순환 유동층 열교환기에서 입자에 의한 열전달 특성

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Particle Convective Heat Transfer in a Circulating Fluidized Bed Heat Exchanger

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1. Introduction

Circulation Fluidized Beds Technology has developed into one of the most important branches of fluidization engineering. Extensive results have been done in recent years to understand the heat transfer mechanism and predict the heat transfer coefficient of circulating fluidized beds. Due to the insufficient information of heat transfer data and hydrodynamic characteristics, a prediction of the heat transfer coefficient for CFB is not accurate enough to guarantee the proper design of heat transfer surface. The purposes of present investigation were the determination of the significance of particle convective heat transfer and the prediction of total heat transfer in circulating fluidized beds.

The test section was designed to measure simultaneously the total and radiative heat flux and the axil variation of heat transfer coefficients. Analysis of experimentally determined heat transfer coefficients reveals the relative importance of three major heat transfer mechanisms (gas convection, particle convection and radiation) in conjunction with flow regimes in a dilute upward suspension flow system.

2. Experiment

The experiments were carried out in a circulating fluidized bed heat exchanger, a schematic diagram of which is shown in Figure 1. The heat transfer test section was water-cooled heat exchanger having a 5.0cm ID of tube and a 7.5 cm ID of shell size and 90cm height.

A commercially available gas pilot was used to maintain the high temperature of suspension. Cyclone was employed as a gas-solid separator and the captured particles were recirculated through the particle reservoir and timing the accumulation of a parked bed of solids through three 15.1mm OD quartz windows mounted along the return column.

The test section is instrumented with six thermocouples at 17.8 cm intervals for the measurements of axial temperature profiles of suspension cooling water. For the direct measurement of suspension-to-wall heat transfer coefficient, wall temperatures were also measured at the same interval as suspension temperature and water temperature by soldering four 1.0mm OD thermocouples on the outer side of the tube. Two pressure taps were mounted at the bottom and the top to measure the pressure drop of the test section. On the middle of the test section, radiometer was installed for the measurement of radiative heat flux from suspension to cold wall. A data acquisition system was employed to take the time average values of temperatures, pressure drop and radiative heat flux. Silica sand and Fcc particles were used as test particles. The superficial gas velocity was varied between 3 m/s and 12 m/s at operating temperatures. Suspension density deduced from the pressure drop covered a range from 3 kg/m^3 to 35 kg/m^3. The maximum operating temperature in this study was 600℃ .

3. Results and Discussions

3.1 Determination of Particle Convective Heat Transfer Coefficient

As an engineering approximation, the three heat transfer mechanisms (particle convection, gas convection and radiation) may be regarded as independent of each other, so that the total heat flux can be written as the sum of three terms.

$$Q_t = Q_{pc} + Q_{gc} + Q_{rad} \tag{1}$$

The term particle convection refer to the mechanism of energy transfer due th the existence of particles. Heat transferred from a particle during its contact with the cool surface mainly by transient conduction. Gas convection is the direct wall to gas heat transfer over those parts of the cooled walls which are not in contact with particles. The radiative component of heat transfer which becomes important for higher temperature, can be estimated from the radiative heat exchange equation between a hot gas-solid suspension and cool wall.

$$Q_r = \frac{\sigma(T_{sus}^4 - T_w^4)}{\frac{1}{\varepsilon_{sus}} + \frac{1}{\varepsilon_w} - 1} \tag{2}$$

Because the main purpose of this study is investigating the characteristics of particle convective heat transfer with respect to operating parameters, following procedure was employed to separate the particle convective heat flux from the total heat flux. Since total heat flux and radiative heat flux (gas+particles radiation) were measured by the calorimetry of cooling water and radiometer, particle convective heat flux was determined by the estimation of gas convection of fully developed turbulent flow given by Sleicher et al.(1975)

3.2 Particle Convective Heat Transfer Model

Because of the simultaneous measurement of total and radiative heat flux in this experiment, particle convective heat transfer coefficient was extracted from the determined total heat transfer coefficient. Theories have been proposed to describe heat transfer mechanism at the surface based on semi-infinite "packet model" rather than "single particle model". The comparison of existing particle convective heat transfer model proposed by Dou (1990), Basu (1990) and Glicksman (1988) with experimenta lly determined particle convective heat transfer coefficients showed a wide scattering. It is believed that the discrepancy resulted from the difficulty in determining the hydrodynamic parameters such as packet contact time and wall solid fraction.

