Comparison of Heat Transfer in Both the Riser and Downcomer of a Circulating Fluidized Bed

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ABSTRACT

The characteristics of heat transfer from horizontal cylinder immersed in both a riser and downcomer of a circulating fluidized beds were investigated experimentally under different values of solids mass flux, superficial air velocity, particle size diameter, and different bed materials. The test results indicated that local heat transfer coefficients in both riser and downcomer are strongly influenced by angular position, and mass flux, as well as by particle size and bed materials. The local heat transfer coefficients around a circumference of the cylinder inside a riser and downcomer of a CFB exhibited a general tendency to increase with decreasing particle size and increasing solids mass flux and vary with different bed materials. Also the averaged heat transfer coefficient calculated from local heat transfer coefficient exhibited the same trend as a local i.e increase with decrease particle size and increasing solids mass flux and vary with varying bed materials. The general trend for a riser local heat transfer coefficient is decrease with increase angle until Φ = 0.5-0.6 (Where at angle =180° Φ =1). Also the general trend for a local heat transfer coefficient in downcomer is to increase with increase the angle until $\Phi = \theta/\Pi$ = 0.3-0.5 (Where at angle =180° Φ =1). Comparison the results of the heat transfer in the riser and downcomer of a circulating fluidized beds shows that they have approximately the same trend but the values of heat transfer coefficients in riser is higher than in downcomer.

Key Words : Heat transfer, CFB, Riser, Downcomer, Horizontal probe

1. Introduction

In the recent past circulating fluidized beds (CFB) have found increasing application and have received extensive research attention. This is no surprise considering that growing world population and sustainable development call for efficient and economic processes preferably with the highest possible integrated pollution control. In the last two or three decades the upflow circulating fluidized bed (CFB, riser) has been developed as a new type of gas-solids reactor and has been applied in the chemical industry given its many intrinstic properties. Its applications include fluid catalytic, cracking, polyethylene production, calcinations and combustion, etc. Most of them have heat transfer and energy exchange during the reaction, so that a clear understanding of the heat transfer process is necessary for the design. The downcomer of the CFB combustors, that has high temperature solid particles slowly moving downward, offers an interesting option to provide the additional heating surface needed. Several investigators [1- 10] have studied heat transfer in both riser and downcomer. A downcomer with built in heat exchanging tubes was tested and reportedly saved about 15 % in exchange surface [10], however, there was no report on the magnitude and mechanism of heat transfer between the heat exchanger surfaces and the bed. The solids flow in the downcomer of a circulating fluidized bed is different from that encountered in the riser. The solids are packed and moving in the downward direction towards

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the L-valve relative to the downcomer wall, gas may flow upward or downward in the standpipe, depending on the downward velocity of the solids. The downcomer gas velocity is two orders of magnitude lower than the riser gas velocity. Two factors may interact to fix the value of the heat transfer coefficient. The first is the contact time between the solids and the probe, and the second is the thickness of the gas layer that may surround each particle and the probe. Like heat transfer in the riser, studies on the subject of internal heat transfer in the downcomer of a CFB are scarce. Many applications of CFB involve heat transfer to or from immersed tubes. The rate of heat transfer between a fluidized bed and submerged tube depends upon a number of factors, including the properties of the bed material and the fluid bed and the tube geometries and the fluidization state. This paper presents comparison of heat transfer coefficients for a cylinder placed in both the riser and downcomer of a CFB for different of particle diameter (88 -497 μm), solids mass flux (0- 60.06 kg/m^2-s)), and air velocity (5.12 - 8.16 m/s) and different bed materials (sand and FCC).

