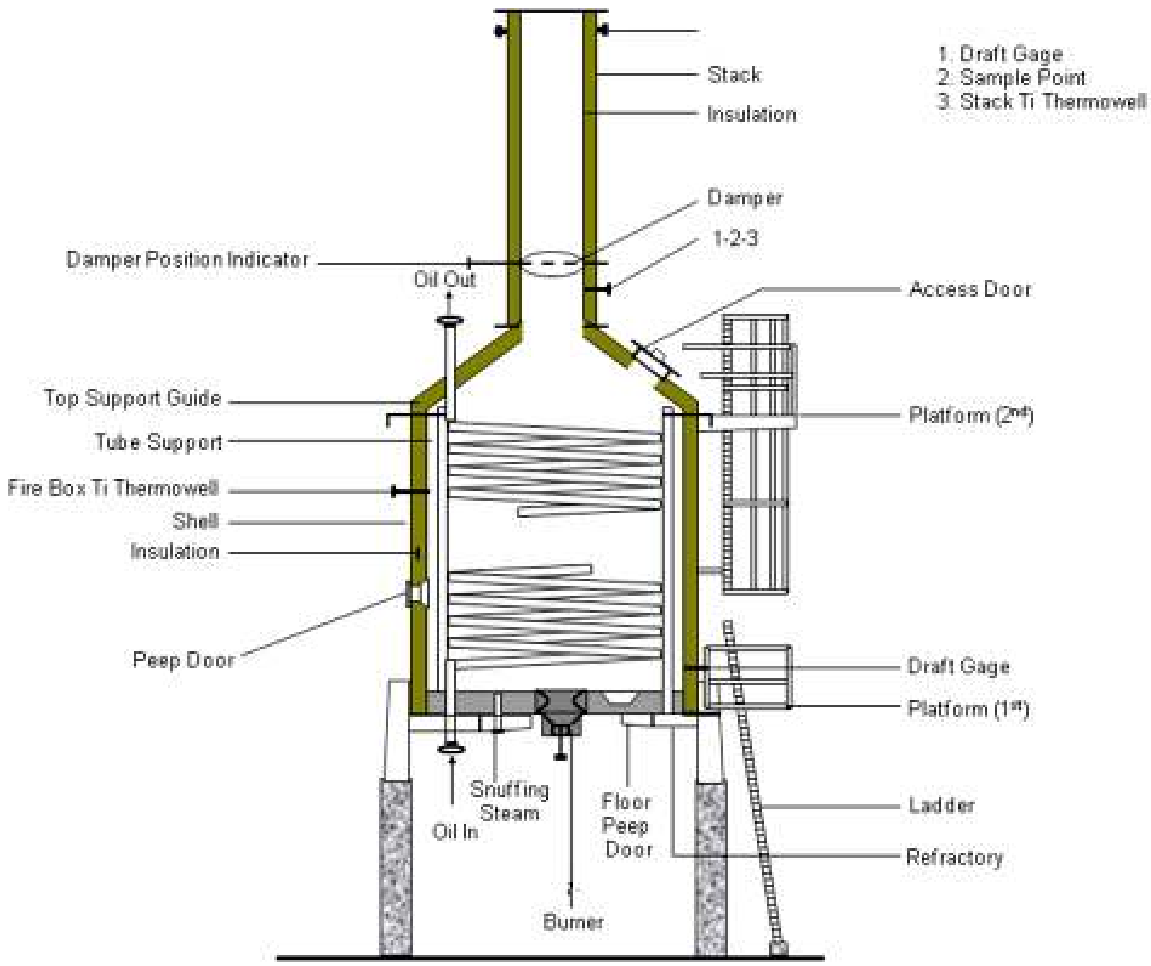
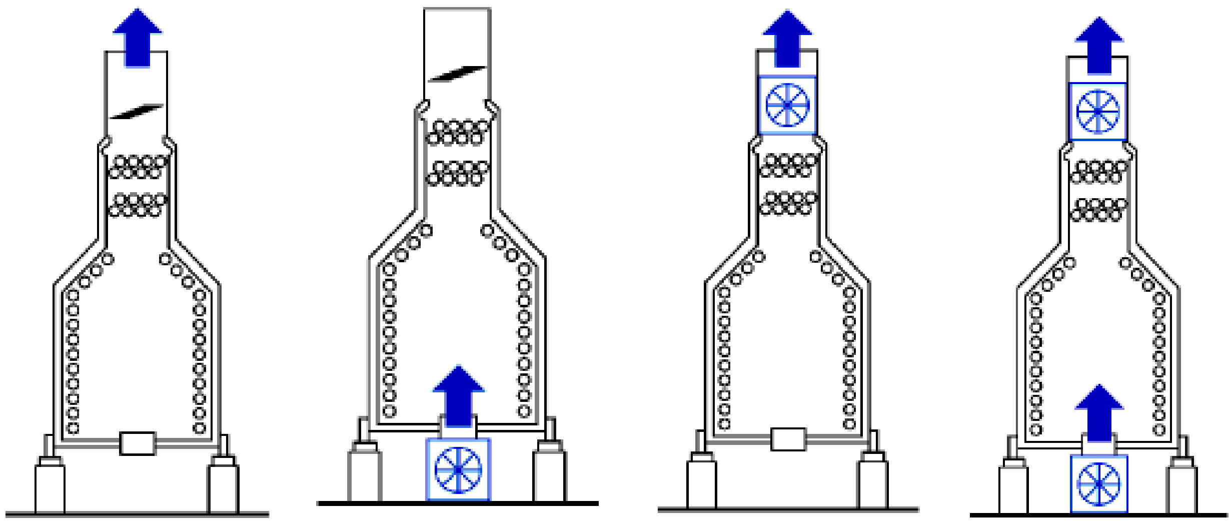


