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Effect of Refractory Emissivity on Heat Transfer in Furnaces

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Abstract: ***In industrial furnaces many designers ignore refractory emissivity in heat transfer calculations. In this paper author tried to explain importance of refractory emissivity in overall heat exchange. Readers will get some idea about it to implement in actual practice.***

Keywords: emissivity, reflectivity, refractory, energy

1. Introduction

In industries mainly, petrochemical, refinery, fertiliser etc. furnaces are used for heating of the process fluid which is used for different purposes at downstream. At broad level, these furnaces contain heating medium i.e. flue gases, heat receiving surfaces i.e. tubes (primary sink) and refractory (secondary sink). Main heat receiving parts are tubes. Hence in industry main importance are given for solving of heat transfer equations between these two parts i.e. flue gases and tubes. Of course it is important but we cannot neglect refractory as well. Most of the designer neglect effect of refractory in design and consider it as a total reflective surface but in actual practice this is not the case. In further discussions we will be able to find the refractory considerations in furnace design. Here refractory word is used since it is well known in furnace industry. In this paper, refractory to be termed as insulating material which may be castable refractory or any other insulation i.e. mineral wool etc.

2. Concept Explanation

In this section efforts are given to understand the importance of refractory considerations in heat transfer design of furnaces. First consideration is well known as a “insulator”. By nature, refractory is a bad conductor of heat transmission hence it is used as a insulator in furnaces. Second consideration is its role in overall heat exchange in the furnace. Henceforth we will try to understand the same in subsequent discussions. Refractory is a very good source of heat storage which you can also observe in regular life as well. Now coming to the use of this refractory property in furnace design concept. Basically furnace is considered as an “adiabatic” in nature means there is no loss of heat to the atmosphere which is prevented by application of refractory. But in reality it is very difficult to make it as an adiabatic system. There is always loss of heat to the atmosphere. This loss of heat is considered in design in different form so that final energy balance should match.

Now we will focus on heat transfer mechanism in furnace to find out second consideration of refractory. Heat transfer in furnace is a very complex mechanism and not as simple as conduction and convection since it is through radiation between three source-sink objects. As radiation itself is a very vast subject to understand but we have to use this principle in industry application with some suitable considerations. Since radiation is the main heat transfer mechanism in furnace, here more focus is given on the same.

As we know, main source of the heat in furnace is flue gases which is generated due to combustion of hydrocarbons in presence of oxygen. But this process is not so simple. Readers are hereby advised to read other source of material to understand combustion process in more depth. Flue gases mainly contains H_2O, CO_2, O_2, N_2 etc. out of these gases mainly H_2O and CO_2 takes part in heat transfer. Now we have identified heat source, next we have to identify heat receivers i.e. tubes or refractory? As discussed earlier, primary receiver are tubes then what about refractory? Refractory is not playing any role in heat transfer with the consideration of adiabatic in nature. Now there is a contradiction in considerations as adiabatic vs loss of heat. We will try to find out the same in subsequent discuss. Basic main consideration is that, heat is totally conserved in furnace and there is total reflection from refractory surface. But in real scenario, this is not possible since every object have absorptivity, reflectivity and transmittance based on their properties. If we consider there are no loss of heat or no participation of refractory in heat transfer mechanism, then refractory must have total reflectivity i.e.1. This case is mostly considered in furnace design. It means refractory have “No Flux” properties and reflects all radiations back into the flue gases. This concept is very true if refractory have “mirror” like surface. But in actual practice this is not the case. Refractory have some emissivity and it absorbs heat in that proportions. If refractory absorbs heat, it again emits some part of the heat into the flue gases and transfers some part to atmosphere via conduction. Hence the concept of total reflectivity holds no more good. Hence importance to be given for “emissivity” of refractory in heat transfer design but question will be how?

We will try to find out answer of the above question in the below discussion. Heat transfer mechanism at refractory is similar to heat transfer mechanism of tubes due to hot flue gases in furnace. This means that we have to consider refractory as a “source-sink” type object. Separate heat balance to be carried out at refractory and effect of the same to be added in the overall heat transfer. Heat balance at refractory and its effect on primary heat sink is not a simple task and it is not the part of this paper. Here author have tried to explain some basic concepts. If we try to do electric circuit analogy of heat transfer mechanism in furnace it will be like figure-1. From figure-1 it is very easy to understand and calculate individual resistances and complete system resistance.

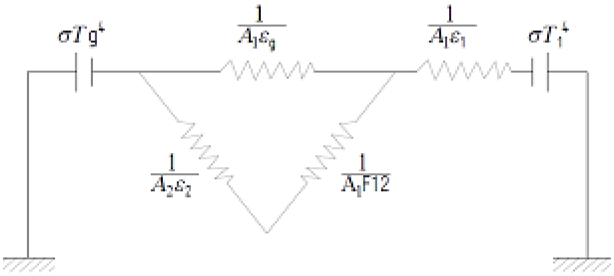

Figure 1: Heater equivalent circuit

Now from figure-1 we can easily understand heat transfer mechanism in furnace and overall heat transfer equation will be as below,

$$Heat\ exchange = A1F1g + \frac{1}{\frac{1}{A1F12} + \frac{1}{A2F2g}}$$

Here our main interest is to find out participation of refractory in heat transfer. You may be able to see that in upper branch heat is transferring to tubes from hot flue gases with its own resistance which is quiet common. In lower branch heat from flue gases is also flowing towards refractory and then based on refractory "emissivity" it is transferred to tubes via it's own resistance. This heat flow is very important.

