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NUMERICAL ANALYSIS OF THE EFFECT OF OPERATIONAL PARAMETERS OF HEAT TRANSFER SURFACES IN CFBS

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ABSTRACT
The design or scale-up of heat transfer systems in fluidized beds require estimation of the effective heat transfer coefficient on heat transfer surfaces in contact with the fluidized medium. In this study, the effects of operational parameters on bed-to-wall heat transfer in CFBs is investigated such as solids volume fraction, particle diameter, suspension density, superficial velocity and solid circulation rate, using modified cluster renewal model. In the modified cluster renewal model, the gas phase properties are used for the dilute phase and similarly the solid phase properties are used for the cluster phase. The gas phase and the solid phase properties are considered in the control volume which is in the vicinity of the heat transfer surface.
Keywords: heat transfer, circulating fluidized bed, particle diameter, modeling

1. INTRODUCTION
Circulating fluidized beds (CFBs) are used in a number of processes, especially combustion and catalytic reactions. They are also characterized by their approximate isothermal nature and high rates of heat transfer between the fluidized medium and the heat transfer surfaces. With better knowledge of heat transfer mechanisms, design and operation can be improved, and the energy evolved during the combustion process can be used with higher efficiency.
Numerous experimental and theoretical investigations to describe the heat transfer to the walls of fluidized beds have been studied since 1949, starting with the work of Mickley and Fairbanks [1]. Since then much experimental and modeling studies have been carried out in both laboratory and industrial scale units. Many authors approximate the overall heat transfer coefficient as the addition of the heat transfer coefficients of particle convection, gas convection and thermal radiation. A number of mechanistic models have been suggested to explain each of these components. The models which describe the particle convective heat transfer component can be classified broadly as single-particle models, cluster renewal models and continuous film models and they have been summarized by Basu and Nag [2]. Since the particle convection coefficient is much greater than the gas convection coefficient, most models pay little or no attention to the dilute phase heat transfer coefficient for the range of particle sizes used in almost all CFB applications. Radiation is a major contributor of heat transfer mechanism in CFB boilers and other high temperature CFB reactors, becoming even more effective especially for the low suspension densities found under turndown conditions. The relative contribution of radiation depends primarily on the wall and furnace temperatures. Basu and Nag [2] and Glicksman [3] presented comprehensive reviews of CFB heat transfer. As mentioned above, many works have been done in modeling of the bed-to-wall heat transfer and the understanding of the process of the heat transfer in a CFB is still in a developing stage. The design or scale-up of heat transfer systems in fluidized beds require estimation of the effective heat transfer coefficient on heat transfer surfaces in contact with the fluidized medium. From this point of view, the objective of this study is to investigate the effects of operational parameters on bed-to-wall heat transfer in CFBs such

as solids volume fraction, particle diameter, suspension density and solid circulation rate. Based on a previously developed 2D CFB model, a modified cluster renewal model is used in this investigation. The model uses the particle-based approach and integrates the hydrodynamics and combustion aspects [4].

2. MODEL DESCRIPTION

Based on a previously developed 2D CFB model which uses the particle-based approach and which simultaneously predicts the hydrodynamics and combustion aspects [4], in this study a modified cluster renewal model which characterizes the bed-to-wall heat transfer mechanism is used.

The gas and solid concentrations at the riser wall along the bottom zone can be estimated with sufficient accuracy using the developed model and as a function of the local bed density, the bed-to-wall heat transfer coefficient is calculated as the expression given by Basu and Nag [1] which was validated previously [4]. The bed-to-wall heat transfer coefficient in the upper zone of CFB, h, is calculated as the sum of the particle conductive, gas convective and particle and gas radiative heat transfer coefficients in the model. The heat transfer equations used in the model are given in Table 1.

In the Table.1, h_p is the conductive heat transfer coefficient for solids phase and h_g is the convective heat transfer coefficient for the gas phase. Heat transfer by particle conduction h_p refers to the energy transfer due to continuous particle motion between heat transfer surface and inner region of the CFB and it is calculated in the model Ryabov et al. [5]. The convection heat transfer from the gas phase to the wall is estimated by the modified equation of Wen and Miller [6].

