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Bed-to-wall heat transfer modelling in the top region of a CFB riser column with abrupt riser exit geometries

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Abstract

The paper presents a mechanistic model to predict bed-to-wall heat transfer coefficient in the top region of a circulating fluidized bed (CFB) riser column by considering the riser exit geometry effects on bed hydrodynamics. With abrupt riser exit geometry, some solids will reflect back in to the riser column, thereby increasing the solids concentration in the top region of the riser column of a CFB. This in turn results in higher bed-to-wall heat transfer coefficients in the top region. At present, not much information exists in the literature to predict bed-to-wall heat transfer coefficient in the top region of a riser column with riser exit geometry effects. In the present work, a mechanistic model is proposed to estimate bed-to-wall heat transfer coefficient with riser exit geometry configurations. The length of influence of gas–solid flow structure from the riser exit due to various riser exit geometries is also presented. The solids reflux ratio is an important parameter, which influences the heat transfer rate in the top region. For the same operating conditions the bed-to-wall heat transfer coefficient increases with the abrupt riser exit geometry configuration compared to a smooth riser exit in the top region. The proposed model predictions are compared with the published experimental data for right angle exit configuration and a reasonable agreement is observed.

Keywords: Heat transfer; Riser exit; Solids concentration; Reflection coefficient; Voidage; Modelling

1. Introduction

The circulating fluidized bed technology (CFB) with its fuel flexibility is widely used for power generation and process heat applications. The CFB technology is used around the world to generate electric power by utilizing various low-grade fuels including coal with reduced pollutants in an environment friendly manner. The hydrodynamic flow structure in the riser column of a CFB is very complex and should be investigated for better understanding of bed-to-wall heat transfer characteristics. The gas–solid flow characteristics are different in the top region of the riser column with the presence of abrupt riser exit geometries, when compared with smooth riser exit geometry. Due to reflection of solids back into the riser column with abrupt riser exits, the solids concentration in the top region increases resulting in higher bed-to-wall heat transfer coefficient values. In the recent past the research has been focused on investigating

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Nomenclature

c	cross-sectional average volumetric solids concentration fraction
c_{pg}	specific heat of gas, J/kg K
c_{ps}	specific heat of bed solid particle, J/kg K
c_{pc}	specific heat of cluster, J/kg K
C_e	constant
D	hydraulic diameter of the riser column, m
d_p	mean bed solid particle size, μm
e_c	emissivity of cluster
e_w	emissivity of wall
e_d	emissivity of dispersed particles
e_p	emissivity of particles
e_g	gas emissivity
f	fraction of the wall covered by clusters
Fr	Froude Number based on superficial gas velocity
Fr_t	Froude Number based on particle terminal velocity
g	acceleration due to gravity, m/s^2
G_s	solids circulation rate, kg/m^2 s
H	height of the riser column, m
h	bed-to-wall heat transfer coefficient, W/m^2 K
h_c	cluster heat transfer coefficient, W/m^2 K
h_g	gas convective heat transfer coefficient, W/m^2 K
h_{cr}	particle phase radiation heat transfer coefficient, W/m^2 K
h_{dr}	dispersed phase radiation heat transfer coefficient, W/m^2 K
h_r	radiation heat transfer coefficient, W/m^2 K
h_p	particle convective heat transfer coefficient, W/m^2 K
h_w	gas layer heat transfer coefficient, W/m^2 K
K	constant
k_c	thermal conductivity of the cluster, W/m K
k_g	thermal conductivity of gas, W/m K
k_s	thermal conductivity of the bed solid particle, W/m K
k_m	solids reflux ratio
Pr	Prandtl number
R	radius of curvature of exit configuration
Re	Reynolds number
R_f	reflection coefficient
t	residence time of the cluster, s
T_b	bed temperature, K
T_w	wall temperature, K
U_0	superficial gas velocity, m/s
U_t	terminal velocity of the bed solid particles, m/s
z	location in the influenced region from the distributor plate, m