A particle convective heat transfer model was proposed based on surface-renewal model.

The unsteady-state conduction equation can be expressed

$$(\rho_p\, sf_w\, Cp_e\, U_s)\frac{\partial T}{\partial y} = K_e \frac{\partial^2 T}{\partial X^2} \tag{3}$$

The equation can be solved analytically based on the assumption of semi-infinite body.

$$\frac{T_{sus}-T}{T_{sus}-T_w} = erf\left(\frac{X}{\sqrt{4Cy}}\right) \tag{4}$$

then

$$h_{pc} = \sqrt{\frac{K_e\, Cp_e\, \rho_p\, sf_w\, U_s}{\pi\, L_c}} \tag{5}$$

For the assumed constant layer velocity, U_s = 1.26 m/s was used as obtained value from visual experiments by Wu et al.(1990) and Glicksman (1988).

In order to obtain the general equation of the wall solid fraction, Dou's (1990) experimental data of bed average solid fraction and wall solid fraction for Fcc and sand particle were used. the correlation of normalized wall solid fraction (sf_w/sf_b) was made as a fraction of particle diameter, gas velocity and axial location z.

The remaining parameter, L_c, was estimated by the back calculation of heat transfer data obtained in this experiment according to the derived particle convective heat transfer equation.

$$L_c = \frac{U_s\, \rho_p\, sf_w\, Cp_e\, K_e}{\pi\, h_{pc}^2} \tag{6}$$

The determined contact length Lc from equation (6) for each operating condition was correlated as a function of modified Froude number.

The proposed heat transfer equation was compared with the existing heat transfer data which were obtained at wide ranges of operating conditions(Tsus = 30-890℃, Ug = 2.5-14 m/s and dp = 80-300μm).

4. Conclusions

Local and test section average heat transfer coefficients between suspension and wall were obtained in a circulating fluidized bed heat exchanger. Heat transfer coefficient is strongly influenced by the suspension density and particle size. By the simultaneous measurements of total and radiative heat flux, particle convective heat transfer coefficients were determined. A decreasing trend of total and particle convective heat transfer coefficients with height was observed due to decreasing bulk density with the height.

A good agreement of experimental heat transfer data and proposed heat transfer equation for the wide range of CFB operating conditions was obtained.

5. References

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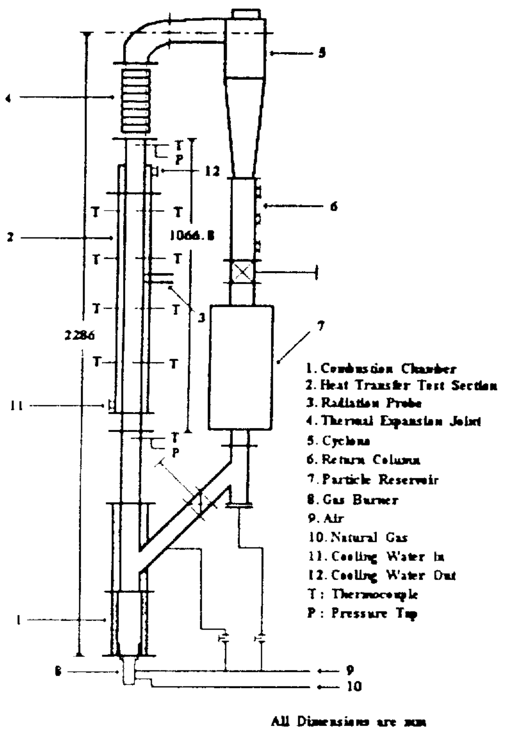

Figure 1. Schematic of Heat Transfer Test Facility