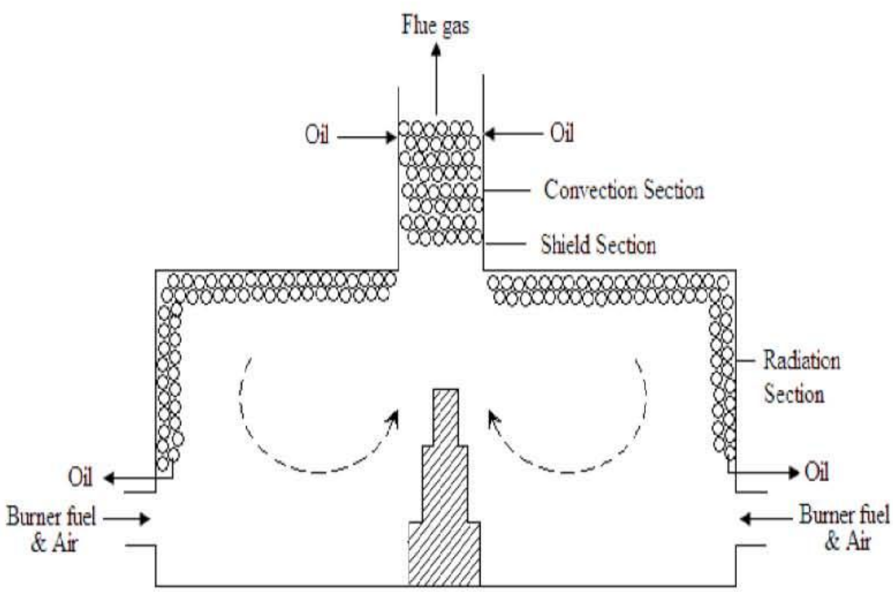
Pipe Still Heaters

Crude oils are heated in pipe still heater before entering into the atmospheric distillation column. This heater is a special type of furnace which heats crude oil up to about 350°C depending on the type of feed.

A large number of tubes connected through bends are housed within the furnace in multiple rows. The still is built with two distinct heating sections, a **radiantion section**, which can receive heat directly from the flame and a **convection section**, which takes heat from the hot gases travelling to the stack.

The hot flue gases arising in the radiation section flow into the convection section where they circulate at high speed through a tube bundle before leaving the furnace through the stack.

Shield or shock section separates the two major heating sections. The tubes in this section are close to the radiation section that protects the convection section tubes from direct radiation. The shield section normally consists of two to three rows of bare tubes that are directly exposed to the hot gases and radiation flame.



Pipe still heater

There are two major types of fired heaters, such as vertical cylindrical or box-type heaters depending on the geometrical configuration of the radiant section.

In box-type heaters, the radiation section usually is of a square or a rectangular cross section. The tubes in the radiation section may be arranged horizontally or vertically along the heater walls and the burners are located on the floor or on the lower part of the longest side wall where there are no tubes. Box-type furnaces are mainly used where large capacities and large heat duties are required.

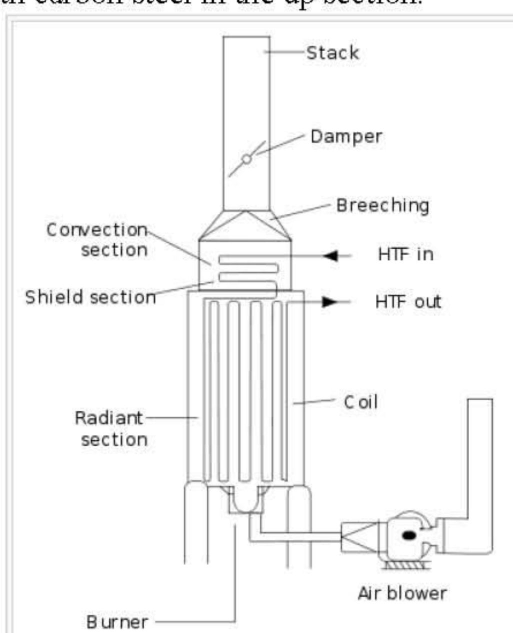
In the cylindrical-type furnace, the radiation section is of the shape of a cylinder having a vertical axis and the burners are situated on the floor at the base of the cylinder.