Greek symbols

ρ_c	density of the cluster, kg/m^3
ρ_g	gas density, kg/m^3
ρ_s	particle density, kg/m^3
ρ_{sus}	suspension density, kg/m^3
ρ_{dis}	cross-section average dispersed phase bed density, kg/m^3
Ψ	slip factor
Ψ_{smooth}	slip factor for smooth exit
Ψ_{exit}	slip factor for other exit configuration
Ω	ratio of length of influence to height
ε_c	volumetric void fraction of the cluster
$\varepsilon, \varepsilon_{ave}$	cross-section average voidage at the considered location
δ	non-dimensional gas layer thickness between the wall and cluster
μ	dynamic viscosity of the gas, N s/m^2
σ	Stefan–Boltzmann constant, W/m^2 K^4

the riser exit effects on hydrodynamics in the riser column of circulating fluidized beds. Grace [1] presented a review on the influence of riser exit geometry on bed hydrodynamics, and reported that the flow behavior is profoundly affected by riser entry and exit configurations, corners and also with wall roughness. Brereton and Grace [2] investigated the end effects on bed hydrodynamics in a 152 mm diameter and 9.3 m height CFB riser for three different riser exit configurations. An abrupt riser exit leads to considerable build-up of solid particles in the upper region of a riser due to inertial separation of particles reaching the top. Van der Meer et al. [3] investigated experimentally the effect of riser exit design on gas–solid flow pattern in a square cross-section CFB riser for seven different riser exit configurations. They measured the solids reflux back in to the riser column and estimated the reflection coefficient as defined by Senior and Brereton [4] for different riser exit configurations. Zheng and Zhang [5] investigated experimentally the effect of different riser exit geometries on internally recycling of bed material in the top region of a circulating fluidized bed riser column. Pugsley et al. [6] presented the relative difference between smooth and abrupt riser exit configurations on the axial and radial pressure profiles in the CFB riser column for two different diameters. From the available experimental data on bed hydrodynamics with different riser exit configurations, Gupta and Berruti [7] proposed empirical correlations to predict the reflection coefficient for different riser exit configurations with 20% relative error for both Geldart A and B particles. Harris et al. [8] reported that the length of influence of gas–solid flow in the top region of the riser column depends on riser exit configurations and proposed an empirical correlation to estimate the length of influence of gas–solid flow with riser exit geometries for different bed properties. Harris et al. [9] experimentally investigated the influence of the riser exit geometry on particle residence time distribution for different riser exit configurations. Davidson [10] discussed the model for prediction of bed hydrodynamics in the CFB riser column by assuming the flow in the riser to follow core-annulus mechanism. Kunii and Levenspiel [11] developed a mathematical model for bed hydrodynamics and compared results with the experimentally available data. Gupta and Berruti [7] analysed the gas–solid suspension profile in the exit region for different riser exit geometries by modifying the predictive hydrodynamic model of Pugsley and Berruti [12]. Zheng et al. [13] investigated the effect of riser exit geometry on heat transfer coefficient in the riser column for various exit configurations. Reddy and Nag [14] observed from the experimental investigations that the bed-to-wall heat transfer coefficient increases towards the riser exit in the top region with 90° riser bend exit configuration. Not much information is reported in the literature on heat transfer predictions in the top region of the riser column with abrupt riser exit configurations. An understanding of the effect of riser exit configurations on bed-to-wall heat transfer in the top region of the riser is required for efficient design of water-wall surfaces in CFB combustors. In the present investigation, a mechanistic model is proposed to predict the bed-to-wall heat transfer coefficient in the top region of a CFB riser column for different riser exit configurations.

2. Model description

To estimate bed-to-wall heat transfer coefficient in the top region of a CFB riser column with abrupt riser exit, it is essential to understand the bed hydrodynamics in that region for different riser exit configurations. The bed voidage in the riser exit region decreases due to reflection of solids back into the top region of riser column with abrupt exit geometries. The solids concentration in the top region increases with abrupt riser exit configuration due to reflection of solids. The effect of abrupt riser exit on bed hydrodynamics is accounted through the solid reflection coefficient (R_f), defined by Brereton and Grace [2] as the fraction of solids reaching the top of the riser which reflux back down internally with out leaving the riser column. The slip factor for the abrupt riser exit geometries depend on the reflection coefficient for different riser exit configurations. In case of smooth riser exit geometry, there should be little to no solids reflection back into the upper region of the riser as the solids are able follow the gas streamlines. In contrast, strong riser exit effects result in solid particles being unable to follow the gas streamlines out of the top of the riser and increasing the value of reflection coefficient and subsequently increase of slip factor values. A generalized empirical slip factor correlation for both groups A and B particles as developed by Patience et al. [15], is used in the present investigation and is given by,

$$\Psi_{\text{smooth}} = 1 + \frac{5.6}{Fr} + 0.047 Fr_t^{0.41} \tag{1}$$

From the definition of slip factor, the average solids concentration can be calculated from the equation of Pugsley and Berruti [12],

