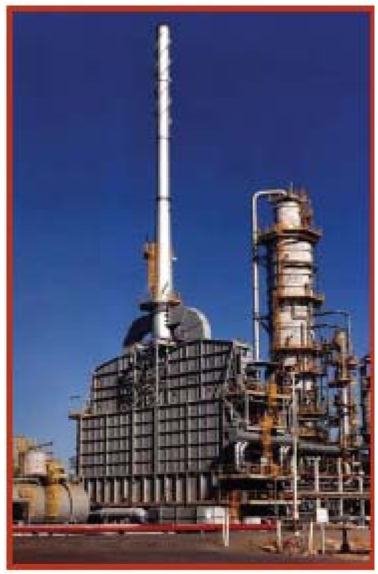
Steps for design of Furnace/Fired Heater

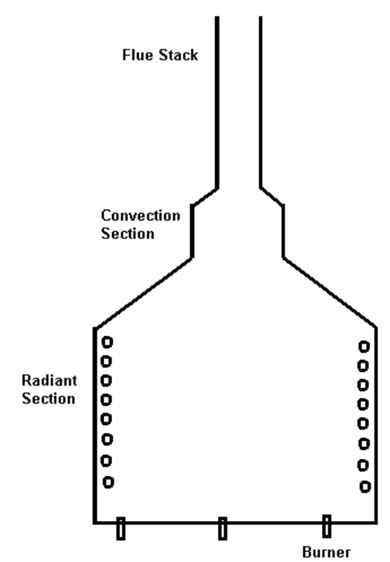
By
Dr. Reyad Shawabkeh
Department of Chemical Engineering
King Fahd University of Petroleum & Minerals
e-mail: rshawabk@kfupm.edu.sa

Note: *some of the information including figures and charts were obtained from Kern, Process Heat Transfer. Others were obtained from internet HeaterDesign site.*

In design of fired heater the flowing main features should be considered:

- Radiant section
- Convective section
- Bridge wall section
- Tubes, pipes and their specifications
- Burner
- Insulation and heat loss.





The total hourly heat transfer to cold surface is estimated by the relation

$$q_T = 0.173 f\left[\left(\frac{T_G}{100}\right)^4 - \left(\frac{T_S}{100}\right)^4\right]\alpha_{CP} A_{CP} + hA(T_G - T_S)$$

Where f is the overall exchange factor. T_G is the temperatures of the flue gases leaving the radiant section and T_S is the surface temperature of the tubes. Both temperatures are in degree Rankin. A_{CP} is the equivalent cold plane surface, ft^2, and α_{CP} is a factor by which A_{CP} must be reduced to obtain effective cold surface.

For natural convection situation, $h \approx 2$, $A \approx 2\alpha_{CP} A_{CP}$ and $f \approx 0.57$

