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Effect of Heat Transfer of Large Particles in Fluidized Bed Combustion System

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Abstract

Heat transfer coefficient varies with the particle size in fluidized bed. Local heat transfer in a fluidized bed combustion system were measured for three sizes of silica sand, with mean diameters of 0.22, 0.34, 0.44 mm. With the variation in size of sand from 0.44 to 0.22 mm for constant fluidization velocity causes increase in particle concentration and hence increase in heat transfer. The lateral distribution of heat transfer to the side of the tube was independent of particle size when the bulk density was similar. It was possible to estimate the vertical distribution of heat transfer coefficient in the fluidized bed combustion system. In present article the work are based on the variation of heat transfer with change of size of the bed particles.

1. Introduction

The study of heat transfer in fluidized beds is particularly recognise to their importance to engineering practice in the combustion of fossil fuels and their potential in energy conversion systems. The solid materials in fluidized bed either enter directly into chemical reaction or as a catalyst enhance heat transfer.Fluidization is an operation by which fine solids are transformed into a fluid like state through contact with a gas (or a liquid).
When air is passed through a fixed or packed bed of particles, air simply percolates through the interstitial gaps between the particles. As the air flow rate through the bed is steadily increased, a point is eventually reached at which the pressure drop across the bed becomes equal to the weight of the particles per unit cross-sectional area of the bed. This critical velocity is called the *minimum fluidization velocity*, U_{mf} . As the air velocity is increased further, the particles are buoyed up and imparted a violently turbulent fluid like motion. There is a high degree of particle mixing and equilibrium between gas and particles is rapidly established. This is called a fluidized bed.
The furnace is divided into two distinct zones:
(1) Lower zone (below the secondary air entry).
(2) Upper zone (above the secondary air entry).
The lower zone in the furnace is fluidized by primary combustion air, which constitutes about 40-80% of the air required for the coal feed [1]. Char particles transported to the upper zone are exposed to an oxygen rich environment, where most of the combustion occurs. The upper zone is much taller than then lower zone. Flue gases desulphurization is achieved by adding a sorbent such as limestone or dolomite to the fluidized bed, where sulphur is absorbed in the solid form.

2. Effects of Operating Parameter

Here are some operating parameters which affects the results and heat transfer

2.1 Suspension density

The suspension density is the most dominant operating factor influencing the heat transfer to the wall. Heat transfer coefficients increased with the suspension density. This is expected because the thermal capacity of solids is much higher than that of the gas. So the heat transfer through the particles contributes more than that across the fluid boundary layer.
Using data from cold beds, Divillo and Boyd [2] obtained the following functional relationship:

$$h_c = 23.2\ \rho_b^{0.55}\ \ \text{W}/m^2\ \text{K} \qquad (1)$$

Which shows that doubling the suspension density within the Bed will increase the convective heat transfer coefficient by 46% . Werdermann and Werther [3] correlated their results for convective heat transfer on vertical walls in the following way:

$$Nu_{gc} = 7.46 \text{ x } 10^{-4}\ Re_t^{0.757}\ \rho_b^{0.562} \qquad (2)$$

Where Re_t is the Reynolds number based on the bed diameter.

2.2 Bed temperature

The heat transfer coefficient increases with bed temperature due to higher thermal conductivity of gas and higher radiation at higher temperatures. Jestin [4] observed this from their measurements in the 125 MWe boiler at Carling the effect of bed temperature on heat transfer coefficient. They correlated their data in the following form Jestin, [4]:

$$\text{h=k}(\Delta\ p)^{\alpha}\,(T_f)^{\beta} \qquad (3)$$

Where Δp is the pressure drop across the entire furnace (a measure of the suspension density), T_f is the temperature of the furnace and k, α, β are empirical constants. This equation gives a little higher value of heat transfer coefficient compared to that obtained from eq. (1).

2.3 Fluidization velocity

Except for a very dilute bed, the superficial gas velocity does not have any great influence on the heat transfer coefficient. Where the combustion air is added at two levels in the furnace, a change in secondary air rate does not have much effect on the heat transfer coefficient in the upper part of the furnace, but an increase in the primary air velocity increases the heat transfer coefficient Anderson [5]. This happens because the increased primary air transports more solids to the upper section increasing the suspension density in that region of the bed.