$$\Psi = \frac{U_0 \rho_s (1 - \varepsilon)}{\varepsilon G_s} \tag{2}$$

From the above equation, the bed voidage can be calculated as,

$$\varepsilon = \frac{U_0 \rho_s}{G_s \Psi + U_0 \rho_s} \tag{3}$$

For abrupt riser exit geometries, the slip factor can be calculated by considering the reflection efficient (R_f) from the equation provided by Gupta and Berruti [7],

$$\Psi_{\text{exit}} = \Psi_{\text{smooth}}(1 + R_f) \tag{4}$$

where R_f is the reflection coefficient, defined by Senior and Brereton [4] as the ratio of downward solids in the riser to the upward solids in the riser column and is given by,

$$R_f = \frac{k_m}{1 + k_m} \tag{5}$$

where k_m is the solids reflux ratio, the solids reflection back in to the riser column due to riser exit configuration. In the present work results are predicted for different riser exit configurations as reported by Van der Meer et al. [3]. The different riser exit geometries considered for the present investigation are shown in Fig. 1 (source: Van der Meer et al. [3]). The experimentally measured values of k_m for different riser exit configurations as reported by Van der Meer et al. [3] (Fig. 1) are used in the present model predictions.

The length of influence of gas–solid flow structure in the top region of a riser column due to different riser exit geometries depends on many factors such as, exit shape, size of the bed, riser height, diameter of particles, superficial gas velocity, solids circulation rate and fluid properties [8]. The dimensionless length of influence (Ω) defined as, the ratio of length affected (gas–solid flow) from the riser exit to riser height, proposed by Harris et al. [8] from the experimental data is used in the present investigation and is given below:

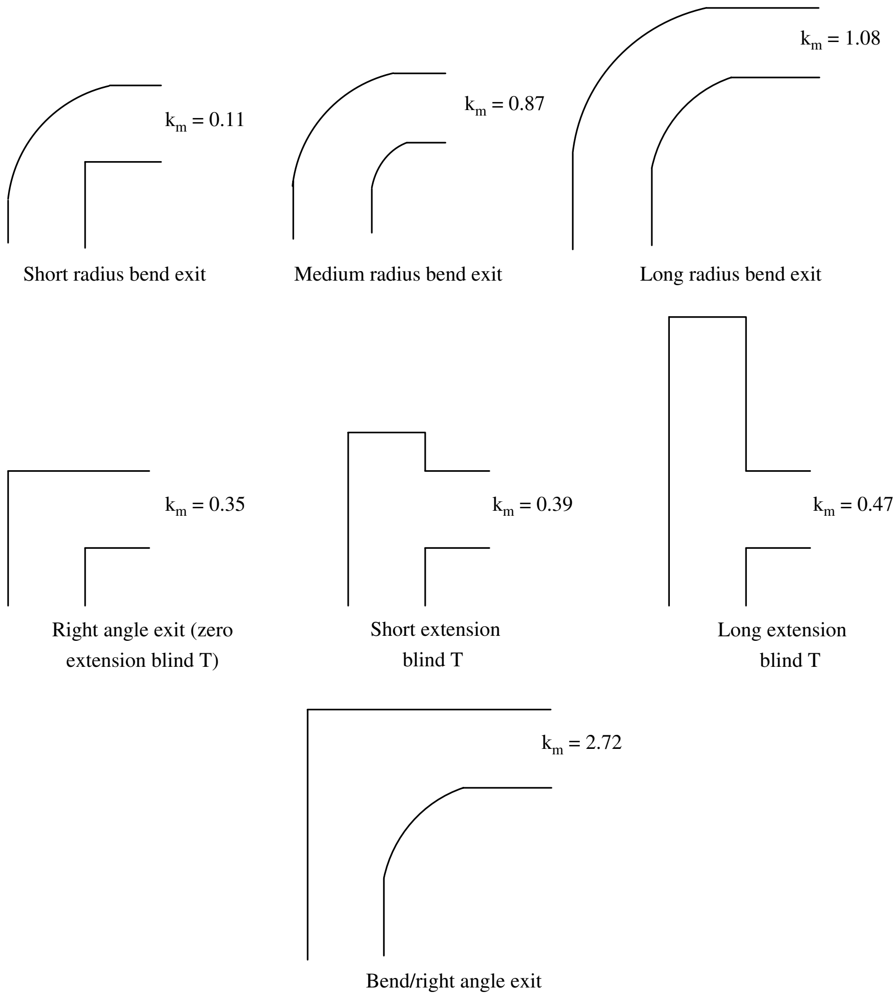

Fig. 1. Schematic diagram of different riser exit configurations considered along with their k_m values (*source*: Van der Meer et al. [3]).

