Characteristics of Grid Zone Heat Transfer in a Gas-Solid Fluidized Bed

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The grid zone in a gas-solid fluidized bed reactor has been observed to play a critical role in governing the reactor performance, particularly in shallow and large beds with fast reactions (Cooke et al., 1968). However, despite its importance the grid zone behavior is far from completely understood, due mainly to its complexity and the few efforts to study it. Grace and DeLasa (1978) have commented that there is a need for further work in the grid region.

One of the important aspects on the grid zone behavior is the heat transfer between the bed and immersed horizontal tubes. Although this subject has been under intensive study in the bubbling zone and freeboard area (George and Grace, 1982; Biyikli et al., 1983), no systematic work has been performed in the grid zone. Andeen and Glicksman (1976) have examined the phenomenon and concluded that the existing heat transfer correlations for the bubbling zone give erroneous results when applied to the grid zone, especially at high velocities. The finding is expected since the two zones are significantly different in their hydrodynamic characteristics.

An example of a process involving grid zone heat transfer is the shallow fluidized-bed heat exchanger described by Virr and Williams (1985). The exchanger is operated at an extremely low bed height (6–10 cm) with horizontal fin tubes in the grid region. The authors reported a higher than expected heat transfer rate (compared to the bubbling bed heat transfer rate) and that, after two years of operation, no erosion marks were

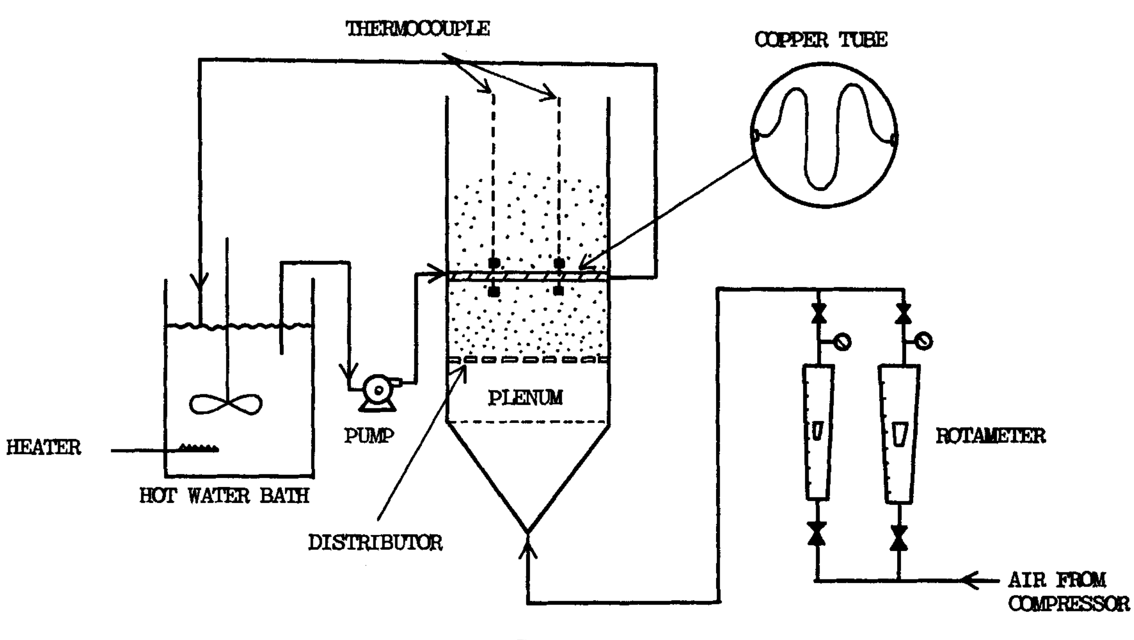

Figure 1. Experimental setup.