2.4 Particle size

Higher heat transfer coefficients for smaller particles were observed by several investigators including Mickley and Trilling, Basu and Nag [6]. The contact resistance is directly proportional to the particle diameter, the above investigators noted lower overall heat transfer coefficients for larger particles. Wederman and Werther [3] suggested that the radiative heat transfer flux increases with increasing particle size and decreasing solid volume fraction, coarser fractions of bed solids are subjected to entrainment giving a segregation of particle size in the furnace.

3. Surface–particle–emulsion heat transfer

If a fluidized bed is operated in the bubble flow regime, an immersed surface (surface of an immersed tube) is covered by bubble phase and emulsion phase alternatively. It is to be assumed that the time fraction of the surface being covered by bubbles is f_0, then heat transfer through the surface is [7]:

$$q_{total} = q_e(1\text{-}f_0) + q_b f_0$$

where

$$q_e = q_{ecd} + q_{ecv} + q_{er}$$
$$q_b = q_{bcv} + q_{br}$$

As we know the convective heat transfer between bubbles and the immersed surface is relatively small, q_{bcv} in above eq. can be ignored. If the temperature of the bed is low then the radiative heat transfer between bubbles and the immersed surface can also be ignored. Then the heat transfer coefficients are to be written as follows. The conductive heat transfer coefficient between the particles in emulsion and the immersed surface is [7]

$$h_{ecd} = q_{ecd}\ /(T_{bed} - T_s)$$

The convective heat transfer coefficient between the emulsion and the immersed surface is [7]

$$h_{ecv} = q_{ecv}/(T_{bed} - T_s)$$

The radiative heat transfer coefficient between the emulsion and the immersed surface is [7]

$$h_{er} = q_{er}/(T_{bed} - T_s)$$

The radiative heat transfer coefficient between bubbles and the immersed surface is [7]

$$h_{br} = q_{br}/(T_{bed} - T_s)$$

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The total heat transfer coefficient between the fluidized bed and the immersed surface is [7]

$$h_{total} = (h_{ecd} + h_{ecv} + h_{er})(1 - f_0) + h_{br} f_0$$

3.1 Conductive and radiative heat transfer between emulsion and an immersed surface

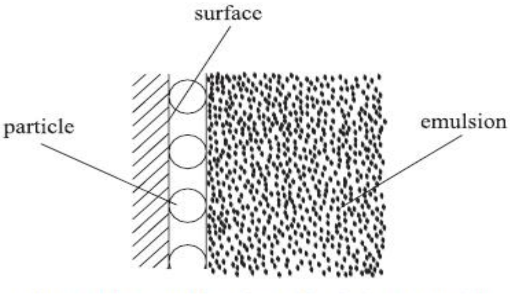

Fig 1: surface particle emulsion model [7]

The process of transfer the heat between the surface and emulsion is as follows:
For distance of one particle diameter, d_p, from the surface, the heat is transfered as through dispersed particles touching the surface; For distance from the surface is larger than particle diameter, d_p, the heat is transfered as through an emulsion with homogeneous properties
Assumptions:
(1) The temperature in the emulsion varies only in the direction perpendicular to the surface.
(2) The surface is an ideal plane and the solid particles are ideal spheres.
(3) The convective heat transfer between gas in the emulsion and the surface is independent of the conductive and radiative heat transfer.
(4) The fluidizing medium is transparent to radiation and does not radiate itself.
A spherical particle which is in contact with the surface can be furthermore simplified as an equivalent cylindrical particle, with diameter and volume equal to those of the spherical particle

.4. Results and discussion

For getting the effect of particle on heat transfer for different location in the combustion chamber D.Pidwerbecki and J. R. Welty perform an experiment with three different size particles of diameter 1 mm, 2 mm, 2.9 mm, with three different locations as dense zone (-127 mm), splash zone(64 mm), free board zone(406 mm) [8].