2. Experimental facility

2.1 Circulating fluidized bed

The cylindrical heat transfer probe is located in both the riser and downcomer of a circulating fluidized bed operating at ambient conditions, as shown in Fig. 1. The riser is made of 0.1 m inside diameter of a plexiglass tubing and it has an overall height of 6.1 m. Throughout the measurements the air is humidified before entering the riser to reduce the production of electrostatic electricity. The solids are fed into the riser 0.15 m above the distributor plate using L-valve. The solids recirculation rate is controlled by varying the flow of air injected at the L-valve. The air flows are measured using orifice plates and the solids recirculation rate is determined during each run using a permeable butterfly valve located near the top of the downcomer. This type of experimental fluidized bed has proven to be reliable and yielding results of

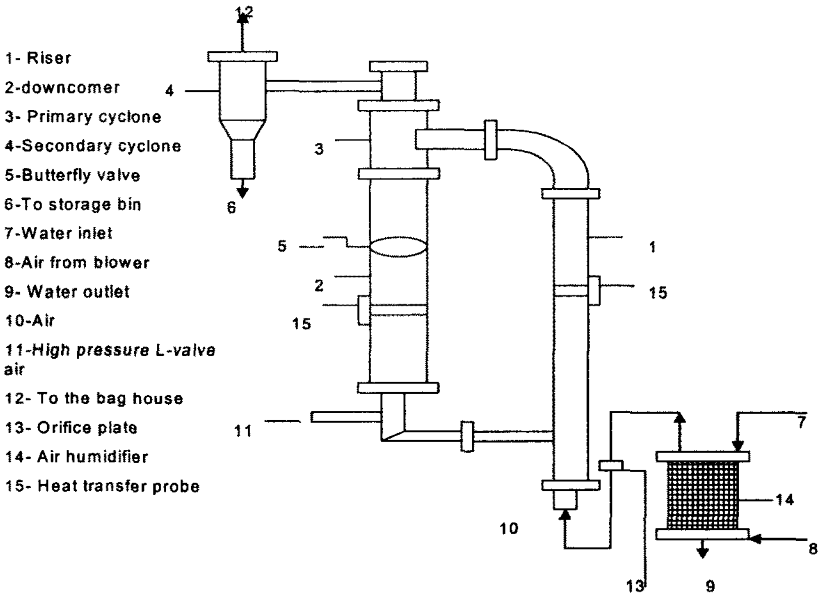

Fig. 1 Schematic of the experimental circulating fluidized bed showing the location of the heat transfer probe

good repeatibility, as discussed in [2] and [8].

2.2 Heat transfer probe

The probe as shown in Fig. 2 is made from 316 stainless steel and consists of three coils, the middle heater 20 mm length and the two guard heater 24.5 mm length. The outer diameter of the probe is 23.76 mm, the construction details of the probe are given in [8].

