Effect of Fins on Heat Transfer of Horizontal Immersed Tube in Bubbling Fluidized Beds

Saeid. Rasouli, Mohammad.R. Golriz

***Abstract*— Steady state time averaged local heat transfer coefficient measurements were made by the local thermal simulation technique in a cold bubbling fluidized bed with horizontally immersed tube initially with no fin and then with three fixed annular fins of constant thickness. Silica sand of mean particle diameter 307 µm and 200 µm were used as the bed materials. The results indicate that although the heat transfer coefficient falls with the use of fins, the total heat transfer rises as the result of the greater surface area. Increasing the particle diameter reduces the heat transfer coefficient not only for unfinned horizontal tube but also for annular finned horizontal tube at the same conditions of fluidized bed. Based on the experimental data, correlations are proposed for predicting heat transfer coefficient from fluidized bed to horizontally immersed tubes with and without fins.**

***Index Terms*— Annular fin, Bubbling fluidized bed, Heat transfer.**

I. INTRODUCTION

Kim et al. [1] determined heat transfer and bubble characteristics in a fluidized bed with an immersed horizontal tube bundle, and showed that the average heat transfer coefficient increases with increasing gas velocity toward a maximum value of the coefficient.

Busoul and Abuein [2] investigated the heat transfer characteristics around a horizontal heated tube immersed in a fluidized bed and reported that the local heat transfer coefficient is inversely proportional to the solid particle diameter in the range 108-856 µm.

Nag et al. [3] developed a mathematical model for the prediction of heat transfer from finned surfaces in a circulating fluidized bed. They summarized their results as follows:

- Bed -to- wall heat transfer increases with increasing suspension density.
- Addition of fins decreases the heat transfer coefficient.
- An increase in the number of fins decreases the heat transfer coefficient.

The objective of this work is to investigate the effect of gas velocity, mean particle diameter and the circular fins on the average heat transfer coefficients between an immersed horizontal tube in a bubbling fluidized bed and develop an empirical correlation based on the experimental data.

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II. MODEL

In general, the heat transfer process in fluidized bed combustor in gas-fluidized beds consists of particle convection/conduction, gas convection and radiation. However, in this work because of low temperature difference between the immersed surface and the bed material the radiation has been neglected. For the mathematical modelling despite of two components of heat transfer, particle convection and gas convection, an average value has been assumed [4].The average heat transfer coefficient from unfinned horizontal tube to bed material, h_{UF}, was determined for each operating condition at steady state from the measured voltage, V, current, I, the average temperatures of the tube surface, T_{base}, and the bed suspension, T_{bed}:

$$h_{UF} = VI / A_{UF}\left(T_{base} - T_{bed}\right) \tag{1}$$

Where A_{UF} is the total surface of the unfinned tube. Uncertainty in the heat transfer coefficient measurements is found by applying the procedure outlined in [5]:

$$\left(U_h/h\right)^2 = \left(U_{VI}/VI\right)^2 + \left(U_A/A\right)^2 + \left(U_{T_{base}}/\left(T_{base}-T_{bed}\right)\right)^2 + \left(U_{T_{bed}}/\left(T_{base}-T_{bed}\right)\right)^2 \tag{2}$$

Substituting the uncertainty of different parameters and the minimum value of the denominators in Eq. (2) ensured an uncertainty of heat transfer measurement less than 7.8%.