Table 1. Types of Distributor Tested

	Plate No.						
	2A	2B	2	2C	6	4	7
Thickness, mm	6.35	6.35	6.35	6.35	6.35	6.35	6.35
Hole dia., mm	4.76	1.59	3.18	4.37	1.59	3.18	1.59
No. of holes	49	49	49	26	193	197	793
Pitch, mm	25.4	25.4	25.4	36.0	12.7	12.7	6.35
Open area ratio, %	2.692	0.299	1.196	1.20	1.18	4.81	4.84

detected. The higher than expected heat transfer rate can be attributed to the fact that the process is governed by the grid zone instead of the bubbling zone heat transfer.

In this study, the characteristics of heat transfer to horizontal tubes in the grid zone and bubbling zone of a gas-solid fluidized bed were examined and compared semiquantitatively. Experiments were conducted in a 0.203 m (8 in.) ID cold air-sand fluidized bed coupled with a simple hot water circulation system. Experimental parameters included particle size, static bed height, superficial gas velocity, distributor open area, distributor hole size, distributor hole number, and location of the heating tube.

Experimental Method

The experimental facilities involved in the study included an air-sand fluidized bed assembly, a hot water circulation system, and temperature measurement devices. A schematic diagram of the experimental setup is shown in Figure 1.

The fluidized bed assembly consisted of a 25 hp compressor, a surge tank, two rotameters, and a 0.203 m (8 in.) ID bed column. Sand of three sizes, 18–20, 20–30, and 30–40 mesh, was used as the fluidized particles. Perforated plates with different open areas, hole sizes, and numbers of holes were used as the distributors; their design specifications are given in Table 1.

The hot water circulation system consisted of a 0.057 m^3 (15 gal) water reservoir maintained at approximately 77°C, a pump, and a 0.6 m (2 ft.) long copper tube of 6.35 mm (¼ in.) OD located in the bed. The water flow rate was measured using a measuring cup and a stop watch. Thermometers were mounted at the inlet and at the outlet of the copper tube to measure the water temperatures. Two sets of thermocouples located in the bed but at different radial positions were used to measure the bed temperatures. Each set involved two thermocouple probes, one placed 10 mm above and the other 10 mm below the tube. Insulation material was applied to the tank and the connecting tubing to reduce heat loss.

For each experimental run the copper tube was mounted at the designed height, a designed amount of sand was charged in the bed, and the superficial velocity was adjusted to the designed value. The hot water flow rate was measured, and temperatures of the water and the bed were monitored. After the system reached steady state, the temperatures and the water flow rate were recorded. The heat transfer coefficient between the bed material and the tube was then calculated according to the following energy balance equation:

$$h_w = \frac{U}{1.0 - U[(d_o/d_i h_i) + d_o \ln(d_o/d_i)/(2K)]} \tag{1}$$

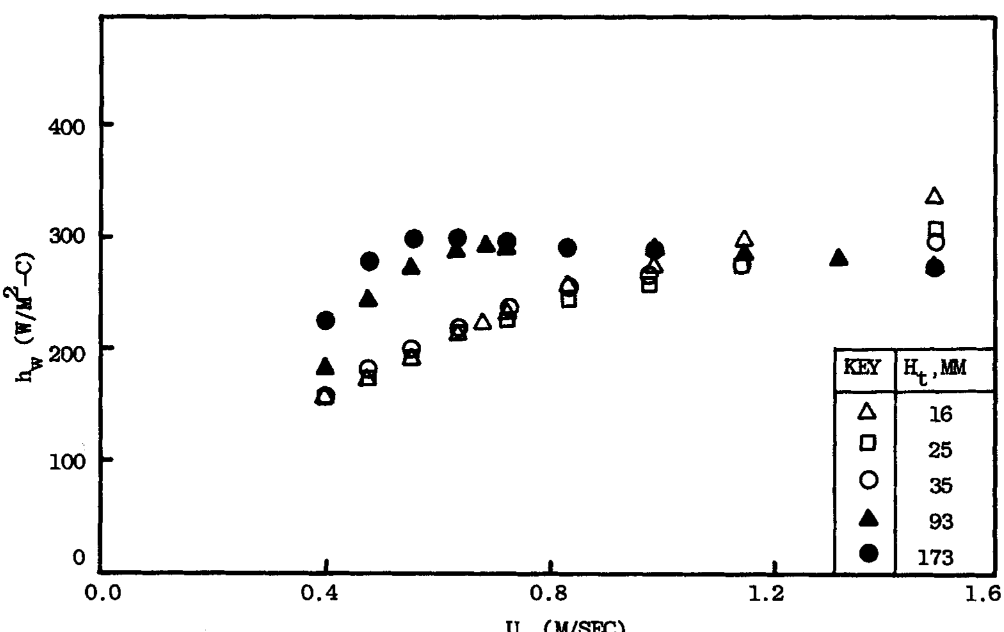

Figure 2. Heat transfer coefficient vs. superficial gas velocity for plate 2.
d_p = 0.715 mm, H_o = 0.25 m

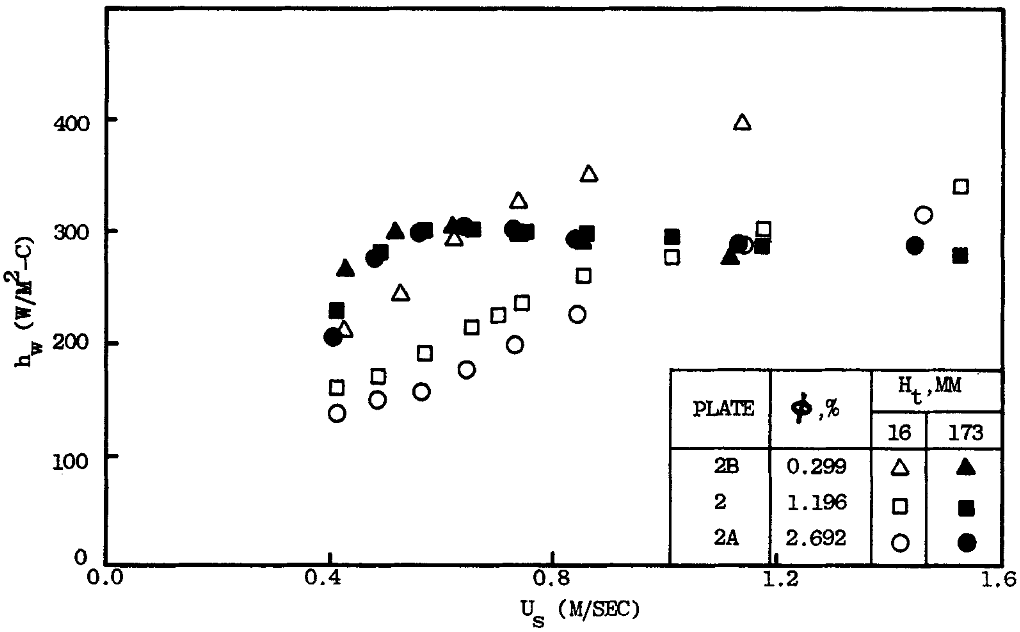

Figure 3. Effect of open area ratio ϕ on heat transfer coefficient for plates 2B, 2, and 2A.
$d_p = 0.715$ mm, $H_o = 0.25$ m

where $U = GC(T_1 - T_2)/A_t(T_f - T_b)_{ln}$, and h_i was estimated from the correlation equation derived by Sieder and Tate (1936).

Results and Discussion

Figure 2 is a typical set of results describing the effect of superficial gas velocity on the heat transfer coefficient with the tube location as the parameter. Note that five tube locations are included in the figure, with $H_t = 16$, 25, and 35 mm being in the grid zone, and $H_t = 93$ and 173 mm in the bubbling zone.

The figure indicates that in the bubbling zone the heat transfer coefficient increases and then decreases with the air flow rate. This observation is in good agreement with those made by other investigators (Saxena et al., 1978). The increase of the heat transfer coefficient at low air flow rates is mainly due to the increase in particle movement; the decrease at high air flow rates, however, is due to the decrease in particle density.