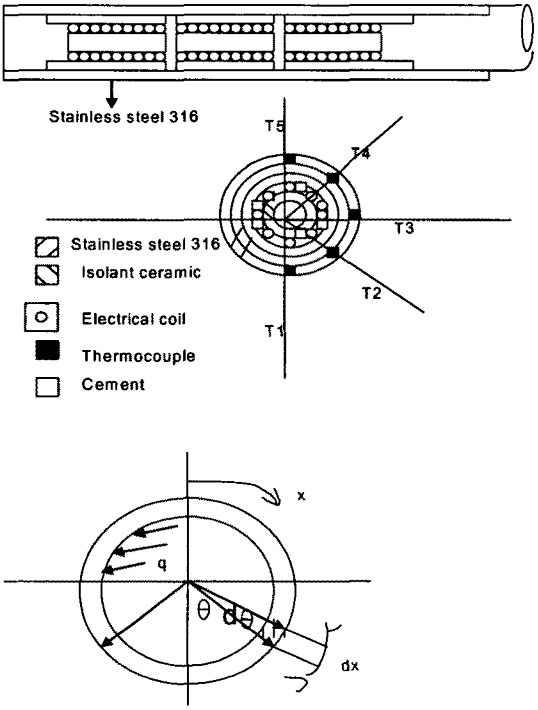

Fig. 2. Heat transfer coefficient and control volume

The local heat transfer coefficient is calculated as shown in Fig. 3

Heat Flux $q'' = \frac{I^2R}{2\pi r_i L}$

Where R : resistance of heater, I current in Amper, L length of the heater

Energy balance on volume element
energy in = energy out

$$q''d\theta r_i L - K\frac{\partial T}{\partial x})_x(r_0 - r_i)L$$
$$-[hd\theta r_0 L(T - T_0) - k\frac{\partial T}{\partial x})_x(r_0 - r_i)L$$
$$+\frac{\partial}{\partial x}(-k\frac{\partial T}{\partial x}(r_0 - r_i)L)dx = 0$$

Where dx = $(r_i + r_o)\ d\theta\ /2$
Thus,

$$q''d\theta r_i L - K\frac{\partial T}{\partial x})_x(r_0 - r_i)L$$
$$-[hd\theta r_0 L(T - T_0) - k\frac{\partial T}{\partial x})_x(r_0 - r_i)L$$
$$+\frac{\partial}{\partial x}(-k\frac{\partial T}{\partial x}(r_0 - r_i)L)(\frac{r_0 + r_i}{2})d\theta = 0$$

where $\Phi = \theta\ /\Pi$ and

$$h = \frac{I^2R}{2\pi r_0 L(T - T_0)} + \frac{2k(r_0 - r_i)}{r_0\pi^2(T - T_0)(r_0 + r_i)}\frac{\partial^2 T}{\partial\phi^2}$$

From measuring values of T along Φ we can calculate the second derivative of temperature with respect to Φ, and in addition to power supply I we can calculate local heat transfer along angle.

3. Sieve analysis of the bed material used

Three different sizes of bed materials are used in this research, two sizes of silica sands with mean diameter of 179 and 220 micron and the third sise of FCC with mean diameter of 85 micron. The cumulative particle size mass fraction for the used bed materials are plotted versus mean diameters as shown in Fig. 4. The mean particles diameter was measured by the screen analysis and calculated using Rosin Ramer formula as

$$\overline{D_p} = \frac{1}{\sum_{all}(\frac{x}{D_p})_i}$$

Where

$\overline{D_p}$ = Mean particle diameter
x_i = Mass fraction of particles of size i
D_{P_i} = Diameter of particles of size i ,
the mean of two screen adjacent openings.

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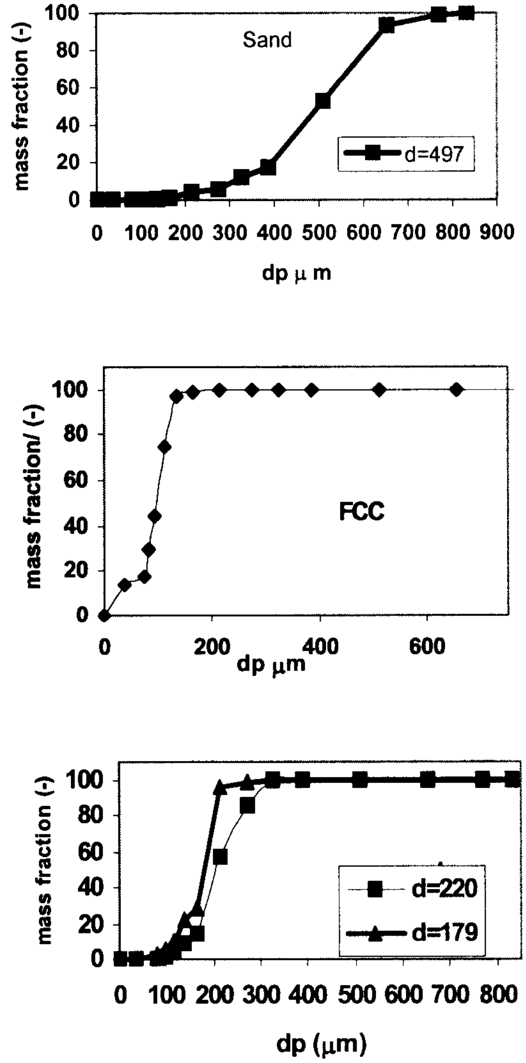