As already mentioned, refractory absorbs heat based on its absorptivity. It again emits and reflects (part of incident radiations) based on its properties which will be partially absorbed by flue gases and remaining reaches to tubes. Tubes again reflects/absorbs and emits based on its own properties. This process goes on continue till equilibrium achieves in the complete system. If we do energy balance at refractory, it will be as below,

Energy exchanged at refractory = Energy exchanged at tubes + Energy lost to atmosphere.

Above energy balance will be solved with the applications of basic radiation principles and view factors.

Here author is giving final energy balance equations in which refractory consideration i.e. emissivity is taken care. If we carefully see the equations for A1F12 and A2F2g, we will find importance of refractory emissivity and flue gas transmittance in heat transfer. Heat exchange equation is used for overall heat exchange calculation. Second parameter in this equation i.e. 1/A1F12 and 1/A2F2g is used for heat exchange between tubes-refractory and refractory-flue gases respectively.

Now, we will expand terms 1/A1F12 and A2F2g as below.

$$A1F12 = GG + RG$$

Where,

$$GG = \frac{x\left(\frac{\varepsilon 1}{\rho 1}\right)\left(\frac{\varepsilon 2}{\rho 2}\right)}{\frac{\frac{1}{\rho 1} - \tau x}{A2} + \frac{\left(\frac{1}{\rho 1} - \tau x\right)\left(\frac{1}{\rho 2} - \tau x\right)}{A1F12\tau x} + \frac{\frac{1}{\rho 2} - \tau x}{A1}}$$

$$RG = \frac{(1-x)\left(\frac{\varepsilon 1}{\rho 1}\right)\left(\frac{\varepsilon 2}{\rho 2}\right)}{\frac{\frac{1}{\rho 1} - 1}{A2} + \frac{\left(\frac{1}{\rho 1} - 1\right)\left(\frac{1}{\rho 2} - 1\right)}{A1F12} + \frac{\frac{1}{\rho 2} - 1}{A1}}$$

$$A2F2g = \frac{\left(\frac{x(1-\tau x)\varepsilon 2}{\rho 2}\right)\left(1 + \frac{A2}{A1} + \frac{\frac{1}{\rho 1\tau x} - 1}{F21}\right)}{\frac{\frac{1}{\rho 2} - \tau x}{A1} + \frac{\left(\frac{1}{\rho 2} - \tau x\right)\left(\frac{1}{\rho 1} - \tau x\right)}{A2F21\tau x} + \frac{\frac{1}{\rho 1} - \tau x}{A2}}$$

To understand above equations, we will solve one simple example. Let us consider, flue gas emissivity 0.33, tubes emissivity 0.9 and unit areas of both tubes and refractory. For different values of refractory emissivity, we will get graph as below (Figure-2),

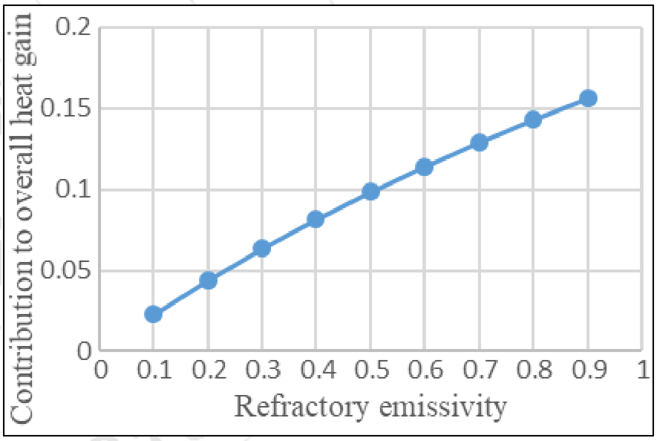

Figure 2: Refractory emissivity-contribution in overall heat gain

Y-axis is the summation of 1/(1/A1F12+1/A2F2g)

3. Discussion

For given example, Figure-2 almost shows linear variation of effect of refractory emissivity on heat transfer in furnace. Also from Figure-2 we can easily interpret that as the emissivity of refractory material increases its contribution in overall heat exchange increases. Finally, performance of the furnace improves.

Nomenclature

x- part of heat transmission in gray gas wavelength
ε- emissivity
ρ-reflectivity
τ-transmittance
A2- refractory (Secondary sink absorption area)
A1- tube (Primary sink absorption plane area)

F12- View factor
Subscript 1- Used for Primary sink
Subscript 2- Used for Secondary sink
Subscript g- Used for flue gas

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Author Profile

Deepak Sake received Post graduate degree in Mechanical Engineering with specialization in Heat transfer from NIT, Allahabad in 2002. During 2002-2014 he worked in Larsen and Tubro Ltd in furnace design group. From 2014 onwards he is working in JNK India Pvt Ltd as a head of Furnace group.