Tube Still Heater

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Tube heaters can be categorized into three types:

1) Box/ Rectangular
2) Cylindrical
3) Radiant Wall

All these furnaces have got separate radiation section and convection section. The most universal classification is based on direction of tubes as well as shape of furnace and mode of application of heat.

In most of the furnaces, the direction of tubes is horizontal as in all box type heaters and vertical in cylindrical stills. Radiant walls also use horizontal tubes, however tubes can be placed vertically also.

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

$$Q_r = bAT^4 = bA(T_G^4 - T_B^4)$$

A: area of radiating surface, ft^2

b : $1.72x10^9$ Btu/ ^oF ft^2 hr at black body conditions.

T: absolute temperature of the surface , ^oF

For a satisfactory design , the following schedule of heat distribution may be employed

Type of heat	Percent
Convection heat transfer	30-50%
Radiant heat transfer	45-60%
Losses (Furnace)	5%
Stack losses	12%

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

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

A_{cp} = wall area
α A_{cp}= equivalent cold plane surface ft^2

L= length

C= Center to center spacing

N= Number of tube per row.

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

A= Projected area

D= Tube diameter (in)

n= no. of rows

$$A = nA_{cp}\frac{D}{C}$$

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

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 petroleum stock at a rate of 1200 bbl/hr. of sp. gr. 0.8524 is passed through a train of heat exchangers and is allowed to enter directly the radiant section of box type heater at 220 ^{o} C . The heater is designed to burn 3500 kgs per hour of refinery off gases as fuel. The net heating value of fuel is 47.46x10^{3} Kj per kg. The radiant section contains 150 sq. meters of projected area of one row of tubes (10.5 cm, 12 m long and spaced at 2 OD).

Find the outlet temperature of the petroleum stock,

Data α=0.88

Air fuel ratio= 25

Average Specific heat of stock=2.268 Kj/Kg ^{o} C.

Solution

Total heat liberated (Q) = m $_{fuel}$ * NHV =47.46*10^{3} * 3500

= 1.66*10^{8} Kj per hour

Projected area of one tube (L * D)=12x0.105

No. of tubes= 150/(12*0.105)=120 tubes

α A $_{cp}$=0.88* 120 * 0.105 * 2* 12=266 Sq. m.

$$\text{Heat absorption \%(R)} = \frac{1}{1+\frac{G\sqrt{Q/\alpha A_{cp}}}{S}}x100 = \frac{1}{1+\frac{25*\sqrt{\frac{1.66*10^8}{266}}}{14200}} = 44\%$$

Outlet temperature of the stock:

Q=m Cp Δt

0.44*1.66*10^{8}= 1200* 200* 0.8524* 2.268* Δt

Δt=157 ^{o} C

So the outlet temperature is equal to 157+220=377 ^{o} C

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

$$A_{cp} = LN\frac{C}{12} = 40x90x10/12=3000$$

α A_{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

Example

A furnace is to be designed for a heat duty of 50x10^6 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 ^{o} F . Steam is used for atomizing at a rate of 0.3 lb/lb of fuel at 190 ^{0} 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 ^{o} F) = 82 Btu/lb

H_{steam} (190 ^{o} F) = 95 Btu/lb

H (flue gases at 1730 ^{o} 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

α A_{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

$Q_{total} = Q_{comb.} + Q_{steam} + Q_{air} = 6.25 * 10^7 + 1.03968 * 105 + 6.5436 * 10^6$

$= 6.9147 * 10^7$ Btu/hr

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

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

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

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.