Fig. 4 Comulative particle size mass distribution

4. Experimental Results

4.1 Local temperature

Using the probe discussed in 2.2 local temperatures are measured at the middle of the main heater in the riser and downcomer at air velocity of 5.71 m/s and different solids mass flux for particle sand diameterof 220 and shown in Fig. 5. It can be seen from the Fig.s 5 that local temperature in riser increase with increasing angular position up to a certain value of angular position [ϕ . 0.62 for sand particle diameter of 220 μm]. It can be seen from Fig. 5 that local temperature in downcomer decrease with increasing angular position up to a certain value of angular position (N =0.3 - 0.4) for sand particle diameter of 220 μm.

4.2 The General Trend for Local Heat Transfer Coefficient Versus Angular Position

The general trend for local heat transfer coefficient versus angular position shown in Fig. 6 to 8, and Fig. 10, is the relation between local heat transfer coefficient and angular position at different condition in both the riser and downcomer. It can be seen that starting at the stagnation point (bottom point of probe equivalent to angle zero), the local heat transfer in riser decreases with increasing angle and this can be explained as a result of laminar boundary layer development. However, a minimum is reached at (ϕ = 0.5-0.6). At this point separation occurs, and local heat transfer coefficient increases with angle because of the mixing associated with vortex formation in the wake, and this results is in agreement with refrence [7]. Also it can be seen from Fig. 6 to Fig. 8 and Fig. 10 that the relation between local heat transfer coefficient in downcomer and angular position at different condition. starting at bottom point equivalent to angle zero, the local heat transfer increases with increasing angular position in the bottom half of the probe where no contact for probe with the particles. However, a maximum is reached at (Φ = 0.4-0.5). After this point the local heat transfer coefficient decreases with increasing angular position as the top half of the probe and this can be attributed to the fact that the solids mass flux decrease with increasing angular position.