$$\Omega = \left[0.046 + 8.37\left(\frac{G_s}{(U_0 - U_t)\rho_s}\right)\right]\left(\frac{(U_0 - U_t)^2}{gD}\right)^{-0.52} \times \left(\frac{\rho_g(\rho_s - \rho_g)gd_p^3}{\mu^2}\right)^{0.22}\left(\frac{d_p}{D}\right)^{-0.08} \times \left(\frac{\rho_s U_0 D}{\mu}\right)^{0.23}\left(\frac{R}{D}\right)^{0.05}\left(\frac{H}{D}\right)^{-0.28} \quad (6)$$

Different riser exit configurations are considered for prediction of bed-to-wall heat transfer coefficient in the top region of riser column of a CFB and corresponding radius of curvature values (R) are taken from the published article of Van der Meer et al. [3].

The effect of riser exit geometry on solids concentration in the top region of a riser column is described by Kunii and Levenspeil [11]. The increase in solids concentration in the exit region for different configurations can be estimated from the following equation.

$$\Delta c = C_e c_{sm} \exp[-K(H - z)] \quad (7)$$

The values of the constants C_e and K, are given by Kunii and Levenspeil [11] for different riser exit configurations.

To predict the bed-to-wall heat transfer coefficient in the top region of a riser column by considering different riser exit geometry effects, the core-annulus flow mechanism is used. The bed-to-wall heat transfer coefficient in the top region of a CFB riser column consists of the contributions of three components i.e., particle phase, dilute phase and radiation components and can be written as,

$$h = fh_p + (1 - f)h_g + h_r \quad (8)$$

where 'f' is the fractional wall coverage by clusters and is a function of average cross-sectional solids concentration fraction 'c'.

The particle heat transfer coefficient, h_p comprises heat transfer from the cluster and through the gas layer.

Assuming the cluster and gas resistances are in series, the particle phase convection component is written as,

$$h_p = \frac{1}{\frac{1}{h_c} + \frac{1}{h_w}} \tag{9}$$

where, h_c is the cluster heat transfer coefficient and is estimated by assuming that there is unsteady heat conduction from the cluster for a period of cluster residence time 't', and is given by Mickley and Fairbanks [16],

$$h_c = \sqrt{\frac{4k_c\rho_c c_{pc}}{\pi t}} \tag{10}$$

The thermal conductivity of the cluster is calculated from the equation developed by Gelperin and Einstein [17] from their experimental investigations,

$$k_c = \left(1 + \frac{(1-\varepsilon_c)\left(1-\frac{k_g}{k_s}\right)}{\frac{k_g}{k_s} + 0.28\varepsilon_c^{0.63\left(\frac{k_g}{k_s}\right)^{0.18}}}\right)k_g \tag{11}$$

and

$$c_{pc} = (1-\varepsilon_c)c_{ps} + \varepsilon_c c_{pg} \quad \text{and}$$
$$\rho_c = (1-\varepsilon_c)\rho_s + \varepsilon_c\rho_g \tag{12}$$

The heat transfer through the gas layer is estimated from the equation provided by Decker and Glicksman [18],

$$h_w = \frac{k_g}{\delta d_p} \tag{13}$$

The gas layer thickness 'δd_p' is a function of cross-sectional average solids concentration fraction 'c'.

The dilute phase heat transfer coefficient, h_g is calculated from the correlation of Wen and Miller [19] proposed for dust laden gas and is given by,

$$h_g = \left(\frac{k_g}{d_p}\right)\left(\frac{c_{ps}}{c_{pg}}\right)\left(\frac{\rho_{dis}}{\rho_s}\right)^{0.3}\left(\frac{U_t^2}{gd_p}\right)^{0.21} Pr \tag{14}$$

For calculation of the fraction of wall coverage by clusters, the equation provided by Lints and Glicksman [20] in terms of average solids concentration fraction 'c' is used.