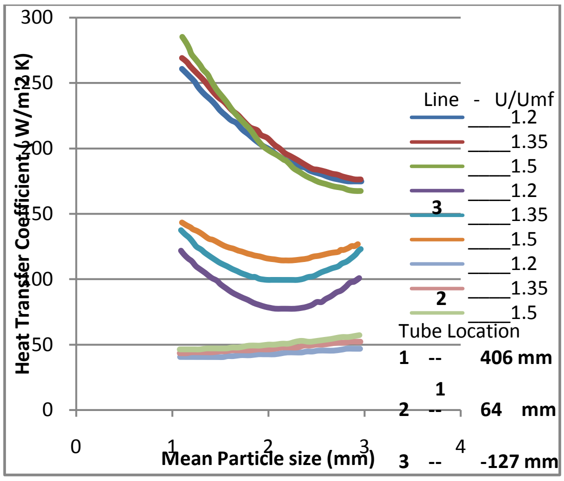

Fig 2: Convective heat transfer coefficients with particle size. T_{bed} = 1003 K. Tube location = 406, 64, and -127 mm. [8]

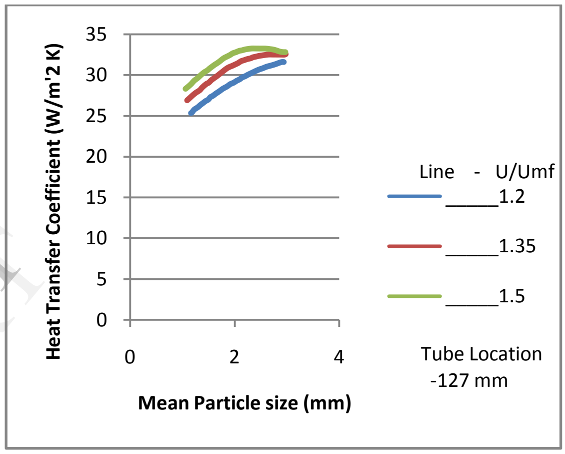

Fig 3: Radiative heat transfer coefficients with particle size. T_{bed} = 1003 K. Tube location = -127 mm. [8]

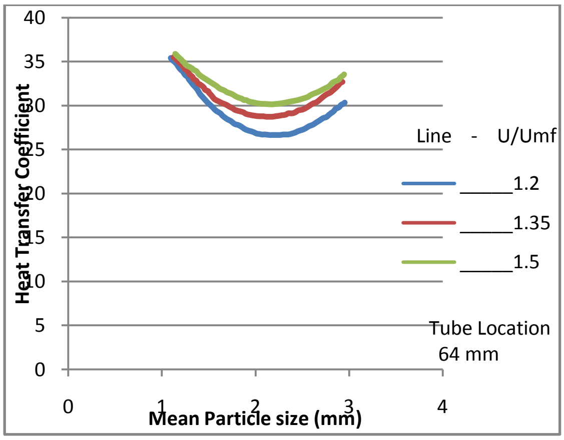

Fig 4: Radiative heat transfer coefficients with particle size. T_{bed} = 1003 K. Tube location = 64mm. [8]

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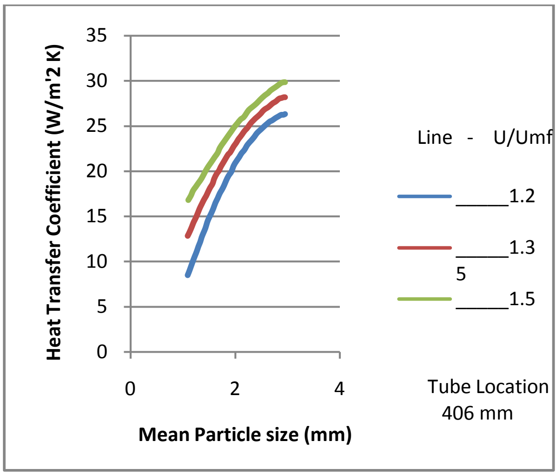

Fig 5: Radiative heat transfer coefficients with particle size. T_{bed} = 1003 K. Tube location = 406 mm. [8]

In Figures 2-5 we can see that the effects of particle size on the heat transfer in a bubbling fluidized bed operating at 1003 K for three superficial velocities at three tube locations. Figure 2 shows the convective heat transfer coefficient, and Figs. 3-5 show blackbody radiative heat transfer coefficients [8].

