STUDY THE EFFECT OF DIFFERENT OPERATING PARAMETERS ON HEAT TRANSFER COEFFICIENT IN GAS-SOLID FLUIDIZED BED USING HORIZONTAL HEAT TRANSFER PROBE

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ABSTRACT

Heat transfer studies were carried out in a laboratory scale gas-solid fluidized bed with 0.1m ID x 1 m length column, using three sizes of local sand particles of 301, 454, and 560 µm. the bed region was heated by a horizontal heat transfer probe. It was made of copper rod (15 mm OD x 50 mm long) and insulated at the ends by Teflon. A hole was drilled at the center of the rod to accommodate a cartridge heater 200 W (6.5 mm OD x 42 mm long). Three bed inventories of sand 1.5 kg, 2.0 kg, and 2.5 kg, four superficial air velocities of 1.0 m/s, 1.25 m/s, 1.5 m/s, 1.75 m/s were used. Three heat fluxes of 1698.9, 2928.4, 4675.7 W m\textsuperscript{-2} were employed. The data obtained showed how the heat transfer coefficient effected by the above operating parameters. The heat transfer coefficient is directly proportional with air superficial velocity as well as the bed inventory and heat fluxes but inversely proportional with sand particles size.

Keywords: Heat Transfer Coefficient, Gas-Solid Fluidized Bed, Horizontal Probe, Fluidization, Horizontal Probe.

1. INTRODUCTION

Fluidization is a unit operation, and through this technique a bed of particulate solids, supported over a fluid-distributing plate (often called the grid), is made to behave like a liquid by the passage of the fluid (gas, liquid, or gas–liquid) at a flow rate above a certain critical value. In other words, it is the phenomenon of imparting the properties of a fluid to a bed of particulate solids by passing a fluid through the latter at a velocity which brings the fixed or stationary bed to its loosest
possible state just before its transformation into a fluidlike bed[1]. There exist high heat transfer rate of fluidized beds and immersed surface, and little temperature variation across the bed, and can be obtained higher heat transfer coefficients compared to a conventional fluidized beds. Due to these advantages, this technology has been applied commercially in various processes, such as fluidized bed combustor, fluidized bed reactor, fluidized bed dryer, etc[2]. Three modes of heat transfer are important with respect to surfaces immersed in fluidized beds: (1) Convection by particles carrying heat conducted through the gas layer in contact with the exchange surfaces; (2) convection by gas, and radiation. Many processes utilizing fluidized beds operate at temperatures below 500 °C where the radiation component is of secondary significance. Gas convective heat transfer becomes significant when the superficial gas velocity is higher or the particle size is large[3].

Kunii and Levenspiel pointed out that heat transfer in fluidized beds is a two part concern: one deals with the bed to surface heat transfer such as heat transfer tubes and the other deals with the gas to particle heat transfer [4]. Kiang et al. measured heat transfer coefficients using 19 mm diameter and 57.2 mm high vertical probe located along the axis at various levels in a 102-mm diameter and 3.66-m-high cold CFB riser. Axial variation of heat transfer coefficients in the range of 45 to 230 W/m².K were reported. B. V. Reddy, P. K. Nag investigated the effect of operating parameters on the axial and radial variation of the heat transfer coefficient in circulating fluidized bed column. They proposed an empirical model with help of dimensional analysis to predict the heat transfer coefficient to a bare horizontal tube in a CFB riser column and they observed a good agreement between the model results and the experimental data. Noor M. Jasem et al. investigated the steady state heat transfer between gas and solid and the surface immersed in gas-solid CFBs. They used a bed column of 76 mm in inside diameter and 1500 mm in height fitted with a horizontal heating tube with outer diameter 28 mm heated electrically with different power supplies (105 W). The fluidizing medium was air at different velocities (4.97, 5.56 and 6 m/s). They employed three different size of sand particle (i.e 194, 295 and 356 μm). They used initial bed heights with different values (15, 25 and 35 cm). They found that the heat transfer coefficients increase with fluidized air velocity and, through clear, with heat flux, but, they show an inverse dependence on particle size, and direct proportional with initial bed height which representation the bed density [5-7].

Sung Won Kim et al. carried out an experiments in a FBHE made of transparent acrylic plate. The effect of gas velocity on the average and local heat transfer coefficients between a submerged horizontal tube and a fluidized bed has been determined in a fluidized-bed-heat-exchanger of silica sand particles. They measured the heat transfer coefficient around the tube circumference by thermocouples and an optical probe. They concluded that the average heat transfer coefficient exhibits a maximum value with variation of gas velocity, the local heat transfer coefficient exhibits maximum values at the top of the tube and the average heat transfer coefficient increases with increasing gas velocity toward a maximum value of the coefficient[8].