The vertical walls of the furnace are the heat transfer area and therefore exhibit circular symmetry with respect to the tube bundles. In the radiation section, the tubes may be arranged in a circular pattern around the walls of the furnace or they may have a cross or octagonal design which will expose them to firing from both sides.

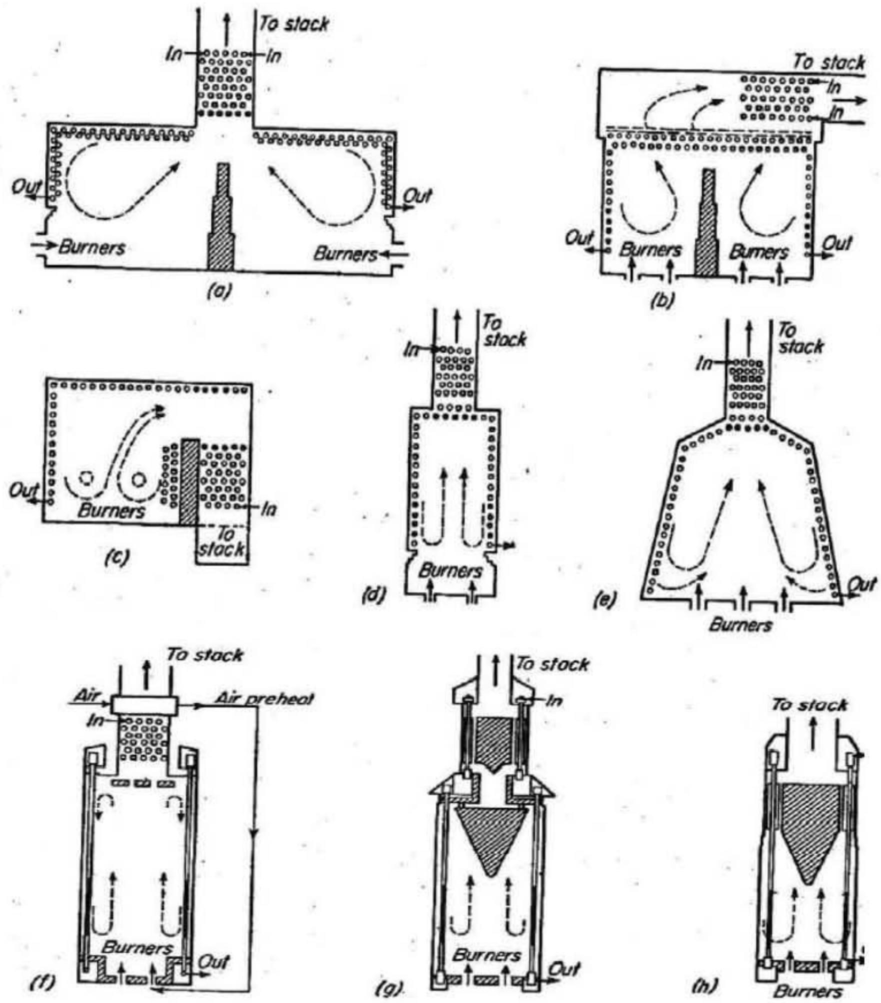
Crude oil is pumped into the furnace through the tubes at the convection section. At this section the crude is preheated and then goes to the radiation section to be heated up to 350°C.

Heat transfer at a high rate is obtained by passing the crude with a high flow rate.

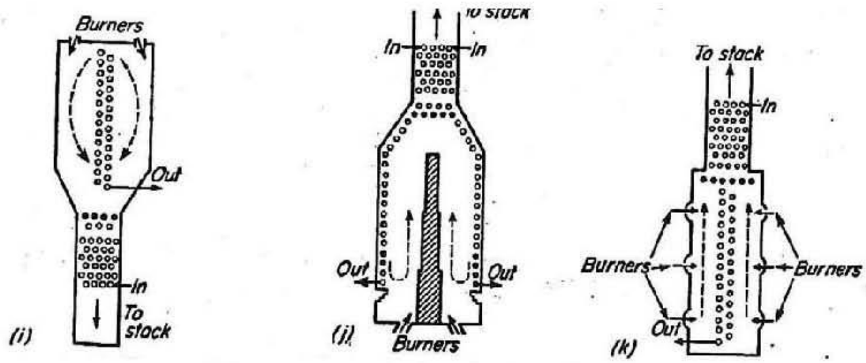
The fired heaters have corrosion and material problems due to the elevated temperatures experienced both on the process side and in the fire-box. The Atmospheric Heater receives flashed crude at about 260°C and sends it to the atmospheric column at about 350°C. For sweet crude, the radiant tubes and lower rows of convection tubes are typically 5% chrome with carbon steel in the up section.