In the model, the last control volume in the annulus region which is in vicinity of the wall is considered as the basis of heat transfer coefficient calculations. The gas phase and solid phase properties (temperature, void fraction, etc.) are considered in the control volume which is in the mentioned region. The temperatures and the heat transfer coefficients at a new time step are computed using properties at the previous time step. The temperatures and the heat transfer coefficients thus obtained are used to calculate the properties at the new time step. A time step of 10^{-6} s was used for the computation. The calculations were programmed in FORTRAN language. The Gauss-Seidel iteration which contains successful relaxation method and combined Relaxation Newton-Raphson methods are used for solving procedure.

Table 1. Heat transfer equations used in the model.

Bottom Zone	
$h = 40\left(\rho_b\right)^{1/2}$	
$\rho_b = \rho\left(1-\varepsilon\right) + C\varepsilon$	
Upper Zone	
$h = \varepsilon_p \cdot h_p + \varepsilon \cdot h_g + \varepsilon_p \cdot h_{r,p} + \varepsilon \cdot h_{r,g}$	
$h_p = \dfrac{k_g}{d_p} \cdot 0.009 \times \mathrm{Pr}^{0.33}\,\mathrm{Ar}^{0.5}$	$h_{r,p} = \dfrac{\sigma\left(T_p^4 - T_{wall}^4\right)}{\left\{\left(e_p^{-1} - e_{wall}^{-1}\right) - 1\right\}\left(T_p - T_{wall}\right)}$
$h_g = \left(\dfrac{k_g}{d_p}\right) \cdot \left(\dfrac{c_p}{c_g}\right) \cdot \left(\dfrac{C}{\rho}\right)^{0.3} \cdot \left(\dfrac{U_{ter}}{g d_p}\right)^{0.21} \cdot \mathrm{Pr}$	$h_{r,g} = \dfrac{\sigma\left(T_g^4 - T_{wall}^4\right)}{\left\{\left(e_g^{-1} - e_{wall}^{-1}\right) - 1\right\}\left(T_g - T_{wall}\right)}$

3. RESULTS AND DISCUSSION

In the present study, the effects of operational parameters on bed-to-wall heat transfer in CFBs such as solids volume fraction, coal particle diameter, suspension density, solid circulation rate are investigated by developed model and also validated with published experimental data in the literature [7-9]. The measurement conditions of experimental data used for the comparison of model is summarized in Table 2.

Table 2. Measurement conditions of the experimental data referred to in this study.

Author(s)	Bed Temp. T(°C)	Bed Diameter D(m)	Bed Height H(m)	Superficial Velocity U_0(m/s)	Particle Diameter d_p(μm)
Shi et al. [7]	140	0.411	8.50	13.000	40-300
Han et al. [8]	650-850	0.2x0.2	6.00	1.5-13	157
Xie et al. [9]	800	0.762	6.10	8.000	65

The solids concentration at the heat transfer surface is a key parameter in the calculation of bed-to-wall heat transfer coefficients in fluidized beds. As Fig.1 shows, bed-to-wall heat transfer coefficients increase as the solids volume fraction at the wall increases which is caused by a denser accumulation of solid particles and also leads to an increase in the particle temperature. The model predictions are in a good agreement with experimental data where the maximum error values do not exceed 0.12. Fig.1 also presents the effect of particle diameter on heat transfer which can be summarized as that the smaller particles result in higher heat transfer coefficients than larger particles for the same solids volume fraction values. This effect is more considerable as the particle size decreases.

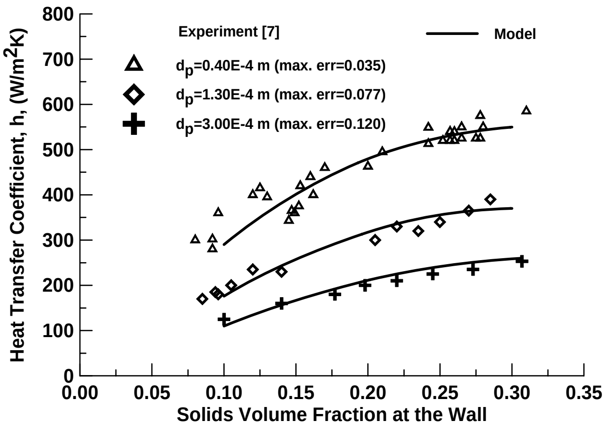

Figure 1. Effects of solids volume fraction on bed-to-wall heat transfer.