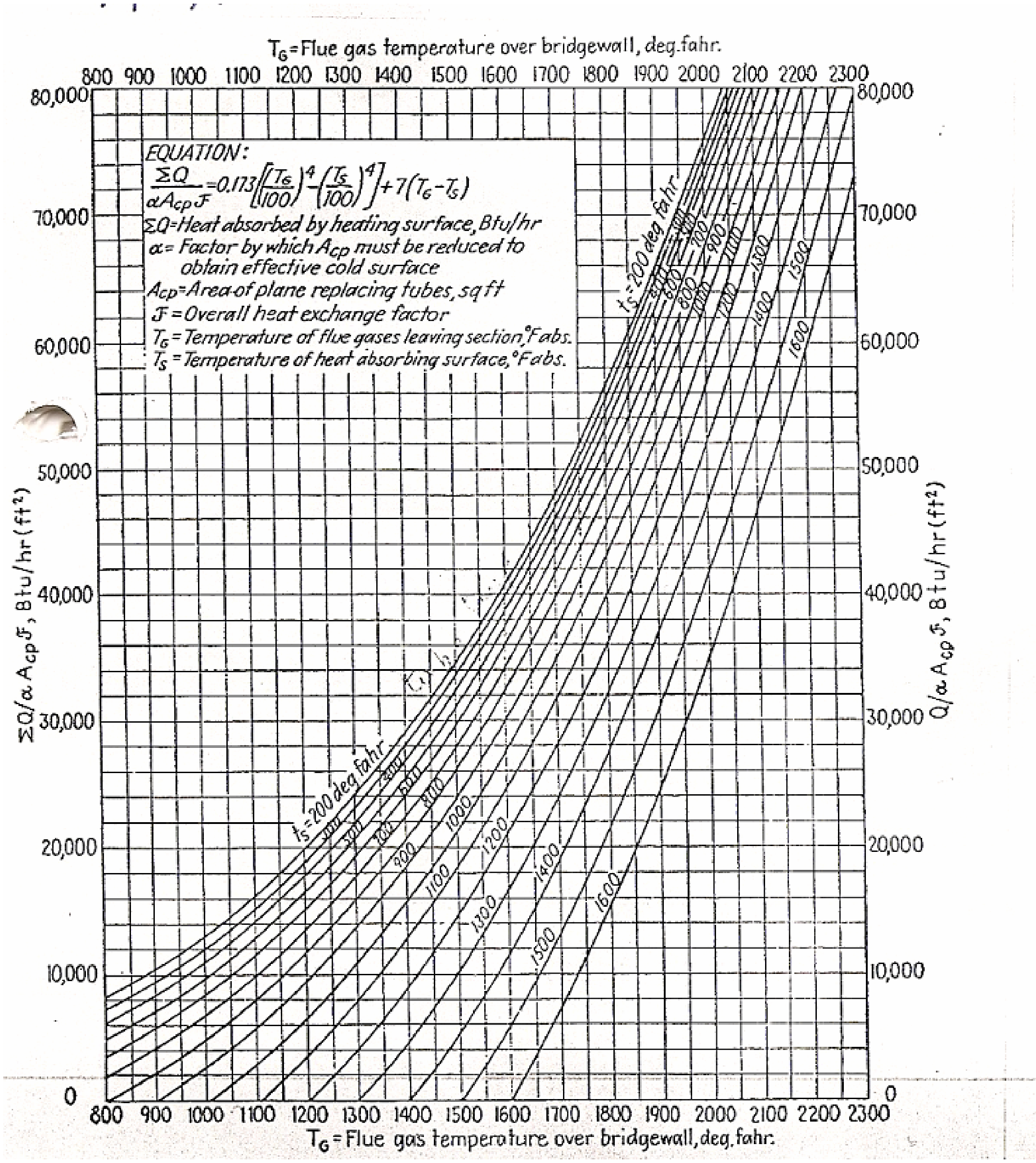
Therefore, the above equation could be written in the form:

$$\frac{\sum Q}{\alpha_{CP} A_{CP} f} = 0.173\left[\left(\frac{T_G}{100}\right)^4 - \left(\frac{T_S}{100}\right)^4\right] + 7(T_G - T_S)$$

1. To design the furnace, the following should be either known or initially assumed
   - Total required heater duty [Btu/hr].
   - Efficiency, η

- Fuel value [Btu/hr].
- Air to fuel ratio
- Temperature of inlet air [^{o}F].
- Amount of atomizing steam and ratio [lb steam/lb fuel].
- Tubes diameters, d_o , and tubes center-to-center distance, *ctc*, [in.]
- Exposed tube length, L [ft].
- Average flux for both radiant and convective sections, q [Btu/hr.ft^2].