Figure 9: Helical coil fired heater

Various liquid and gas fuels are fired. These include natural gas, refinery fuel gas, propane, fuel oils, residual oils and refinery waste gases. Each has advantages and disadvantages. Cleaner burning fuels are those that produce very little particulate and sulphur oxide emissions. Unless nitrogen oxide emissions are a concern, emission control systems are not typically required. Natural gas is generally considered to be the cleanest of fuels. The downside with using clean fuels can be fuel costs.

Over 75 percent of process heaters are natural draft; air is drawn to the burners by a pressure differential created by the heat of combustion. Natural draft heaters are simpler and less expensive to construct,

Another type of process heater, the mechanical draft heaters, uses one or more fans to supply combustion air to, and remove flue gases from, the heater. Further, mechanical draft systems can use combustion air preheat, which increases energy efficiency and decreases fuel consumption. However, higher heater temperatures that result from the use of preheated combustion air lead to increased thermal NOx formation in the heater. This accounts for higher NOx emissions from mechanical draft heaters than from natural draft heaters.



(a) (b) (c) (d)

(a) natural draft –heater in which a stack effect induces the combustion air and removes the flue gases

(b) forced-draft –heater for which combustion air is supplied by a fan or other mechanical means

(c) induced-draft –heater that uses a fan to remove flue gases and to maintain negative pressure in the heater to induce combustion air without a forced-draft fan

(d) balanced draft –heater that uses forced-draft fans to supply combustion air and uses induced draft fans to remove the flue gases

Figure 10: Draft Types

DEFINITIONS

Air Preheater - Heat exchanger device that uses some of the heat in the flue gases to raise the temperature of the air supply to the burners.

Breeching - The hood that collects the flue gas at the convection section exit.

Bridge-wall Temperature - The temperature of the flue gas leaving the radiant section

Bulk Temperature - The average temperature of the process fluid at any tube cross section.

Center Wall - A refractory wall in the radiant section, which divides it into two separate cells.

Coil - A series of straight tube lengths connected by 180^o return bends, forming a continuous path through which the process fluid passes and is heated.

Convection Section - The portion of a heater, consisting of a bank of tubes, which receives heat from the hot flue gases, mainly by convection.

Corbelling - Narrow ledges extending from the convection section side walls to prevent flue gas from flowing preferentially up the side of the convection section, between the wall and the nearest tubes.

Crossover - Piping which transfers the process fluid either externally or internally from one section of the heater to another.

Damper - A device to regulate flow of gas through a stack or duct and to control draft in a heater.

Draft - The negative pressure (vacuum) at a given point inside the heater, usually expressed in inches of water.

Excess Air - The percentage of air in the heater in excess of the stoichiometric amount required for combustion.

Extended Surface - Surface added to the outside of bare tubes in the convection section to provide more heat transfer area.

Film - A thin fluid layer adjacent to a pipe wall that remains in laminar flow, even when the bulk flow is turbulent.

Film Temperature - The maximum temperature in the film, at the tube wall.

Fire Box - A term used to describe the structure which surrounds the radiant coils and into which the burners protrude.

Flue Gas - A mixture of gaseous products resulting from combustion of the fuel.

Fouling - The building up of a film of dirt, ash, soot or coke on heat transfer surfaces, resulting in increased resistance to heat flow.

Forced Draft - Use of a fan to supply combustion air to the burners and to overcome the pressure drop through the burners.

Fired Heater Efficiency - The ratio of heat absorbed to heat fired, on a lower heating value basis.

Header Box - The compartment at the end of the convection section where the headers are located.

Heat Available - The heat absorbed from the products of combustion (flue gas) as they are cooled from the flame temperature to a given flue gas temperature.

Heat Density - The rate of heat transfer per unit area to a tube, usually based on total outside surface area.

Heat Duty - The total heat absorbed by the process fluid, usually expressed in MBtu/hr

Induced Draft - Use of a fan to provide the additional draft required over that supplied by the stack, to draw the flue gas through the convection section, and any downstream heat recovery equipment.

Lower Heating Value (LHV) - The theoretical heat of combustion of a fuel, when no credit is taken for the heat of condensation of water in the flue gas.

Mass Velocity - The mass flow rate per unit of flow area through the coil. Typical units are lb/s-sq. ft.