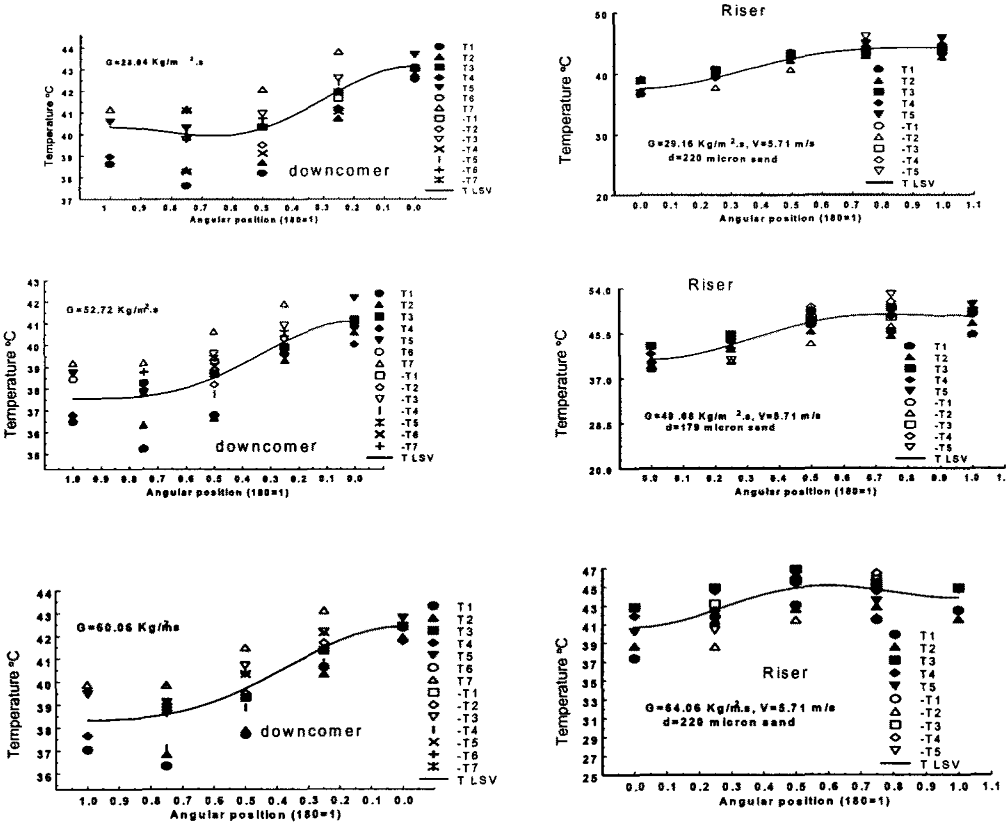


Fig. 5. Local measured temperature at the middle of the main heater in the downcomer and riser at an air velocity of 5.71 m/s for Sand particle size diameter of 220μ at different values of solids mass flux.

4.3 Effect of Some Parameters on Local Heat Transfer Coefficients

The local heat transfer coefficients obtained around a cylinder immersed in both a riser and downcomer of CFB are plotted in Fig. 6 through Fig. 8, under different operating conditions. In the following sections we will study the effect of each parameter upon the local heat transfer coefficient.

Effect of air velocity on local heat transfer coefficient

The effect of air velocity on local heat transfer coefficient for sand particle diameter of 220 micron and solids mass flux of 29.16 kg/m^2-s and for (Dp=497 and G=3.74) is shown in Fig. 6 for riser and downcomer respectively. As shown in the Fig. the local heat transfer coefficient vary significantly with changing air velocity and changing angular position around the cylinder. It can be seen that for the riser as the air velocity decrease the local heat transfer increases. This can be attributed to the fact that the lower air velocity give chance to particle to make contact with cylinder surface i.e increase residence time of particle and so increase heat transfer by particle from probe and vice versa. Also the effect of air velocity on local heat transfer coefficient in the downcomer It can be seen that the local heat transfer coefficient do not vary significantly with changing air velocity in the riser. And this can be explained as the downcomer contain solids only after the air has separated in the cyclones

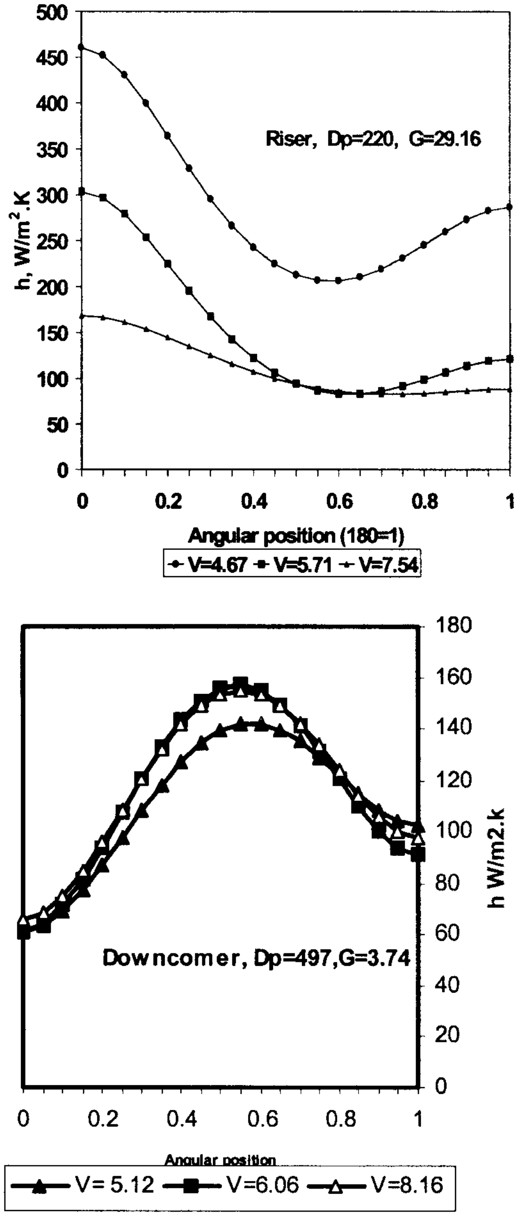
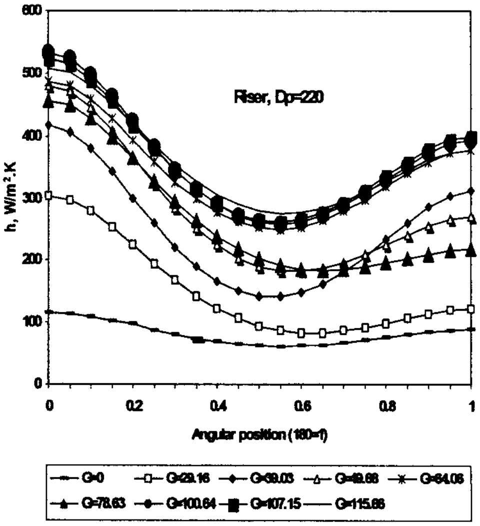