Vanderschuren and Delvosalle (1980), Delvosalle and Vanderschuren (1985), as well as Molerus (1997) reported that particle–particle and particle–surface collisional heat transfers may play significant role in fluidized beds under certain conditions. Therefore, because of intensive motion of particles in the turbulent fluidized regime, it appears to be of interest of modeling and investigating heat transfer processes induced by particle–particle and particle–surface collisions in order to study these phenomena separately of the remaining thermal characteristics of the bed [9].

D. Karageorgieva, and R. Stanev studied the influence of some factors on total heat transfer coefficient and the convective heat transfer one in low temperature circulating fluidized bed. They compared their data with that in the literature, they found a very good agreement between them [10].

The heat transfer characteristics between a circulating fluidized bed and a surface immersed inside it were investigated by M. A. Al Busoul. He presented a statistical model describing the mechanism of heat transfer and the relation between the heat transfer coefficient and the main parameters of the bed. The proposed model yields a satisfactory representation of heat transfer
process in the circulating fluidized bed. Heat transfer from an immersed heating surface to a liquid-solid and liquid-liquid solid fluidized beds were studied by Balasim A. Abid et al. The experiments were carried out in a (0.22) m column diameter fitted with an axially mounted cylindrical heater heated electrically. They developed new correlations to predict the heat transfer coefficients in liquid-solid and liquid-liquid-solid fluidized beds. They compared the obtained heat transfer coefficients with those estimated from other correlations reported in the literature. The comparison showed a good agreement with the data obtained for the gas-liquid-solid fluidized beds using low-density particles.

Qin-Fu Hou, et al. investigated heat transfer characteristics of different powders in gas fluidization were by means of a combined approach of discrete element method and computational fluid dynamics. The results confirmed that the convective heat transfer was dominant, and radiative heat transfer becomes important when the bed temperature is high. However, conductive heat transfer also played a role depending on the flow regimes and material properties.

Many investigations were done to study the effect of particles sizes on heat transfer coefficient and they obtained that the heat transfer coefficient decreases with increasing particle size.

Experiments were carried out by Nima Masoumifard, et al. in a fluidized bed in order to verify the influence of the axial position, particle diameter and the superficial gas velocity on the heat transfer coefficient from a small horizontal tube \(D_t = 8\) mm immersed in the fluidized bed. The solid particles used were 280, 490 and 750 \(\mu m\) diameter sand particles, fluidized by air. They showed that the heat transfer coefficient was increased with increasing the gas velocity, up to a maximum, and then decreases with a slight slope. The heat transfer coefficient was found to decrease by increasing the particle size. The probe position had less influence on the heat transfer coefficients.

P. Neto et al. studied the heat transfer in a laboratory scale bubbling fluidized bed with 54.5 mm ID, using five different sizes of silica sand particles of 107.5, 142.5, 180, 282.5, and 357.5 \(\mu m\). The bubbling bed region was heated by a 2 kW electrical resistance and the heat was transfer towards membrane cooling wall placed above the free surface bed. They found that there were two heat transfer mechanisms are responsible for the thermal energy transportation towards the membrane cooling walls (1) the convective heat transfer from the mainly fluidized air flow, (2) the heat carried by the bed solid particles in the to-and-from movement created by their upward projection, due to the bursting bubbles reaching the bed surface, their collisions against the membrane walls and subsequent return to the hot bubbling bed. The objective of the present study is to investigate in detail heat transfer and to ascertain the effect of important parameters on the heat transfer coefficient between the horizontal heat transfer surface and the fluidized bed in a lab-scale fluidized bed system.

2. EXPERIMENTAL SETUP

Laboratory scale fluidized bed setup can be shown in fig. 1, the experiments were conducted in a 0.1 m ID and 1 m height mild steel fluidization column. Air was supplied by a compressor. The air flow was measured by a rotameter. The air was passing through the plenum chamber filled by glass beads to maintain uniform distribution of air through bed, with a height of 0.1 m and upper diameter of 0.1 m and bottom diameter of 0.015 m. The air was distributed by a perforated plate of mild steel with a diameter of 0.1 m and a thickness of 0.003 m will consists of 256 holes of 2.7 mm diameter drilled on a 7.5 mm square pitch. An ultrafine mesh was fixed on the distributor plate to prevent bed particles leakage. There were 10 pressure ports in the fluidized column for pressure drop measurements. The heat transfer section consisted from horizontal heat transfer probe.
Fig. 1: Experimental setup of fluidized bed column, 1-compressoe, 2-Valve, 3-air rotameter, 4-plenum chamber, 5- Horizontal heat transfer probe, 6-thermocouples, 7- digital screen, 8- DC power supply, 9-five U manometers.