The results shown in Figure 2 in the grid zone region, i.e., with $H_t = 16$, 25, and 35 mm, indicate that the heat transfer coefficient increases with the air flow rate both in the low and high

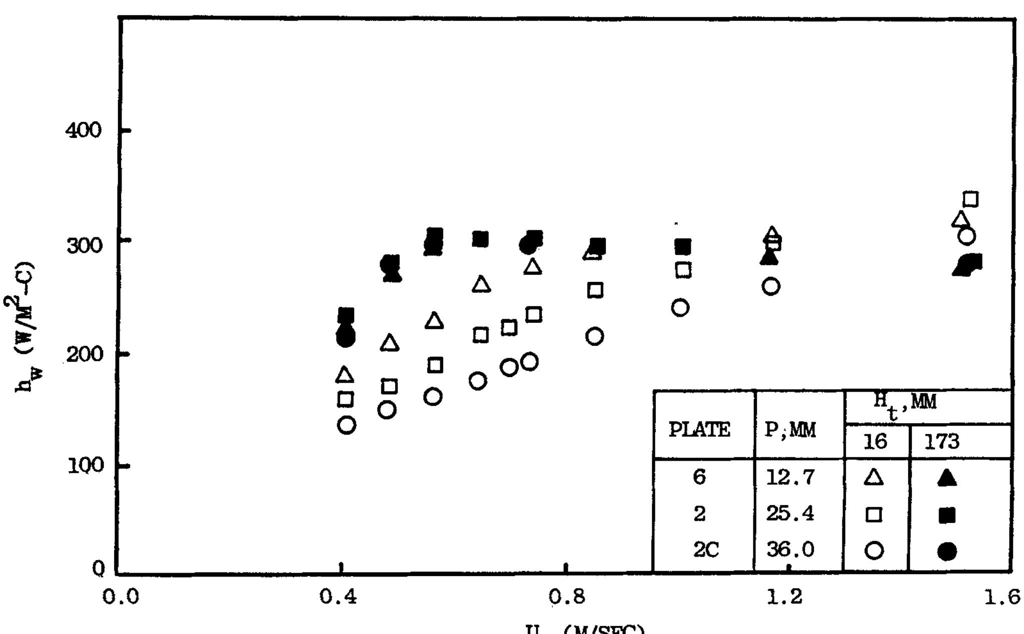

Figure 4. Effect of pitch distance P on heat transfer coefficient for plates 6, 2, and 2C.
$d_p = 0.715$ mm, $H_o = 0.25$ m