Fig. 6 Local heat transfer coefficients at the middle of the main heater in both riser and downcomer for sand at different air velocity in the riser

Effect of solids mass flux on local heat transfer coefficient

The effect of solids mass flux on local heat transfer coefficient in both of the riser and downcomer at (5.71 m/s air velocity, sand particle diameter of 220 and at 5.71 m/s, FCC of particle diameter of 85) is shown in Fig.s 7and 8 respectively It can be seen that the solids mass flux affect local heat transfer coefficients in both the riser and downcomer and it can be seen that the minimum local heat transfer is at solids mass flux of zero. As solids mass flux increases we found that local heat transfer increase and this continuous until a certain limit , above this limit we can see that solids mass flux do not affect the local heat transfer coefficient and this can be seen in Fig. 7 for riser where solid mass flux of 100.54, 107.15, and 115.66 approximately coincident on each others. . This can be attributed to the fact that as solids mass flux increase the number of particles that collides with probe increases , which means that the surface of contact with probe increases and this increases heat transfer which directly increase local heat transfer coefficient. This will continue until a certain value of solids mass flux after which the lower half of probe is completely covered by particle so any increase in solids mass flux do not affect heat transfer as shown in Fig. 7. Also with respect to downcomer it can be seen that most of the effects are concentrated on the top of the probe.



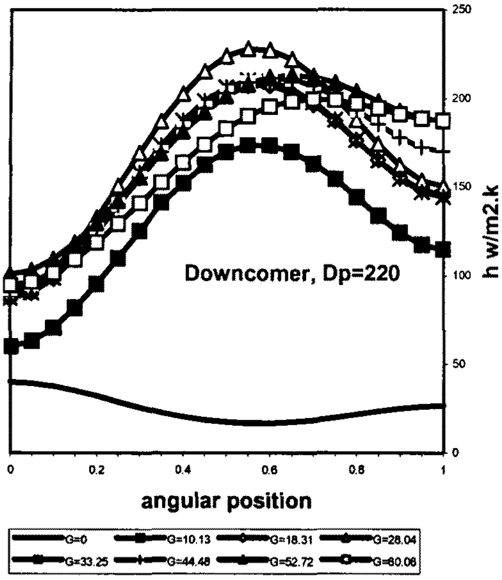


Fig. 7. Local heat transfer coefficients at the middle of the main heater in the riser and downcomer for a sand particle diameter of 220 m at different values of solids mass flux and at an air velocity of 5.71 m/s.

