Lecture 17: Heat Utilization in Furnaces

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Key words: Available heat, furnace, fuel economy, oxygen enrichment

Heat Balance

Complete heat balance of a furnace shows the flow of heat in a furnace. Heat balance contains the information regarding the sources of heat input like sensible heat of reactants, calorific value of fuel, heat of exothermic reactions etc. Heat balance also shows the heat output like wall losses, sensible heat in POC, opening losses, heat carried by the charge etc.

We have to differentiate between the quantities of heat directly related to combustion from the quantities of heat that relate to the process in order to control combustion or to study the factors affecting the fuel utilization. Sensible heats of air and fuel and amount of air relate to the quantities affecting combustion, whereas heat carried by the charge relate to the process, that is if it is required to heat the material at 900°C, the heat carried-away by the charge would be corresponding to 900°C. Losses could also be considered as the parameters relating to the process.

Fuel Utilization

In analyzing utilization of heat from fuel combustion, both amount of heat and the temperature are important since furnace is heated by the heat transfer from POC. Heat transfer rate is proportional to the temperature difference between temperature of POC and the furnace. In this connection adiabatic flame temperature is a very important parameter for fuel utilization (Fuel utilization and heat utilization are essentially similar since heat is derived from combustion of fuel.

An obvious requirement is that the flame temperature must be greater than furnace temperature so that POC is able to transfer heat for heating. Rapid heating of the furnace is achieved by greater temperature difference, which means higher flame temperature. Higher flame temperature, though
increases the heat transfer rate but at the same time it may cause overheating and destroy the lining.

We have seen in lecture 13 that adiabatic flame temperature (AFT) decreases with increase in excess air. Control of excess air is important to utilize fuel effectively.

**Temperature of POC**

In heat utilization, it must be born in mind that heat carried by POC is not available. Heat carried by POC, i.e. $H_{POC}$

$$H_{POC} = \text{mass of POC} \times \text{specific heat of POC} \times (T_{POC} - 298),$$

where $T_{POC}$ is the temperature of POC leaving the furnace. The temperature of POC can be related with the process critical temperature. The process critical temperature is the temperature at which a process can be carried out. POC must exit at the critical process temperature. A POC temperature lower than critical process temperature means that some portion of the furnace is cooler than the rest, whereas POC temperature greater than critical process temperature means overheating of some portion in the furnace. Overheating will cause increase in fuel consumption.

**Available heat**

The sensible heat in POC at the critical process temperature is not available to the furnace. The higher the process critical temperature higher would be the sensible heat in POC. This sensible heat in POC is very important from the point of view of fuel utilization. We define gross available heat (GAH) as

$$\text{GAH} = \text{Calorific value of fuel} + \text{sensible heat of reactants} - \text{Heat carried by POC}$$  \hspace{1cm} (1)$$

GAH may also be considered as the heat given by POC in cooling from its flame temperature (flame temperature is AFT in the following which is $T_{AFT}$) to the process critical temperature ($T_{CRIT}$). If we assume that specific heat capacity of POC does not vary significantly with temperature and then

$$\text{GAH is proportional to } (T_{AFT} - T_{CRIT})$$  \hspace{1cm} (2)$$

$$\text{GAH, } \% \text{ of total heat input } \approx 100\left(\frac{T_{AFT} - T_{CRIT}}{T_{AFT}}\right)$$  \hspace{1cm} (3)$$

If for example $T_{CRIT}$ is $1200^\circ\text{C}$

A combustion process generating $T_{AFT} = 1200^\circ\text{C}$ can not be used. A combustion process generating $T_{AFT} = 1600^\circ\text{C}$ would be 25% and that generating $T_{AFT} = 1800^\circ\text{C}$ would be 33% efficient according to eq.3
GAH represents the heat available at the critical process temperature; it may not represent heat available to perform a given function due to the various types of losses. GAH may be used as a criterion for comparing different fuel-combustion systems.

Once the furnace is designed and built, the heat losses are not within the control of the operator; it is governed by the process critical temperature, refractory lining thickness and thermal conductivity of the refractory. Defining net available heat (NAH) as

\[ \text{NAH} = \text{GAH} - \text{Heat losses} \]  

4)

NAH can be used as a criterion for comparing the smelting/melting/heating efficiency of different furnaces.

**Variables affecting heat utilization**

For a given furnace design and the daily heat requirements, GAH is fixed and it is required to supply this much of heat on per day basis, we can calculate

\[ \text{Fuel consumption} = \frac{\text{Required GAH per unit of time}}{\text{GAH per kg of fuel}} \]  

5)

If heat supply is the critical factor in determining the process throughput then GAH can not determine the throughput, we have to consider the NAH

\[ \text{Furnace throughput} = \frac{\text{NAH generated per unit of time}}{\text{Required NAH per unit of throughput}} \]  

6)

Heat utilization or fuel utilization according to equation 5 is inversely proportional to GAH/kg of fuel. We can derive the factors affecting heat utilization by considering eq.1

Air adjustment: Calorific value (CV) of fuel is the energy obtained on complete combustion of fuel with theoretical amount of air. Excess air, air leakage, furnace draft, fuel/air ratio will control the fuel consumption

Sensible heat of reactant; this heat directly adds to the furnace, fuel consumption will decrease.

POC temperature: an increase in POC temperature will increase fuel consumption

Incomplete combustion or un-burnt fuel; corresponding to incomplete combustion part of the CV of fuel is lost in POC.