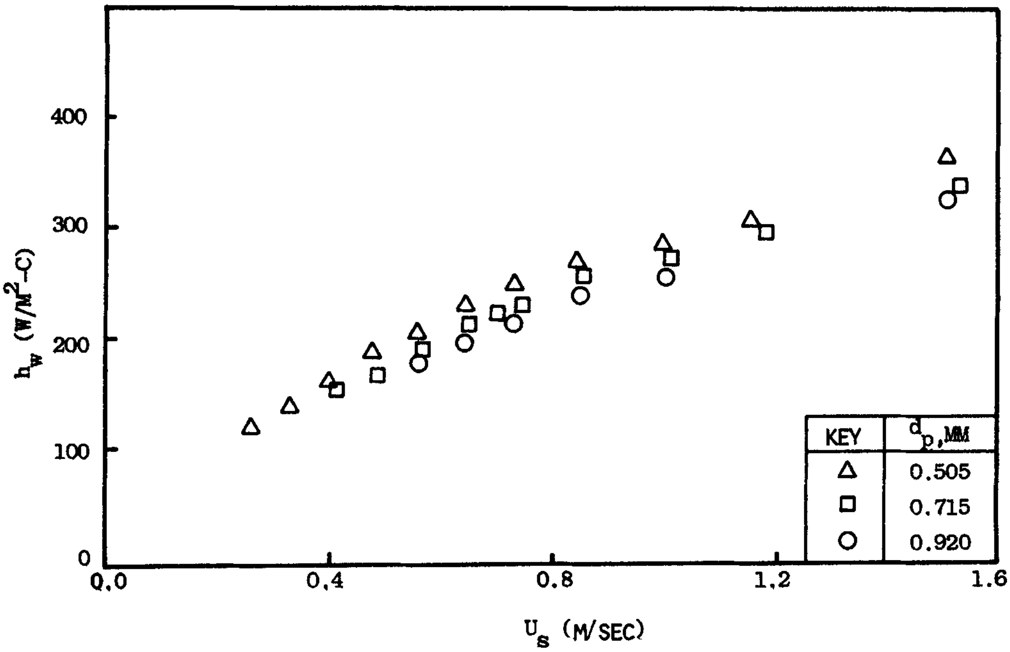

Figure 5. Effect of mean particle size on heat transfer coefficient for plate 2.
H_o = 0.25 m, H_t = 16 mm

flow rates. The differing trends imply that the jetting effect on the heat transfer coefficient is different from that of the effect of bubbling. This clearly suggests that the characteristics of heat transfer in the grid zone are significantly different from those in the bubbling zone.

Effect of distributor open area ratio

Figure 3 shows the effect of distributor open area ratio on the heat transfer coefficient both in the grid zone region (H_t = 16 mm) and in the bubbling zone region (H_t = 173 mm). Note that the three distributors used have the same number of holes and hole pattern. The results in the figure indicate that in the bubbling zone, the distributor open area ratio affects the heat transfer coefficient only at low air flow rates. A low open area ratio corresponds to a slightly higher coefficient. This observation is similar to that made by Davidson and Harrison (1971). In the grid zone, however, the heat transfer coefficient increases with the decrease in open area ratio at all air flow rates. Since a

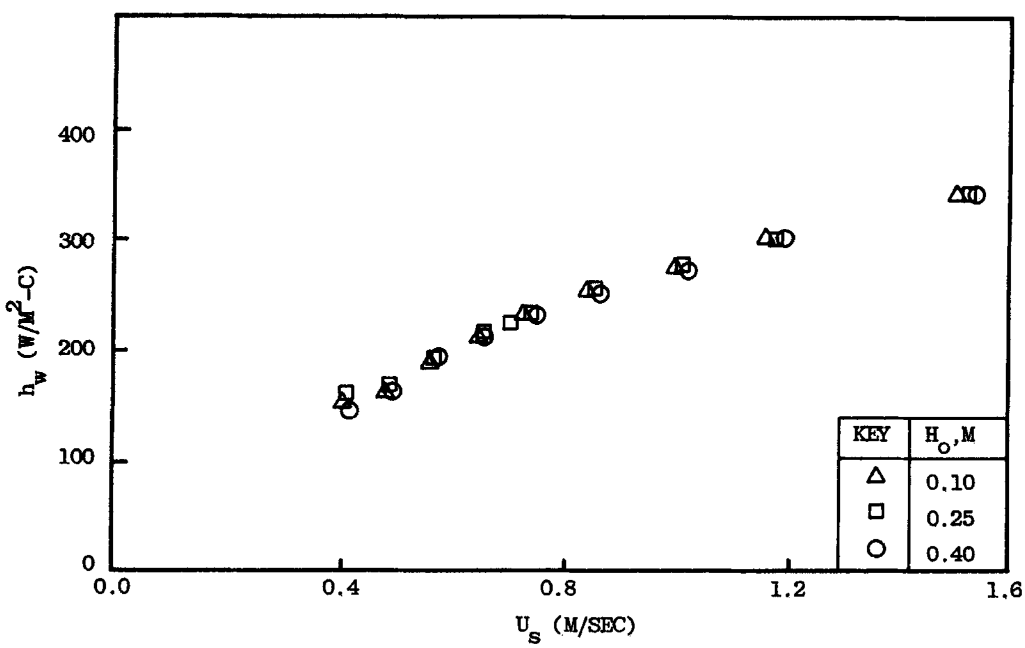

Figure 6. Effect of static bed height on heat transfer coefficient for plate 2.
d_p = 0.715 mm, H_t = 16 mm

smaller open area ratio implies a higher jetting velocity, the results suggest that jetting velocity strongly affects the grid zone heat transfer.