Effect of particle size on local heat transfer coefficient

The effects of particle size on local heat transfer coefficient in both riser and downcomer at air velocity of 5.71 m/s are shown in Fig.9 for solids mass flux of 29.16, for riser and 28.64 Kg/m2.s for downcomer respectively. It can be seen from the Fig. that for riser as the particle size decreases the local heat transfer increases, and this can be explained as follow at the same value of solids mass flux and air velocity smaller particle size has more surface area than the larger particle size and hence the contact area for smaller size will be more than larger size. On the other hand for downcomer the effects of particle size on local heat transfer coefficient are shown that the particle size does not have much effect but in general as the particle size decreases the local heat transfer increases.

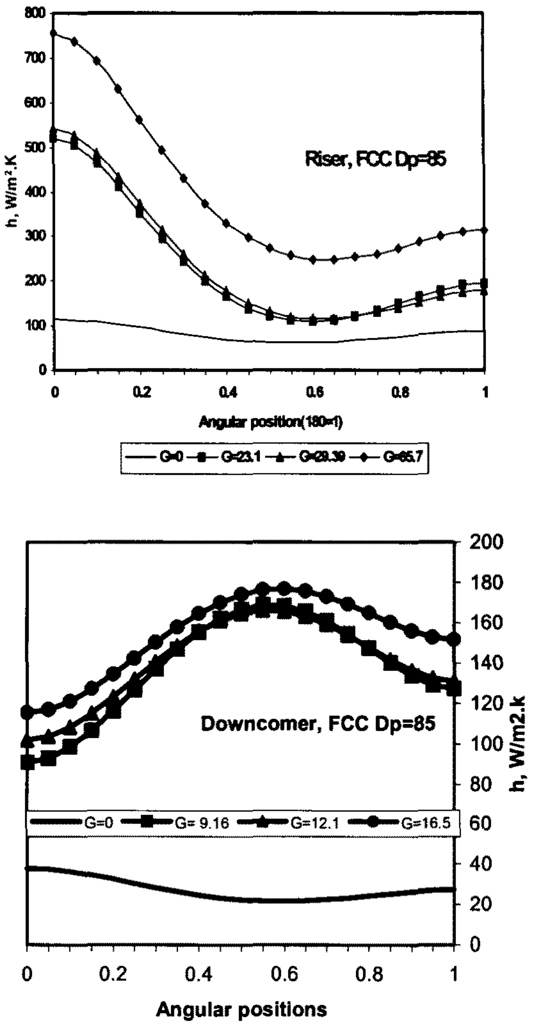


Fig. 8 Local heat transfer coefficients at the middle of the main heater in riser and downcomer for FCC particle diameter of 85 m at different values of solids mass flux and at an air velocity of 5.71 m/s.

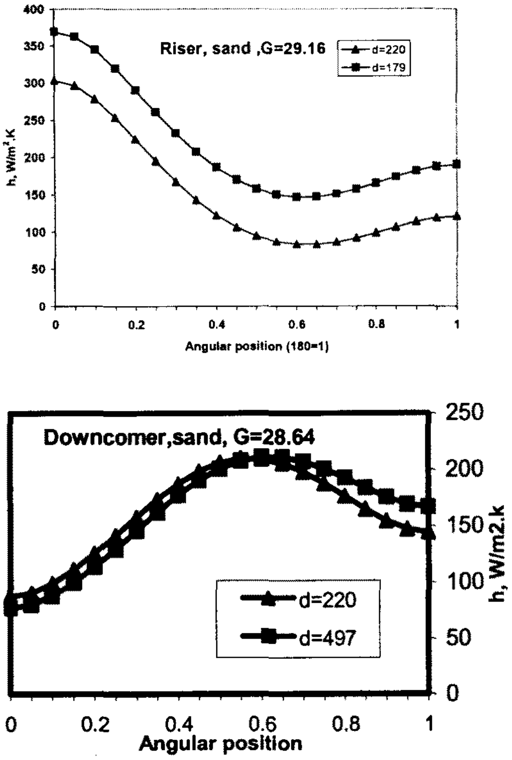


Fig. 9 Local heat transfer coefficients at the middle of the main heater in the riser and downcomer, at an air velocity of 5.71 m/s, and solids mass flux of 29.16 kg/m^2-s for different particle size diameters.