For a circular fin as a radial shape around a cylindrical tube in [6]:

$$r^2 \frac{d^2\theta}{dr^2} + r\frac{d\theta}{dr} - m^2 r^2 \theta = 0 \tag{3}$$

Where: $\theta = T - T_{bed}$

Solution of Eq. (3) is:

$$\theta(r) = C_1 I_0(mr) + C_2 K_0(mr) \tag{4}$$

And then coefficients C_1 and C_2 were obtained as:

$$C_1 = \frac{\theta_{base} K_0(mr_2) - \theta_{top} K_0(mr_1)}{k_0(mr_2) I_0(mr_1) - I_0(mr_2) k_0(mr_1)} \tag{5}$$

$$C_2 = \frac{\theta_{base} I_0(mr_2) - \theta_{top} I_0(mr_1)}{K_0(mr_1) I_0(mr_2) - K_0(mr_2) I_0(mr_1)} \tag{6}$$

Total heat transfer from the circular fins to the bed may be calculated as:

$$Q_{total} = h_F A_{base}(T_{base} - T_{bed}) + N_F \left(-k(2\pi r_1 t) \left(\frac{d\theta}{dr} \right)_{r=r_1} \right) = VI \tag{7}$$

Then the averaged heat transfer coefficient between finned tube and fluidized bed, h_F, for each operating condition of steady state from the measured rate of heat flux and the temperatures can be determined.

III. EXPERIMENTAL APPARATUS AND FACILITY

The bubbling fluidized bed unit in which experiments were conducted comprised of a 90 mm inside-diameter and 260 mm- tall main columns, made up of Plexiglas to allow visual observation., Fig. 1. For determining heat transfer coefficient around an unfinned horizontal tube, a heat transfer probe (15 mm outside diameter × 50 mm long) was made of steel rod and insulated at the ends. A hole was drilled at the center of the rod to accommodate a resistance heater (6.5 mm outside diameter × 42 mm long), Fig. 2a. The finned heat transfer probe was made of polyethylene rod (15 mm outside diameter × 50 mm long) with three fins (27 mm outside diameter and 4 mm thick), Fig. 2b. The power input to the heater was controlled by a variable direct current power supply. The supplied heat flux is determined by measuring voltage (V) and current (I). Because the temperature of the probe was higher than the bed temperature, heat was transferred from the probe to the bed, i.e. in the opposite direction to that in a real fluidized bed heat exchanger.

Air velocity was varied from minimum fluidization velocity, u_{mf}, to near $3\times u_{mf}$, and two different silica sand diameters were used as shown in Table 1. For each of the sand particles the heat transfer coefficients were determined for 8 to 10 different gas velocities, and for each of the velocities the measurements were repeated 4 to 6 times.

Table 1. Properties of solid particles

Material	d_p (μm)	ρ (k_g/m^3)	u_{mf} (m/s)	$1-\varepsilon_0$
Sand # 1	200	2660	0.062	0.56
Sand # 2	307	2720	0.082	0.53

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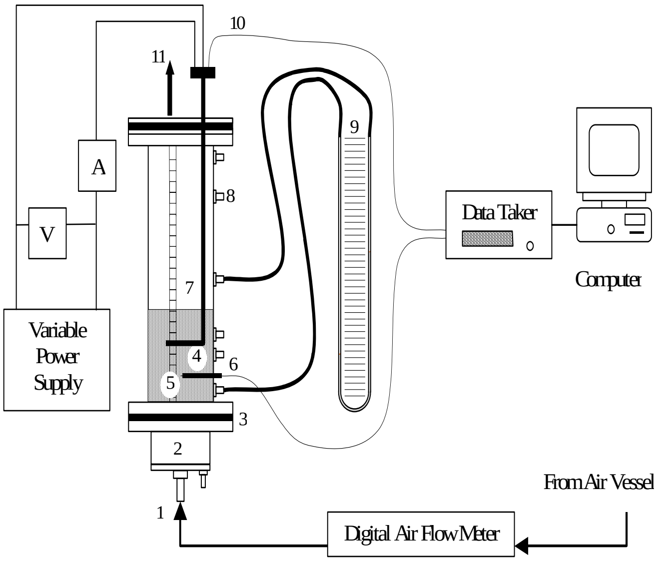
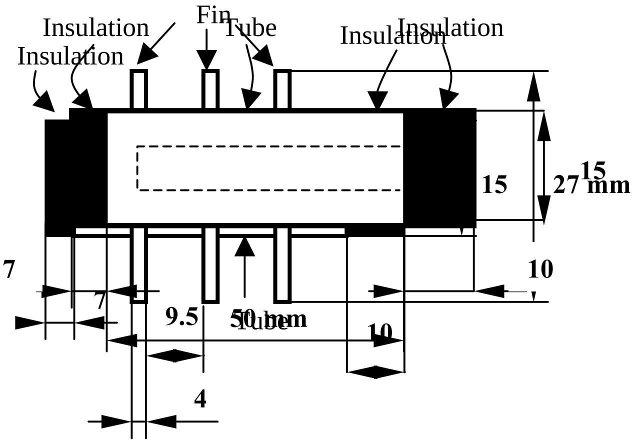