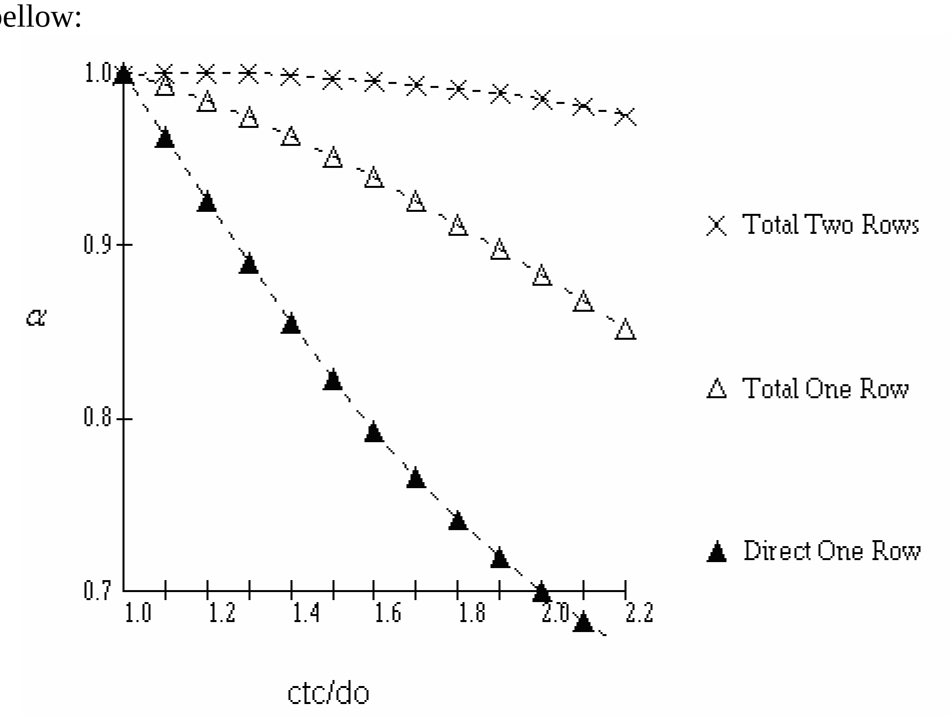
2. Assume $\dfrac{\sum Q}{\alpha_{CP} A_{CP}} = 2 \times (\text{Average flux})$ then obtain $\dfrac{\sum Q}{\alpha_{CP} A_{CP}\, f}$
3. Assume a tube surface temperature, T_S and use the chart bellow to obtain outlet gas temperature, T_G .



4. Calculate the heat liberated by fuel, $Q_F = \dfrac{\text{Total required heater duty}}{\eta}$
5. Calculate the amount of required fuel, $m_{fuel} = \dfrac{Q_F}{\text{Fuel value}}$, then calculate the required amount of air, $m_{air} = \dfrac{air}{Fuel} m_{Fuel}$
6. Assume 25% excess air, then the $\text{Total required amount of air} = 1.25\,\text{m}_{\text{air}}$
7. Calculate the inlet heat by air, $Q_{air} = m_{air} Cp_{air} (T_{air.in} - T_{ref.})$. Assume $T_{ref} = 60\,^{o}\text{F}$.
8. Usually the amount of atomizing steam is 0.3 lb/lb Fuel. Therefore, Total atomizing steam required is equal to $0.3 m_{fuel}$
9. Amount of heat associated by steam is $Q_{steam} = m_{steam} Cp_{steam} (T_{steam.in} - T_{ref})$
10. Calculate heat absorbed by the furnace wall. Usually $Q_{wall} = 2\%\, Q_F$
11. Calculate the heat of exhaust gases, $Q_{exhaust} = m_{fuel}(1 + G')Cp_{average}(T_G - 520)$, where T_G is in [^{o}R] and G' is the air to fuel ratio.

    The average specific heat, $Cp_{average} = \sum x_i Cp_i$, x_i is the mass fraction of the exit gases such as excess air, CO_2, H_2O, steam, and others (if applicable).

12. The net heat liberated, $Q = Q_{fuel} + Q_{air} + Q_{ateam} + Q_R - Q_{wall} - Q_{exhaust}$ where Q_R for re-circulating gases and may be neglected in your calculations.
13. Calculate the number of tubes required to exchange the desired heat, $N_{tubes} = \dfrac{Q}{2\pi r L q}$ where $r = d_o / 2$
14. Calculate the cold plane area, $A_{CP} = ctc \times L \times N$
15. calculate total α for single raw, refractory backed surface from the Figure bellow:

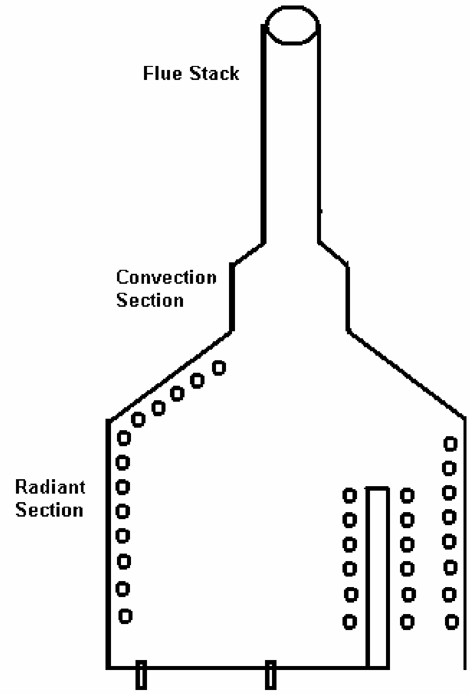


16. Assume furnace shape as shown in the Figure bellow

Calculate the top and bottom surfaces, side surfaces, Bridge surface, and end wall surfaces.