An ultrafine mesh was fixed on the top end of the column to avoid escaping the particles from the top. Local sand of three different sizes 301µm, 454µm, and 560 µm were used as the bed material. Three bed inventories of sand 1.5 kg, 2.0 kg, and 2.5 kg, four superficial air velocities of 1.0 m/s, 1.25 m/s, 1.5 m/s, 1.75 m/s were used. Three heat fluxes of 1698.9, 2928.4, 4675.7 W m$^{-2}$ were employed.

The local heat transfer coefficient along the probe were estimated from the equation:

$$h_i = \frac{V_l}{A_h(T_{s_i} - T_{b_i})} = \frac{q}{T_{s_i} - T_{b_i}}$$

(4)

The probe average heat transfer coefficient was estimated from the local heat transfer coefficients:

$$h_{avg} = \frac{h_1 + h_2 + h_3 + ... + h_i}{i}$$

(5)

3. RESULTS AND DISCUSSION

3.1 Effect of air superficial velocity on heat transfer coefficient

Fig. 3 shows the effect of superficial gas velocity of 1.0, 1.25, 1.5, 1.75 m/s on the surface-to-bed heat transfer coefficient in the fluidized column at heat fluxes of 1698.9, 2928.4, 4675.7 W m$^{-2}$, 1.5 kg bed inventory and 301µm particles size. From the figure, it is noticed that the heat transfer coefficient increased with increasing the fluidization velocity. The increase in heat transfer may be due to enhanced turbulence in the column for higher velocity which in turn causes for intermixing of solids and gas solid suspension.
3.2 Effect of bed inventories on heat transfer coefficient

The effect of bed inventories on heat transfer coefficient can be shown in fig. 4. Inventory in the bed was varied as 1.5, 2.0, and 2.5 kg. It is observed that increase in the inventory of sand in the column increases the bed temperature and heat transfer coefficient. This is because sand particles concentration increases with increase bed inventory. Consequently, more quantity of particles in the lower splash region promotes more heat transfer through conduction because of which bulk temperature of bed was observed to be higher than that of lower inventory. W/m²

Fig. 2: Effect of gas superficial velocity on heat transfer coefficient at I=1.5 kg, dₚ=301µm and three different heat fluxes

Fig. 3: Effect of bed inventories on heat transfer coefficient at q=1698.9 W m⁻², dₚ=301µm and four different gas superficial velocities

Fig. 4: Effect of bed inventories on heat transfer coefficient at q=2928.4 W m⁻², dₚ=301µm and four different gas superficial velocities
3.3 Effect of sand particle size on heat transfer coefficient

Fig. 7, 8, and 9 show the effect of particle size on the heat transfer coefficient between the heat transfer probe and the bed particles. Sand particles size of 301, 454, and 560 µm were used. It is found that the heat transfer coefficient decreases for large particles mainly because of the higher thermal resistance offered by the particles. Also, with increase of particle size, the gas gap thickness between the surface and particles increases resulting in a decrease of the heat transfer coefficient. Moreover, the smaller particles can increase the effective heat transfer area covered by particle itself.
Fig. 8: Effect of particles size on heat transfer coefficient at $q=4675.7 \text{ W m}^{-2}$, $I=1.5 \text{ kg}$, and four different gas superficial velocities

3.4 Effect of heat fluxes on heat transfer coefficient

The variation of heat transfer coefficient for different heat flux conditions against gas superficial velocity for a particular bed inventory is shown in fig. 3. The heat transfer coefficient is high for higher values of heat flux and it is decreasing with the decrease in heat flux. For higher heat flux condition, the bed temperature increases. This is due to increase of amount of the heat which transferred to the fluidized bed system, which in turn tends to enhance the heat transfer coefficient.

4. CONCLUSIONS

The main focus of this study was the effect of different operating parameters on heat transfer coefficient in gas-solid fluidized bed. Following conclusions obtained from the experimental results:

1. Heat transfer coefficient is found to be increasing with increase air superficial velocity.
2. Heat transfer coefficient is directly proportional to the heat fluxes and bed inventory.
3. Smaller particles size yield higher heat transfer coefficient and vice versa in present heat transfer studies.
4. The data show trends similar to those in published literatures.

REFERENCES

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