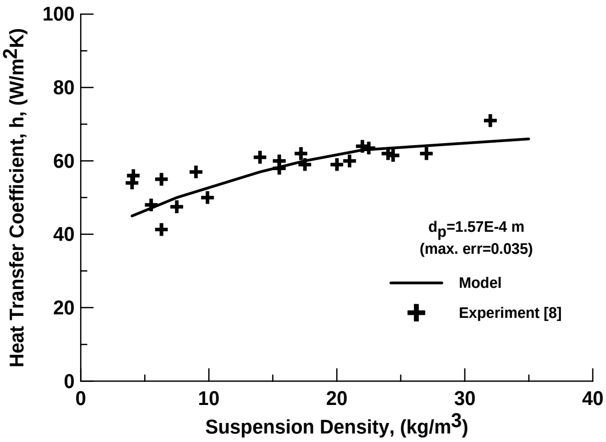

Figure 2. Effects of suspension density on bed-to-wall heat transfer.

It is widely recognized that CFB heat transfer is strongly correlated with the overall suspension density. A higher suspension density results in a thicker wall layer having a higher concentration of particles. Also, there is a greater rate of particle exchange between the core and the wall layer which augments the transfer of heat from the bulk to the wall. On the other hand, a thicker wall layer and higher particle concentration increases the radiation resistance between the bulk and wall, thereby decreasing the radiation contribution. This phenomenon is also confirmed by Pagliuso et al. [10]. Fig.2 presents the bed-to-wall heat transfer coefficient as a function of the suspension density along the riser. The heat transfer coefficient increase with suspension density. This predicted influence of suspension density is consistent with experimental results where the maximum error value is 0.056.

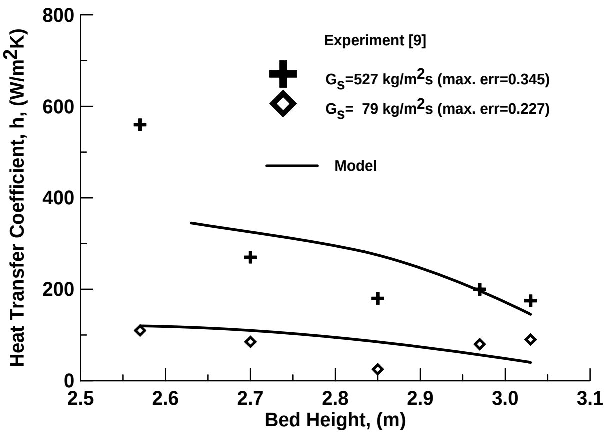

Figure 3. Effects of solid circulation rate on bed-to-wall heat transfer.

The bed-to-wall heat transfer coefficient increases with the increase of solids circulation rate. This is due to higher solids concentration in the annulus region of the riser column, as well as increased suspension density. The relationship between the heat transfer coefficient and the circulated solids mass flux is less sensitive to particle diameter than that with suspension density; probably because the mass flux itself is a function of particle diameter [10]. This can be explained by the fact that circulated flux is also directly proportional to the average density suspension in the riser and inversely proportional to the particles diameter. Feugier et al. [11] also observed a linear relationship between the solid mass flux and the average heat transfer coefficient. The effect of solids circulation rate on bed-to-wall heat transfer coefficient along the bed height is presented in Fig.3. As the figure displays, more particles accumulate in the column especially the region close to the wall as the solids circulation rate increases due to the hydrodynamic behavior of CFB which results in higher heat transfer and a fairly good agreement is observed with experimental data.

4. CONCLUSION

The design or scale-up of heat transfer systems in fluidized beds require estimation of the effective heat transfer coefficient on heat transfer surfaces in contact with the fluidized medium. In this study, the effects of operational parameters on bed-to-wall heat transfer in CFBs are investigated such as solids volume fraction, particle diameter, suspension density, superficial velocity and solid circulation rate.

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