Average heat transfer coefficient

The averaged heat transfer coefficient around the circumferential of the cylinder in both the riser and downcomer at air velocity of 5.71 m/s is shown in Fig. 10 (for Dp=179, 220 micron particle size in riser and for Dp=220,497 micron particle size in downcomer). It can be seen that the averaged heat transfer coefficient exhibited the same trend as local heat transfer coefficient i.e increase with decrease in particle and increasing solids mass flux as shown in the Fig.

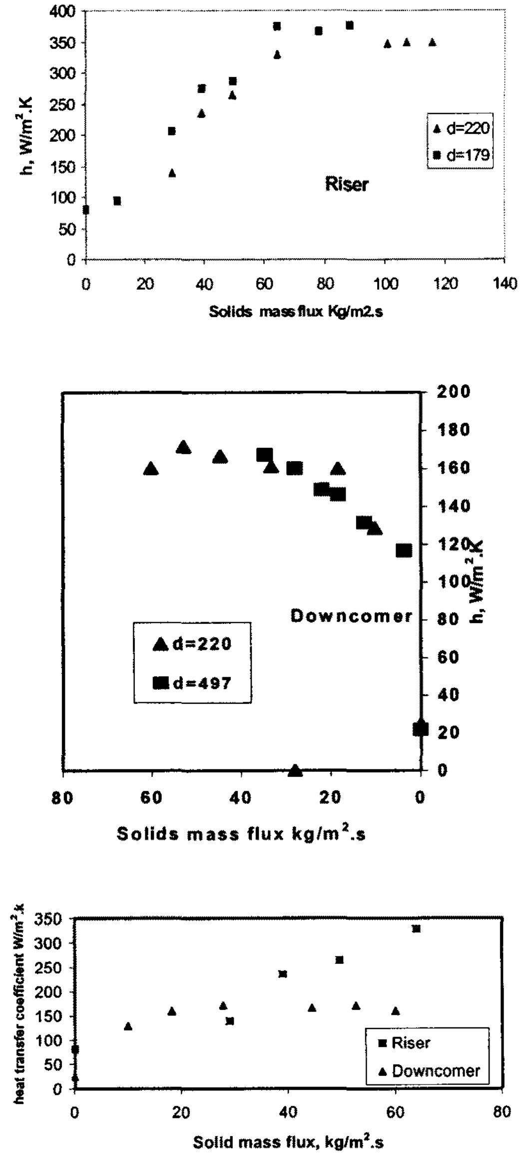


Fig. 10 Average heat transfer coefficients in both riser and downcomer for different sand particles diameters at an air velocity of 5.71 m/s and at different values of solids mass flux

5. Conclusions

Local heat transfer coefficients around horizontal probe in both a riser and downcomer of CFB was found to be significantly different for different circumferential positions. In addition the magnitude of the local coefficients were affected by both particle size and air velocity, as well as by solids mass flux. Likewise, the circumferentially averaged coefficients were also affected by the same parameters as local coefficients, showing a generally increasing trend with decreasing particle size and increasing solids mass flux. The minimum values of local heat transfer coefficients in riser occur approximately at $\Phi = \theta / \Pi$ =(0.5 - 0.7). On the other hand the maximum values of local heat transfer coefficients in downcomer occur approximately at $\Phi = \theta / \Pi$ = (0.4 - 0.5). It can be seen also that the effect of air velocity and particle diameter on local heat transfer coefficient is more obvious in riser than in downcomer. Finally it can be seen that the of local and averages values of heat transfer coefficient is higher in riser than in downcomer.

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