The radiation heat exchange is calculated similar to parallel planes approach in radiation [21]. The cluster radiation component is calculated from the equation,

$$h_{cr} = \frac{\sigma(T_b^4 - T_w^4)}{\left(\frac{1}{e_c} + \frac{1}{e_w} - 1\right)(T_b - T_w)} \tag{15}$$

the cluster emissivity is estimated from $e_c = 0.5(1 + e_p)$ [22]. The dispersed phase radiation component is calculated from the following equation,

$$h_{dr} = \frac{\sigma(T_b^4 - T_w^4)}{\left(\frac{1}{e_d} + \frac{1}{e_w} - 1\right)(T_b - T_w)} \tag{16}$$

The radiation heat transfer component can be estimated from the equation,

$$h_r = fh_{cr} + (1-f)h_{dr} \tag{17}$$

3. Results and discussion

In order to estimate the effect of riser exit geometry on solids concentration and bed voidage in the top region of the riser column, it is required to know the reflection coefficient for different riser exit geometries and these values are taken from Van der Meer et al. [3] as shown in Fig. 1 in the present model predictions. The variation of average solids concentration fraction predicted from the present model (from Eq. (3)) for different superficial gas velocities in the top region of a CFB riser column for smooth and abrupt riser exit geometries is presented in Fig. 2. For the same solids circulation rate, particle size and bed temperature conditions, the solids concentration fraction decreases with the increase of superficial gas velocity for smooth and abrupt riser exit configurations in the top region. With abrupt riser exit configurations solids reflect back into the riser column resulting in higher solids concentration in the top region. The bed-to-wall heat transfer coefficient variation for smooth and right angle riser exit configurations predicted from the model for different superficial gas velocities is demonstrated in Fig. 3. The bed-to-wall heat transfer coefficient decreases with superficial gas velocity due to increased bed voidage in the top region. With the right angle exit configuration, more solids reflect back in to the top region of the riser column. For the same operating conditions, the bed-to-wall heat transfer coefficient values are high with the right angle exit configuration due to increased solids concentration in the top region. The solids reflux ratio is taken from the literature and the slip factor is calculated based on the riser exit configuration. The bed-to-wall heat transfer coefficient values

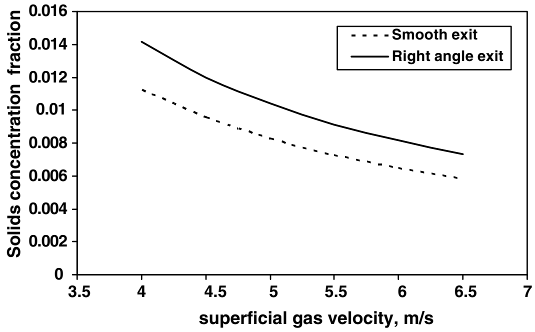

Fig. 2. Effect of superficial gas velocity on solids concentration fraction in the top region for smooth and right angle riser exit geometries ($G_s = 35$ kg/m^2 s).

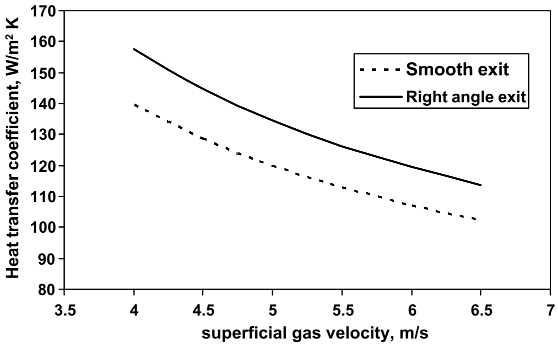

Fig. 3. Bed-to-wall heat transfer coefficient variation in the top region for different superficial gas velocities ($G_s = 35$ kg/m^2 s).

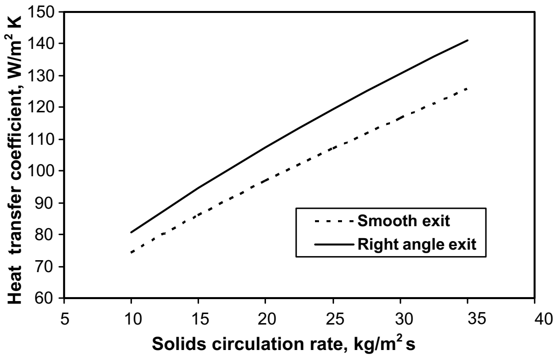

Fig. 5. Effect of solids circulation rate on bed-to-wall heat transfer coefficient for smooth and right angle riser exit configurations ($U_0 = 6$ m/s).

are high with the right angle exit configuration due to increased solids concentration in the top region of the riser column. Since the solids concentration is high, the bed-to-wall heat transfer coefficient is higher for abrupt riser exit configurations than smooth riser exit in the top region for the same operating conditions.