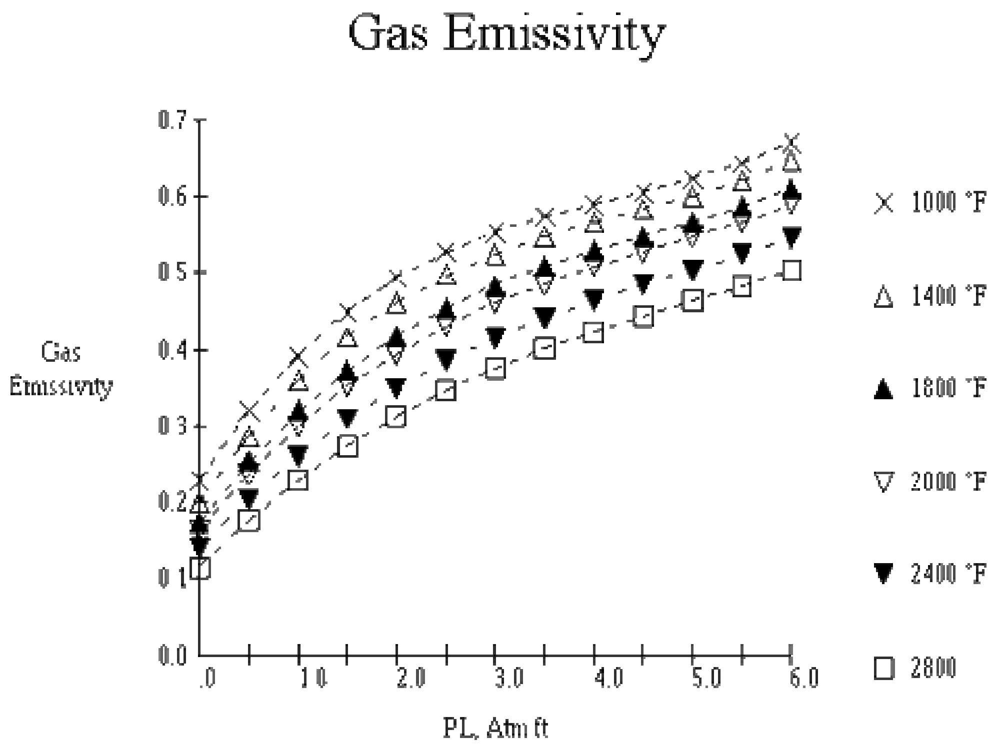
Then total exposed area, A_T is the sum of all areas calculated above.

The dimensions ratios of length, width and height should be 3:2:1. Based on this ratios, the mean length of radiant beams can be calculate using the table bellow:

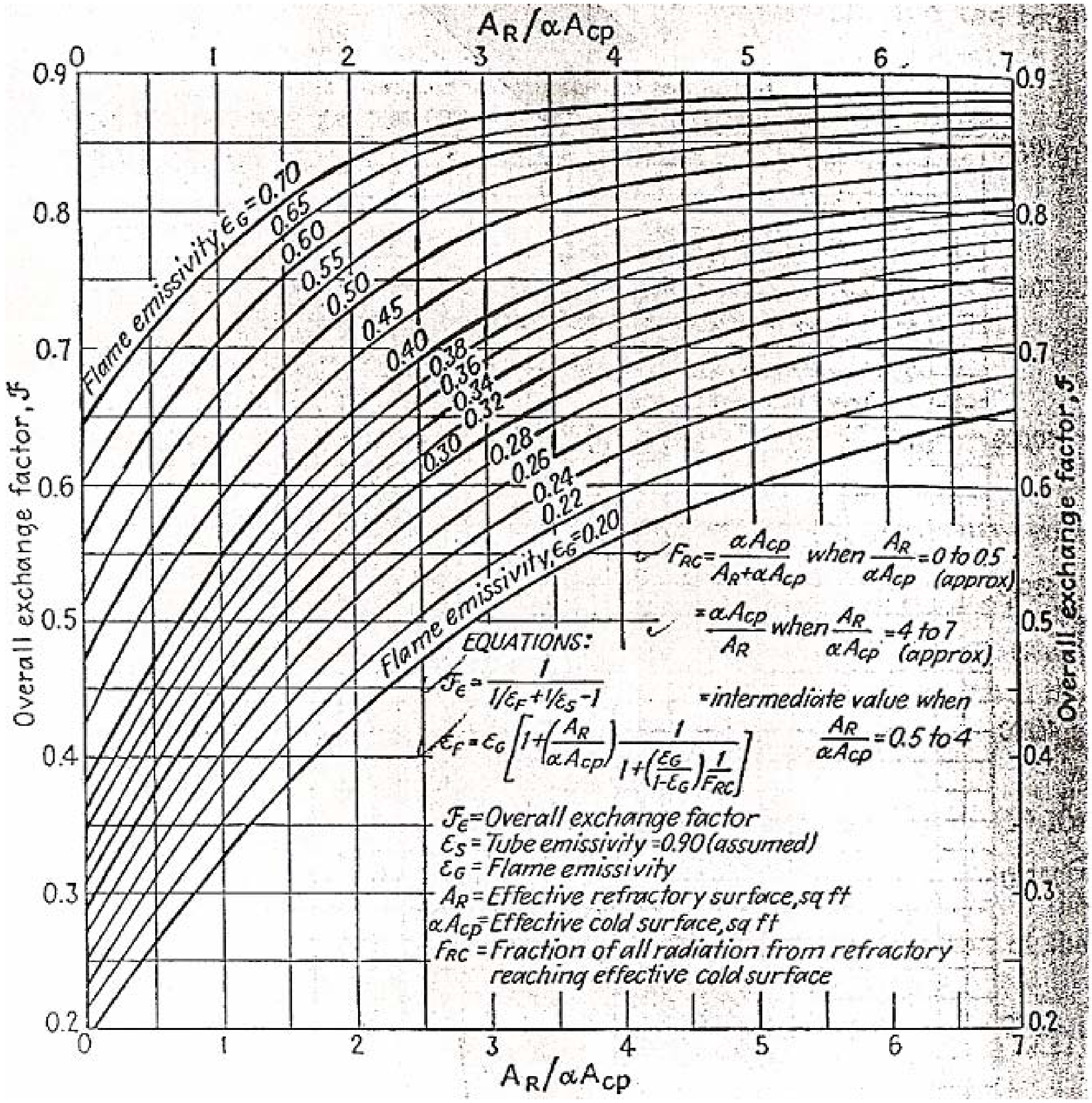


For Box Type Heaters	
Dimension Ratio	Mean Beam Length
1-1-1 to 1-1-3 1-2-1 to 1-2-4	2/3(Furnace Volume)$^{1/3}$
1-1-4 to 1-1-inf	1 x Smallest Dimension
1-2-5 to 1-2-inf	1.3 x Smallest Dimension
1-3-3 to 1-inf-inf	1.8 x Smallest Dimension
With the box dimensions, length, width, and height being in any order	
For Vertical Cylindrical Heaters	
Length/Diameter < 2	(((L/D)-1)*0.33 + 0.67)*D
Length/Diameter >= 2	Diameter

17. Calculate the effective refracting surface, $A_R = A_T - \alpha A_{CP}$
18. Obtain the gas emissivity, ε_{gas} based on the product pL from the figure bellow:
    Where pL is the product of the Partial Pressure of the carbon dioxide and water times the Beam Length, in atm-ft.



19. Based the value of gas emissivity and the product $\frac{A_R}{\alpha A_{CP}}$ obtain the overall exchange factor, f from the figure bellow:



20. Obtain the new value of $\dfrac{\sum Q}{\alpha_{CP} A_{CP} f}$, then go back to step (3) to obtain the new value of gas temperature, T_G . Compare the obtained new value with old one. If it is closed then your assumption is valid; tabulate your results. Otherwise, used the new value of T_G and continue until the difference between two values of this temperature is negligible.