Fig. 1. Schematic diagram of the experimental set-up: (1) Air inlet, (2) Air distribution chamber, (3) Distributor plate, (4) Horizontal tube, (5) Scaling for bed height measurement, (6) Thermocouple for bed temperature, (7) Hollow tube, (8) Pressure taps, (9) Pressure difference measurement device, (10) Test probe thermocouple, (11) Exhaust air openings

(a)



(b)

Fig. 2. Schematics of finned tube (a), unfinned tube (b) (units in mm).

IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

Figs 3-4 present the results obtained from the experiments. Fig. 3 illustrates the variation of heat transfer coefficient with superficial gas velocity around unfinned and inned horizontal tubes. The experimental results show increase in h_{UF} *and* h_F as u_g increased with increasing gas velocity. As mentioned, in the bubbling fluidized bed, heat transfer coefficient depends on two major parameters: particle residence time at tube surface (particle convection) and bed porosity adjacent to the tube surface (gas convection). When the gas velocity is increased, particle residence time is decreased due to the rising bubbles and the higher bed porosity. In low velocity (below $2\times u_{mf}$), these competing effects result in an increase in heat transfer coefficient when the fluidizing velocity is increased. Also, the results show that the heat transfer coefficient decreased with increase in particle size. One possible explanation for this could be that the net surface area of particle contact with the tube for smaller solid particle diameter increases. Another explanation could be that due to changes in the particle motion/hydrodynamics, the particle convection would increase for smaller particles.

h_F/h_{UF} is fin tube performance which indicates the heat transfer coefficient for a finned tube compared to that obtained of an unfinned tube under similar bubbling fluidized bed conditions. Fig. 4.shows that this ratio decreases as particle Reynolds number, Re_p, increases. One reason for this is that the void fraction around the tube increases as Re_p increases. That causes a lower heat transfer coefficient because of the lower heat transfer coefficient of air compared to the particles.

The capacity function, $A_Fh_F/A_{UF}h_{UF}$, which is a direct measure of the heat transfer capability for a finned tube relative to an unfinned tube with similar superficial bed volume, is also plotted as a function of particle Reynolds number in Fig. 4. The reason for the reduction of this ratio is the same as explained for the fin tube performance. However, it is to be noted that the values of capacity function were between 1.4 and 1.8 for the test conditions of bubbling fluidized bed. This represents a substantial increase in heat transfer capacity over the unfinned tube of the order of 40-80%.

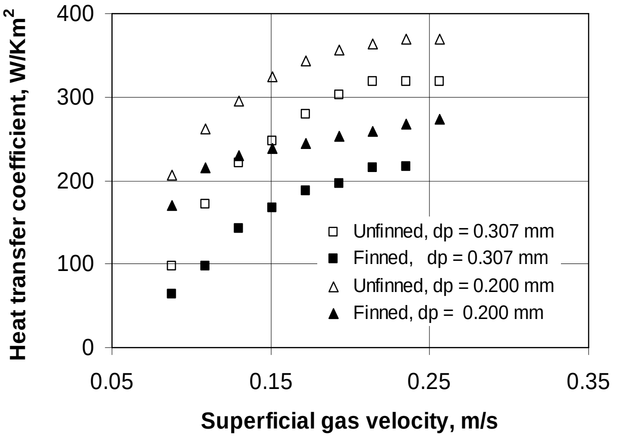


Fig. 3. Heat transfer coefficient around immersed horizontal unfinned and finned tubes versus superficial gas velocity for different particle diameters.