Types of Stills:



(a) Large box-type
(b) Separate-convection (Lummus)
(c) Down-convection
(d) Straight-up (Born)
(e) A-frame (Kellogg)
(f) Circular (DeFlorez)
(g) Large isoflow (Petrochem)
(h) Small isoflow (Petrochem)
(i) Equiflux (UOP)
(j) Double-upfired (UOP)
(k) Radiant wall (Selas)



The radiant section design is based on ***Stefan 's law of radiation*** :

Stefan's law of radiation is fundamental.

$$Q = bAT^4$$

where A = area of radiating surface, sq ft
T = absolute temperature of the surface, °F
Q = Btu transferred per hr
b = 1.72×10^{-9} Btu/(°F diff.)(sq ft)(hr) at black-body conditions

But a surface cannot radiate all this heat to another surface because the cooler surface also radiates heat. For a small body completely surrounded by a hotter body the foregoing statement simplifies to

$$Q = \text{net heat transferred} = Q_2 - Q_1 = bA(T_2^4 - T_1^4) \quad (18\text{-}1)$$

This expression involves the assumption that all the energy emitted by the hot body is absorbed by the cooler body and that all the energy emitted from the cooler body is absorbed by the hotter body. In practice most materials fail to absorb all the radiant energy that falls upon them, and hence the constant b is different for all materials.

Radiation Constants

Material	$b \times 10^{-9}$
1. Perfect black body	1.72
2. Brass, matte	0.374
3. Cast iron, rough and highly oxidized	1.57
4. Clay	0.65
5. Copper	0.278
6. Ceramics ware, unglazed	1.34
7. Field soil	0.63
8. Granite, smooth but not polished	0.745
9. Lampblack	1.56
10. Lime mortar, rough	1.51
11. Sheet iron, matte oxidized	1.55
12. Sheet iron, polished	0.466

Materials that have a rough or dull-finish surface absorb radiation almost as completely as perfect radiation absorbers (black bodies), but polished surfaces or even clean metallic rough surfaces reflect a large part of the radiation that falls upon them. Furthermore, surfaces such as a brick wall at incandescent temperatures appear to reflect much of the radiation that falls upon them.

Radiant-absorption Rate. Radiation between solid surfaces is dependent upon the fourth power of the temperature difference and upon a constant, the value of which is dependent on the kind of material and the condition of the surface. Radiation from a flame, as in pipestill or boiler furnaces, is governed by the same laws except that the size of the flame and the conditions within the flame are so difficult to evaluate that empirical relationships have been adopted. The most important factors that affect radiation from flames are (1) percentage of total heat that is absorbed as radiant heat, (2) ratio of air to fuel, (3) arrangement and spacing of absorbing surface, and (4) kind of fuel.

Design of a furnace radiation section is based on ***Hottle, Wilson method*** and radiant heat absorption is given as:

$$R = \frac{1}{1 + \frac{G\sqrt{Q / \alpha A_{cp}}}{S}} x100$$

R= % heat absorbed in radiant section

G= Air /fuel ratio (wt. basis)

α = Factor to convert actual exposed surface to cold surface

0.986 for ***two*** rows at spacing 2 OD.

0.88 for ***one*** rows at spacing 2 OD.

If Q in Kj / hr	S=14200	Area in m^2
Q in Btu/hr	S=4200	Area in ft^2
Q in Kcal/hr	S=6930	Area in m^2

A_{cp}= Area of wall having tubes in front of it

$$A_{cp} = LN\frac{C}{12}$$

L= length

C= Center to center spacing

N= Number of tube per row.