Fig. 4 represent the effect of solids circulation rate on solids concentration fraction for smooth and abrupt right angle riser exit configurations in the top region of the riser column as predicted from Eq. (3). The average particle concentration in the top region increases with increase of solids circulation rate (G_s). For higher solids circulation rate, more solids reflect back into the riser column with abrupt riser exit geometries resulting in higher solids concentration fraction than for smooth riser exit. With the increase in solids circulation rate, the solids concentration in the top region increases at a faster rate for abrupt riser exit than for smooth riser exit as demonstrated by the results. The effect of solids circulation rate on bed-to-wall heat transfer coefficient in the top region for smooth and right angle riser exit configurations for a particular superficial gas velocity

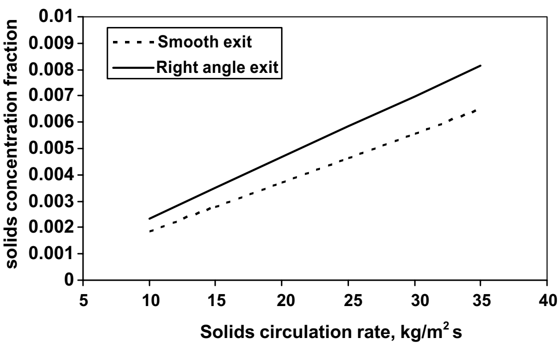

Fig. 4. Variation of solids concentration fraction in the top region for different solids circulation rates for smooth and right angle riser exit configurations ($U_0 = 6$ m/s).

is presented in Fig. 5. The bed-to-wall heat transfer coefficient increases with the increase of solids circulation rate. This is due to more concentration of solids in the top region of the riser column, as well as increased solids concentration in the top region due to reflection of solids back in to the riser with abrupt riser exit geometry employed. For low solids circulation rate, the drag force acting on the solid particles dominates due to less number of particles present in the column. Hence, the concentration of particles reduces resulting in low bed-to-wall heat transfer coefficient values. There is a drastic improvement in bed-to-wall heat transfer coefficient values with right angle riser exit configuration in comparison to smooth riser exit configuration for the same solids circulation rate in the top region of the riser column. With the 90° riser exit configuration, more solids reflect back in to the top region of the riser column resulting in higher bed-to-wall heat transfer coefficient values. With abrupt riser exit geometries the enhancement in bed-to-wall heat transfer coefficient is high for higher solids circulation rates, due to the reason that more solids will reflect back in to the top region of the riser column.

Fig. 6 presents the variation of average solids concentration fraction in the top region of the riser column for different values of k_m as predicted from Eq. (3) for different riser exit configurations. The considered riser exit configurations in the present investigation along with corresponding k_m values are taken from Van der Meer et al. [3] as shown in Fig. 1. The solids concentration fraction increases with the increase of reflection ratio for different riser exit configurations. The bed-to-wall heat transfer coefficient is estimated for different riser exit configurations i.e., short radius bend exit ($k_m = 0.11$), right angle exit with zero extension ($k_m = 0.35$), right angle exit with short extension ($k_m = 0.39$), right angle exit with long extension ($k_m = 0.47$), medium radius bend exit ($k_m = 0.87$), and right angle exit with higher inner radius ($k_m = 2.72$) (Fig. 1). The bed-to-wall

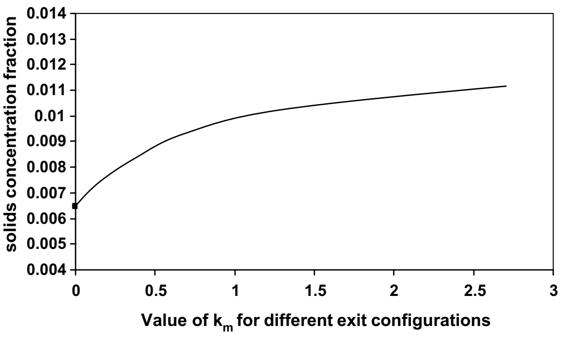

Fig. 6. Effect of riser exit configurations on average solids concentration fraction in the top region of a CFB riser column ($G_s = 35$ kg/m^2 s; $U_0 = 6$ m/s).