Natural Draft - System in which the draft required to move combustion air into the heater and flue gas through the heater and out the stack is provided by stack effect alone.

Net Fuel - The fuel that would be required in the heater if there were no radiation losses.

One-Side Fired Tubes - Radiant section tubes located adjacent to a heater wall have only one side directly exposed to a burner flame. Radiation to the back side of the tubes is by reflection/ re-radiation from the refractory wall.

Pass - A coil that transports the process fluid from fired heater inlet to outlet.

Radiant Section - The section of the fired heater in which heat is transferred to the heater tubes primarily by radiation from high-temperature flue gas.

Service Factor – A measure of the continuity of operation, generally expressed as the ratio of total running days for a given time period to the total calendar days in the period.

Shield Section - The first two tube rows of the convection section.

Sootblower - A steam lance (usually movable) in the convection section for blowing soot and ash from the tubes using high-pressure steam.

Stack - A cylindrical steel, concrete or brick shell which carries flue gas to the atmosphere and provides necessary draft.

Stack Effect - The difference between the weight of a column of high-temperature gases inside the heater and/or stack and the weight of an equivalent column of external air, usually expressed in inches of water per foot of height.

Stack Temperature - The temperature of the flue gas as it leaves the convection section, or air preheater directly upstream of the stack.

Two-Side Fired Tubes - Radiant section tubes which are exposed on both sides to direct radiation from the burners.

NOMENCLATURES

A_{cp}	Cold plane area, (ft^2)
A_r	Radiant surface area (ft^2)
A_{rl}	Right and left area (ft)
A_{shield}	Tube shield area, (ft^2)
A_{tube}	Area of tube, (ft^2)
A_w	Refractory surface (ft^2)
C	Capacity design (btu/hr)
C/H	C/H ratio, %
cp_a	Specific heat capacity of the air, Btu/lb.°F
cp_f	Specific heat capacity of the fuel, Btu/lb.°F
cp_m	Specific heat capacity of the atomizing medium, Btu/lb.°F
e_f	Fuel efficiency, %
E_{ff}	Efficiency of furnace, %
e_g	Gross thermal efficiency, %
F	Exchange factor
G	Flue gas flow rate (lb/sec ft2)
G_f	Flue gas rate, (lb/hr)
H	Shell height (ft)
H_{CS}	Height of convection section (in)
h_H	Higher massic heat, Btu/lb
h_L	Lower massic heat value of the fuel burned, btu/lb
$H_{persection}$	Height per section (in)

h_r	Radiation massic heat loss, btu/lb
h_s	Massic heat content, btu/lb
H_{wall}	Wall height (ft)
L	Shell length (ft)
L_{bft}	The total length of bare of finned tubes, (ft)
L_{bm}	Mean beam length (ft)
L_{exp}	Exposed length (ft)
m_{st}	Mass of atomizing steam per unit mass of fuel, lb/lb
$N_{bsection}$	Number of radiant burner per section
N_{burner}	The number of burner
N_r	Amount of radiant section
$N_{t1\ section}$	Number of tube in 1 section
N_{tc}	Number of tube in ceiling area,
$N_{tchamber}$	Number of tube in 1 chamber,
N_{tr}	Number of tube in radiant section,
N_{trl}	Number of tube in right and left area,
N_{trl}	Number of tube in right and left area,
N_{ts}	Number of tube in shield area,
OD	Outside tube diameter (in)
P	Partial pressure of CO2 and H2O (atm)
P_{vap}	Vapour pressure of water at the ambient temperature, mbar a
Q_a	Heat absorbed needed (btu/hr)
Q_{conv}	Heat in convective zone, (btu/lb)
Q_n	Heat released (btu/lb)
Q_{ra}	Radiant heat absorption (btu/hr)
Q_{rac}	Radiant heat absorbed calculated (btu/hr)
Q_{rf}	Radiant heat flux (btu/hr ft^2)
Q_{rfc}	Radiant heat flux (btu/hr ft^2)
R_H	Relatieve humadity, %
r_l	adiation heat loss, %
T_a	Air temperature, F
T_d	Datum temperature, F
T_e	Flue gas temp. to the stack, F
T_f	Fuel oil temperature, F
T_i	Inlet process stream temperature (^{o}F)

T_{LI}	Inlet temperature (°F)
T_{LO}	Outlet temperature (°F)
T_m	Temperature of the atomizing steam, F
T_o	Outlet process stream temperature (°F)
T_S	Stack temperature (°F)
T_{SA}	Stack approach temperature (°F)
T_t	Tube wall temperature (°F)
Uc	Overall heat transfer coefficient (btu/hr ft^2)
$V_{furnace}$	Furnace volume (ft^3)
W	Shell wide (ft)
X_{air}	Fraction excess air
Δh_a	The sensible massic heat corrections, btu/lb
Δh_f	Fuel sensible massic heat correction, btu/lb
Δh_m	Atomizing medium sensible massic heat correction, btu/lb

Greek Leters

Φ	Gas emissivity
αA_r	Effective absortivity (ft^2)
ρ	Density (lb/ft^3)

Superscript

M	Mass molecular