A_{cp} = wall area

αA_{cp}= equivalent cold plane surface ft^2

$$A = LnN\frac{D}{12}$$

A= Projected area

D= Tube diameter (in)

n = no. of rows

$$A = nA_{cp}\frac{D}{C} \Longrightarrow A_{cp} = \frac{A}{n}\frac{C}{D}$$

RQ = Aq

q= rate of heat absorption per square foot of projected tube area

$$Q = \frac{Aq}{R} = \frac{nA_{cp}(D/C)q}{R}$$

$$R = \frac{1}{1 + \frac{G\sqrt{\frac{q}{R}\frac{n}{\alpha}\frac{D}{C}}}{S}} x100$$

$$q(\frac{D}{C}\frac{n}{\alpha}) = \frac{(1-R)^2}{R}(\frac{S}{G})^2$$

For a most commercial case D/C=0.5 , n=2

$$1.014\, xq' = \frac{(1-R)^2}{R}(\frac{S}{G})^2$$

$$q = 1.014\, x\frac{C}{D}x\frac{a}{n}q'$$

Example

A pipe still uses 7110 lb per hour of a cracked gas (Net Heating Value (NHV) 20560 Btu per lb). The radiant section contains 1500 sq ft of projected area, and the tube (5 in. outside diameter) are spaced at a center-to-center distance of 10 in. there is only one row of radiant tubes, and they are 40 ft long. The ratio of air to fuel is (21 (30 percent excess air).

a) What percentage of the heat liberation is absorbed in the radiant section?

b) How many Btu are absorbed per hour through each square foot of projected area?

Solution

Total heat liberated(Q)=m $_{fuel}$ * NHV=7110*20560=146000000 Btu/hr

$$A = LnN\frac{D}{12}$$

A=1500

$$N = \text{number of tubes} = \frac{1500}{40 * 5/12} = 90$$

$$A_{cp} = LN\frac{C}{12} = 40\text{x}90\text{x}10/12 = 3000$$

αA_{cp}=0.88x3000=2640 sq ft

$$\text{Heat absorption \%(R)} = \frac{1}{1+\frac{G*\sqrt{Q/\alpha A_{cp}}}{S}}x100 = \frac{1}{1+\frac{21*\sqrt{\frac{1.46x10^{6}}{2640}}}{4200}} = 45.8\%$$

Heat absorption in radiant section = 0.458*146*10^6=66900000 Btu per hr
Heat absorbed per sq ft projected area = q= 66900000/1500=44500 Btu per hr

Notes:

Heat duty: The amount of heat transferred of 1 kg of hot fluid to the 1 kg of could fluid in one hour.

$$Q_{comb.} = \frac{heatduty}{efficiency}$$

$$Q_{total} = Q_{comb.} + Q_{steam} + Q_{air}$$

$$Q_{steam} = m_{steam} * H_{steam}$$

$$Q_{air} = m_{air} \text{ x } H_{air}$$

$$Q_{flue\ gases} = m_{flue\ gases} \text{ x } H_{flue\ gases}$$

$$\% \text{ stack loss} = Q_{\text{flue gases}} / Q_{\text{total}} * 100$$

$$\% \text{ convection} = 100 - \% R - \% \text{ stack loss} - \% \text{ wall loss}$$

Example

A furnace is to be designed for a heat duty of 50×10^6 Btu/hr if the overall efficiency of the furnace is 80% and an oil fuel with a NHV=17130 Btu/lb is to be fired with 25% excess air (17.5 lb air/ lb fuel) with the air being preheated to 400 °F . Steam is used for atomizing at a rate of 0.3 lb/lb of fuel at 190 °F. Furnace tubes are of 5 in OD., 38.5 ft length and 10 in spacing arranged in a single row. 1500 ft^2 of projected area is available.

H_{air} (400 °F) = 82 Btu/lb

H_{steam} (190 °F) = 95 Btu/lb

H (flue gases at 1730 °F)=148 Btu/hr

Calculate :

1) The no. of tube required in radiation section.
2) % heat absorbed in convection section assuming wall losses of 5 %.
3) The heat rate available per unit projected area.