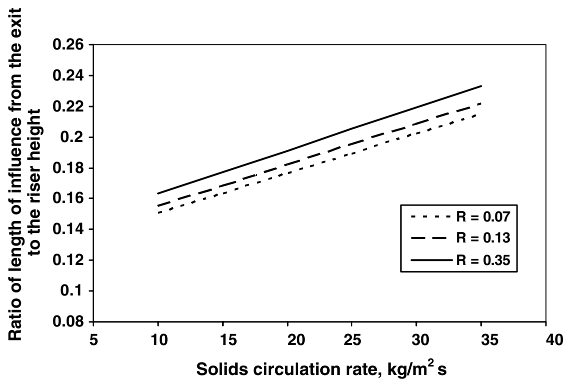

Fig. 8. The ratio of length of influence of gas–solid flow to riser height vs solids circulation rate for different riser exit configurations ($U_0 = 6.0$ m/s).

heat transfer coefficient vs k_m value is represented in Fig. 7. For the same operating conditions, with the increase of k_m, the bed-to-wall heat transfer coefficient increases due to reflection of more number of solids back in the top region of the riser column.

For the same operating conditions, with the presence of abrupt riser exit geometry compared to a smooth riser exit, the gas–solid flow behavior is different up to a certain length from the riser exit in the top region of the riser column. The influenced gas–solid flow length ratio from the riser exit region has been estimated for different riser exit configurations based on Eq. (6). The radius of curvature of riser exit geometry plays an important role in influencing the gas–solid flow. The influenced gas–solid flow length for different R values against the solids circulation rate is shown in Fig. 8. The radius of curvature values for different geometries as reported by Van der Meer et al. [3] are used in the present model investigations for the evaluation of length of influence of gas–solid flow from the riser exit in the riser column. From Fig. 8, it is observed that the length ratio increases with the increase of radius of curvature values. With the increased radius of curvature, the solids reflect back more deep in to the riser column from the riser exit resulting in higher influenced length for gas–solid flow in the top region. The ratio of length of influence of gas–solid flow to riser height increases with the increase of solids circulation rate as expected. For higher solids circulation rates, more solid particles reflect back in to the riser column with various abrupt riser exit configurations. Hence the influenced length is more for higher values of solids circulation rates.

The length of influence of gas–solid flow in the top region to riser height ratio with abrupt riser exit geometries for different superficial gas velocities and for a particular solids circulation rate (G_s) is presented in Fig. 9 (predicted from Eq. (6)). The influenced length ratio is higher for lower value of superficial gas velocity. With the increase of superficial gas velocity, the ratio of length of influence of gas–solid flow to riser height decreases due to increased drag force. For higher superficial gas

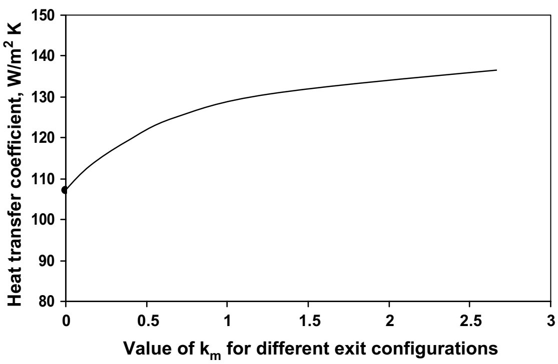

Fig. 7. Effect of riser exit configuration on bed-to-wall heat transfer coefficient in the top region for different exit configurations ($G_s = 35$ kg/m^2 s; $U_0 = 6$ m/s).

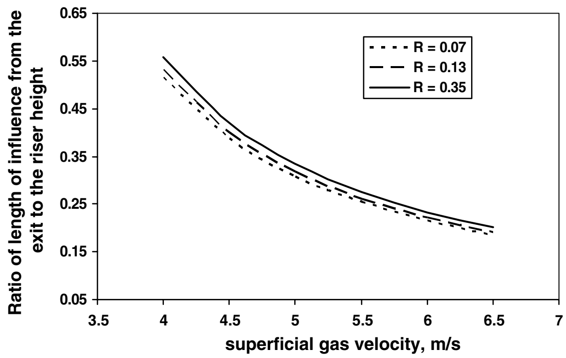

Fig. 9. Effect of superficial gas velocity on length of influence of gas–solid flow to riser height ratio for different riser exit configurations ($G_s = 35$ kg/m^2 s).

velocity, the influenced length for gas–solid flow is less for different riser exit configurations, due to the reason that the particles will not have enough time to travel down.