Figure 2 represents the results for a tube located in the dense phase (-127 mm location)[1] of the fluidized bed. It is obtained that the maximum convective heat transfer coefficient for all three particle sizes occurred with the tube located in the dense phase of the fluidized bed. At this location, the 1.1 mm particle size gives the maximum convective heat transfer coefficient. We can easily described by the respected figure that particle size affects the convective heat transfer mostly for the tube located within the bed. The 2 mm particle convective heat transfer coefficients value are approximately 75% of the values for the 1.l mm particles, and the value of heat transfer coefficients for 2.9 mm particle are approximately 65% of the 1.l mm particle values [8].

It is seen in the figure that for a tube located in the splash zone (64 mm location), the convective heat transfer coefficient is less than for a tube located in the dense phase. The reason behind this variation of values is increasing the void fraction in the splash zone, hence the particle convective component of convective heat transfer coefficient decreases. The convective heat transfer coefficient increases with increasing superficial velocity, it indicates that the void fraction in the splash zone decreases, increases particle convective effects on the tube and also increases the gas convective effects. We can also see that the convective heat transfer coefficients are similar for all three particle sizes. The above concepts are explained as the gas convection is the prominent heat transfer mode for increasingly larger particles and the residence time (it is the time for which a particle rest or keep in touch with the tube) of the particles on the tube surface is very less for a tube located in the splash zone than for a tube located in the dense phase; hence the particle convective effects become less.

The values of convective heat transfer coefficients for the tube located in the freeboard (406 mm location) is lowest for all the three positions, and because of very low particle densities at this location, the particle convective effects are lowest. It is to be seen that blackbody radiative heat transfer coefficients is relatively small compared to convective heat transfer coefficients for the tube located in the dense phase, but radiative heat transfer coefficients becomes a larger fraction of the total heat transfer coefficients with the tube located in the splash zone and in the freeboard. The values of radiative heat transfer coefficient are lower for dense phase than those reported because of the tube location. The tube is located in the dense phase, where a large bubble could periodically expose the tube surface to the surroundings, which results lowering the radiant values.

In figures 3-5 we can see the blackbody radiative heat transfer coefficient variations with respect to particle size for the tube located in the all three regions of the fluidized bed. Figure 3 shows that, for a tube located in the dense phase, particle size has very less effect on the radiative heat transfer coefficients, but the superficial velocity ratio has greater influence. It has been seen that at the lower superficial velocity ratio (U/U_{mf} = 1.2), particle size has a significant effect on the radiative heat transfer. For the lower velocities, the blackbody radiative heat transfer coefficient is minimum for the 1.1 mm particles [8]. This is due to the greater thermal mass of the larger particles which causes a more constant particle temperature during their residence time near the tube surface. For higher superficial velocities, blackbody radiative heat transfer coefficients are increasing in values with increasing velocities, this indicates that particles have a shorter surface residence times. The 2 mm and

2.9 mm particles gives approximately the same radiative heat transfer coefficients as the superficial velocity increased, this result can show that particle temperatures remained constant; this means the thermal masses of the particles are large compared to the transient energy loss during their short residence times on the tube surface.

5. Conclusion

Most of the convective heat transfer coefficients are present in the dense phase of the fluidized bed. It has been seen that there is approximately 17% difference between the nominal convective heat transfer coefficient for the 2 and 2.9 mm particles[8], and difference between the nominal convective heat transfer coefficients for 2 mm and 1.1 mm particles is approximately 33% [8], while difference between nominal convective heat transfer coefficients for 2.9 mm and 1.1 mm particles is approximately 54% [8]. Most of the blackbody radiative heat transfer occurred in the splash zone or the dense phase of the fluidized bed. However The value of this radiative heat transfer are smaller than value of the maximum convective heat transfer coefficients.

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