Effect of distributor pitch distance

Figure 4 is a typical result showing the effect of distributor hole pattern on the heat transfer coefficient both in the grid zone and in the bubbling zone. Note that plates 6, 2, and 2C have the same open area ratio but have different hole sizes and numbers of holes. The jetting velocities are the same for the three plates at any air flow rate. The results in the figure again indicate that the distributor design has little effect on the bubbling zone heat transfer; however, it strongly affects the grid zone heat transfer. The grid zone heat transfer coefficient with plate 6 appears to have the highest values. This may be due to the fact that the percentage of the tube surface covered by the jetting air is the highest with plate 6. On the other hand, the results with plate 2C show the lowest coefficient because of its lowest coverage of the jetting air on the tube surface.

Effect of particle size

The effect of particle size on the grid zone heat transfer is shown in Figure 5. It appears that the heat transfer coefficient with smaller particles is slightly higher than that with larger particles. Note that this trend is in agreement with that observed in the bubbling zone by other investigators (Saxena et al., 1978).

Effect of static bed height

The static bed height has little effect on the grid zone heat transfer to horizontal tubes, as can be seen in Figure 6. The observation is consistent with that of Fan et al. (1984), which states that the static bed height has little effect on the grid zone hydrodynamics.

Notation

A_t = outside surface area of tube, m^2
C = heat capacity of water, J/kg · °C
d_o, d_i = outside, inside diameter of tube, mm
d_p = mean particle diameter, mm
G = water flow rate, kg/s
H_t = tube location, mm
h_i = heat transfer coefficient from inside wall to water, W/m^2 · °C
h_w = heat transfer coefficient, W/m^2 · °C
H_o = static bed height, m
K = thermal conductivity of tube material, W/m · °C
p = pitch distance, mm
T_1, T_2 = water temperature at tube inlet and outlet, °C
$(T_f - T_b)_{ln}$ = log mean temperature difference between tube water and bed
U_s = superficial gas velocity, m/s
U = overall heat transfer coefficient referred to outside diameter of tube, W/m^2 · °C
ϕ = distributor open area ratio, %

Literature cited

Andeen, B. R., and L. R. Glicksman, "Heat Transfer to Horizontal Tubes in Shallow Fluidized Beds," *ASME Papers*, **76-HT-67** (1976).
Biyikli, S., K. Tuzla, and J. C. Chen, "Heat Transfer Around a Horizontal Tube in Freeboard Region of Fluidized Beds," *AIChE J.*, **29**, 712 (1983).
Cooke, M. J., W. Harris, J. Highley, and D. E. Williams, "Kinetics of Oxygen Consumption in Fluidized-Bed Carbonisers," *Inst. Chem. Eng. Symp. Ser.*, **30**, 21 (1968).
Davidson, J. F., and D. Harrison, *Fluidization*, Academic Press, New York, 509 (1971).
Fan, L. T., T. C. Ho, N. Yutani, and W. P. Walawender, "Statistical Study of the Frequency of Free Bubbling in a Shallow Gas-Solid Fluidized Bed," *Fluidization IV*, 4th Int. Conf. Fluidization, Engineering Foundation, New York, 1-3-1 (1984).
George, S. E., and J. R. Grace, "Heat Transfer to Horizontal Tubes in the Freeboard Region of a Gas-Fluidized Bed," *AIChE J.*, **28**, 759 (1982).
Grace, J. R., and H. I. DeLasa, "Reaction Near the Grid in Fluidized Beds," *AIChE J.*, **24**, 364 (1978).
Saxena, S. C., N. S. Grewal, and J. D. Gabor, *Advances in Heat Transfer*, Academic Press, New York, **14**, 149 (1978).
Sieder, E. N. and G. E. Tate, "Heat Transfer and Pressure Drop of Liquids in Tubes," *Ind. Eng. Chem.*, **28**, 1429 (1936).
Virr, M. J., and H. W. Williams, "Heat Recovery by Shallow Fluidized Beds," *Chem. Eng. Prog.*, **81**, 50 (July, 1985).

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