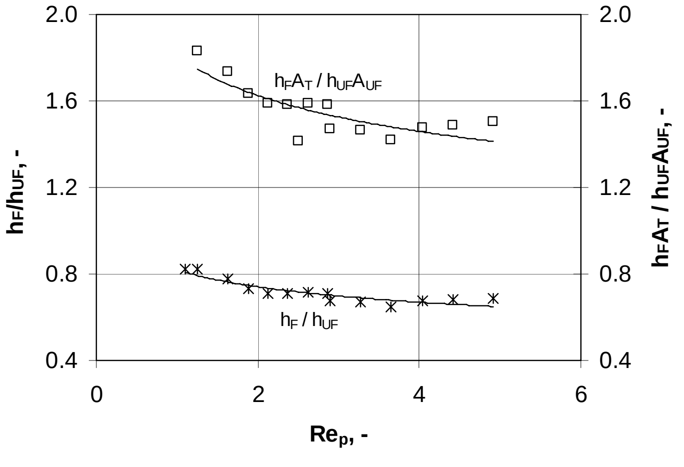


Fig. 4. The ratio of heat transfer coefficients and capacity function for finned to unfinned horizontal tube versus Re_p.

V. EXPERIMENTAL CORRELATION

The heat transfer coefficient data presented in the previous section was correlated as a function of Re_p and Prandtl number, Pr, and the following correlation is suggested for the average unfinned and circular finned horizontal immersed tube-to-bed heat transfer coefficient:

$$Nu_{UF} = 1.754\,\mathrm{Re}_p^{0.556}\,\mathrm{Pr}^{0.3} \tag{8}$$

for unfinned tube and

$$Nu_F = 1.475\,\mathrm{Re}_p^{0.404}\,\mathrm{Pr}^{0.3} \tag{9}$$

For finned tube. Fig. 5 shows the experimental data plotted versus predictions from equations (8) and (9). A very satisfactory agreement is clear at higher heat transfer coefficients.

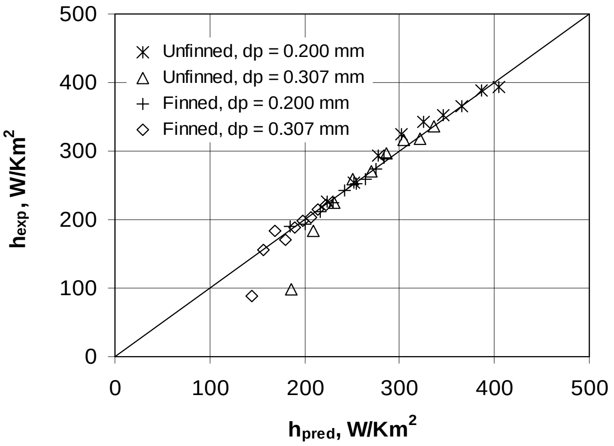


Fig. 5. Predicted heat transfer coefficients versus experimental data for horizontal unfinned and finned tubes.

VI. CONCLUSIONS

The following conclusions were reached within the operational conditions of this work:

- Heat transfer coefficient of circular horizontal finned tube is lower than that of the unfinned horizontal tube but total heat transfer increases because of the larger surface area.
- Bed-to-tube heat transfer with and without fin is empirically correlated as a function of particle Reynolds number and Prandtl number using a power-type relation. It was found that the model predictions were in good agreement with experiments at higher heat transfer coefficients and overestimates at lower heat transfer coefficients.

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