Solution

$$Q_{comb.} = \frac{heatduty}{efficiency} = \frac{50 * 10^7}{0.8} = 6.25 * 10^7 \ Btu / hr$$

A=nxLxNxD/12

A= 1500 ft^2

1) N=1500*12/(1*38.5*5)

N= 94 tube/row

A_{cp}= L * C/12 * N =38.5*10/12*94=3015.8 ft^2

αA_{cp}=0.88*3015.8=2653.9 ft^2

$Q_{total} = Q_{comb.} + Q_{steam} + Q_{air}$

$Q_{comb.} = m_{fuel} * NHV$

$m_{fuel} = 6.25 * 10^7/17130 = 3.648 * 10^3$

0.3 lb steam / 1 lb fuel

$m_{steam} = 0.3 * m_{fuel}$

$m_{steam} = 0.3 * 3.648 * 10^3 = 1.0944 * 10^3$ lb/hr

$Q_{steam} = m_{steam} * H_{steam}$

$= 1.0944 * 10^3 * 95 = 1.03968 * 10^5$ Btu/hr

17.5 lb air / 1 lb fuel

$m_{air} = 17.5 * m_{fuel}$

$m_{air} = 17.5 * 3.648 * 10^3 = 6.384 * 10^4$ lb/hr

Excess air =25 %

$m_{air} = 1.25 * 6.384 * 10^4 = 7.98 * 10^4$ lb/hr

$Q_{air} = m_{air} \times H_{air}$

$Q_{air} = 7.98 * 10^4 * 82 = 6.5436 * 10^6$ Btu/hr

$m_{flue\ gases} = m_{fuel} + m_{air} + m_{steam}$

$m_{flue\ gases} = 3.648 * 10^3 + 7.98 * 10^4 + 1.0944 * 10^3 = 8.454 * 10^4$ lb/hr

$Q_{flue\ gases} = m_{flue\ gases} \times H_{flue\ gases} = 8.454 * 10^4 * 148 = 1.25 * 10^7$ Btu/hr

$Q_{flue\ gases} = m_{flue\ gases} \times H_{flue\ gases} = 8.454 * 10^4 * 148 = 1.25 * 10^7$ Btu/hr

$Q_{total} = Q_{comb.} + Q_{steam} + Q_{air} = 6.25 * 10^7 + 1.03968 * 10^5 + 6.5436 * 10^6$

$= 6.9147 * 10^7$ Btu/hr

% stack loss = $Q_{flue\ gases}/Q_{total}$ * 100 = $1.25 * 10^7 / 6.9147 * 10^7 * 100 = 18\ \%$

$$\text{Heat absorption } \%(R) = \frac{1}{1 + \frac{G * \sqrt{Q / \alpha A_{cp}}}{S}} x100$$

$$= \frac{1}{1 + \frac{17.5 * \sqrt{\frac{6.9147\ x10^7}{2653.9}}}{4200}} = 59.88\%$$

2) % convection = 100 - %R - % stack loss - % wall loss

% convection = 100 - 59.88 – 18 – 5 = 17.12 %

3) $q = RQ/A = 0.5988 \times 6.78 \times 10^7 / 1500$

$q = 2.7 \times 10^4$ Btu/ hr ft^2

H.W (1)

A furnace is to be designed for a heat duty of 30 x 10^5 Btu/hr and efficiency of 75%. The furnace is fired with gaseous fuel at a rate of 17 lb air / lb fuel (NHV = 17000 Btu/lb). The tube are arranged in two rows and are of 5 in OD., 40 ft length and 2x OD. Spacing, heat rate of 35000 Btu/hr of projected area is recommended calculate:

1) % heat absorbed in radiation section (R %).

2) Heat absorbed in the convection section. (State any assumptions used).

3) The number of tubes in the radiation section.

H.W (2)

7000 lb/hr of cracked gas of 20560 Btu/lb NHV is used as a fuel in a furnace. The radiant section absorbed 44500 Btu/hr ft^2 of projected area. The tubes are 5 in. OD. , 10 in. spacing, and 20 ft long. They arranged in two rows. The air to fuel ratio is 21.0. Calculate 1) the number of tubes in the radiation section 2) the amount of heat absorbed in this section.