The bed-to-wall heat transfer coefficient values are estimated in the gas–solid influenced region of the riser column towards the riser exit for different riser exit configurations. Comparison has been made between smooth riser exit and right angle riser exit configurations along the riser height in the influenced zone (top region). The heat transfer coefficient values are plotted along the length of riser column in the top region for smooth and right angle riser exit configurations as shown in Fig. 10. From the figure, it is observed that the heat transfer coefficient increases with right angle riser exit configuration along the height. This is due to the fact that, more solids reflect back into the top region of the riser column, resulting in higher values of solids concentration. Hence the heat transfer coefficient increases in the top region with abrupt riser exit configurations compared to smooth riser exit. The heat transfer coefficient value tends to increase at a faster rate towards the exit due to more concentration of reflected particles in the top most region of the riser column with abrupt riser exit geometry. For smooth riser exit configuration, there is no solids reflux back into the riser column resulting in a uniform bed-to-wall heat transfer coefficient in the top region towards the riser exit.

The present model predictions are compared with the experimental data of Reddy and Nag [14] for a CFB riser column with abrupt right angle riser exit with zero extension. Experimental investigations are conducted by Reddy and Nag [14] in a CFB riser column of 102 mm × 102 mm in cross-section, 5.25 in height with right angle exit configuration. The test sections are located in the top region of the riser column, and the test sections are electrically heated and the experimental investigations are conducted for different superficial gas velocities and solids circulation rates. From the

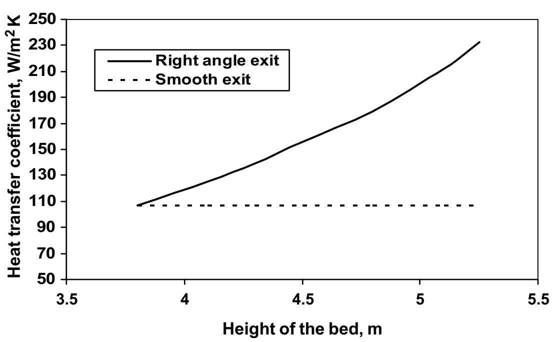

Fig. 10. Bed-to-wall heat transfer coefficient variation along the riser column in the top region for smooth and right angle exit configurations ($G_s = 35$ kg/m^2 s).

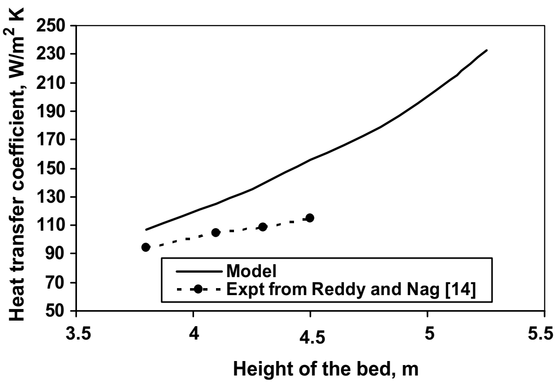

Fig. 11. Comparison of model predictions with expt. data of Reddy and Nag [14] for right angle exit with zero extension ($G_s = 35$ kg/m^2 s; $d_p = 248$ μm).

experimental investigations it is observed that, the wall-to-bed heat transfer coefficient increases towards the riser exit in the top region due to reflection of particles back into the riser column, which results in higher particle concentration. Fig. 11 shows the comparison of experimental data of Reddy and Nag [14] for right angle riser exit configuration with the model predictions (right angle exit with zero extension) along the riser height in the top region of the riser column. In both the cases, the heat transfer coefficient increases towards the riser exit along the height due to increased solids concentration, due to reflection of solids back in to the riser column with abrupt riser exit geometry. The model predictions are high due to the assumptions involved in the development of correlations, which are used in the model formulation and predictions. The better understanding of hydrodynamics in the top region with abrupt riser exit geometries will help to improve the model predictions.

4. Conclusion

With abrupt riser exit geometry, the solids concentration profiles tend to increase in the top region towards the riser exit of the CFB riser column. The solids reflux rate increases with abrupt riser exit geometries. The bed-to-wall heat transfer coefficient increases towards the riser exit in the top region due to increased solids concentration with the employment of abrupt riser exit geometries. For a fixed solids circulation rate (G_s), the influenced length for gas–solid flow for different riser exit configurations decreases with the increased superficial gas velocity, and increases with the increased solids circulation rate. For the same operating conditions the bed-to-wall heat transfer coefficient enhances in the top region with abrupt riser exit geometries due to reflection of solids back in to the top region of the riser column, which results in higher particle concentration. The bed-to-wall heat transfer coefficient predictions from the model in the top region of the CFB riser are compared for smooth and right angle riser exit configurations. The model predictions are compared with the experimental bed-to-wall heat transfer coefficient values [14] for right angle exit configuration with zero extension and the model and experimental trends are in reasonable agreement with each other.

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