EXPERIMENTAL STUDY AND NUMERICAL SIMULATION OF THE FLOW STRUCTURE IN THE CIRCULATING FLUIDIZED BED (CFB) SYSTEM

Seong W. Lee*, G.Q. Zhang, S. Mukira

(ph)410-319-3137 (fax)410-319-3843 *(e-mail)slee@eng.morgan.edu
Morgan State University School of Engineering
Baltimore, MD 21239

ABSTRACT

In order to provide an experimental basis for more reliable computation/simulation of the complex gas-solid particle flows in the riser of the CFB system, newly designed measurement systems have been developed.

Pressure drops of the distributor plate and the cyclone were measured for the system tests. First, test was conducted without the feeding solids into the CFB riser were analyzed. The primary air flow rate was measured by the specially designed pitot tube. The air flow rate was a function of the pressure drop. Tests were also conducted with feeding solids into the riser under different primary air flow rate. The solid feed rate increased as the aeration flow rate increased. The void fraction was reduced with an increasing pressure drop in the CFB riser column.

Numerical simulation of the typical gas flow patterns in the CFB system is conducted using the computational fluid dynamics (CFD) code, Fluent. The simulation results predicted the velocity vector and pressure profiles along the CFB riser.

1. INTRODUCTION

Advantages of the circulating fluidized bed combustor (CFBC) system over the conventional bubbling FBC system include higher combustion efficiency, increased limestone use due to the greater efficiency of smaller particle sizes and long solids residence time in CFBC, reduced NOx formation resulting from staged combustion, a simpler control system due to the separation of combustion/heat transfer in the solids heat-recovery bed, and a higher turndown ratio resulting from the large ratio between the operating gas velocity and the solids suspension velocity in CFBC [1].

Although CFB boilers have today reached commercial status, there is still much to learn about the heat transfer and hydrodynamics which take place in the combustion chamber. The particle convective component is of key importance in these processes and is controlled by the particle flux to the heat transfer surface.

The bench-scale circulating fluidized bed (CFB) system [2] was carefully designed/fabricated to better understand the fluid dynamics of gas/particle flow in the CFB riser. Auxiliary characteristics. The computer-assisted data acquisition system was developed for the systematic instrumentation of flow measurements in CFB system. The system tests were conducted with/without the feeding solids into the riser under different test conditions.

2. EXPERIMENTS

2.1 Experimental Apparatus and Procedures

The system test of Circulating Fluidized Bed (CFB) System was conducted by the bench-scale CFB system [2]. Solid particles were kept in a steel storage surge tank. The solid particles were fed to the riser column through a connection L-valve tube feeding system which was mounted to the CFB riser column. The solid flux could be controlled with the aeration air flow rate into the L-valve.

Primary air was supplied through was supplied through a gas distributor plate at the bottom of the riser tube to transport the solid particles. At the exit of the riser column, a cyclone separated the solid particles from the fluidizing air. The solid particles were fed back to the storage surge tank vessel after passing the solid flow rate measuring valve in order to record the solid accumulated height during a certain time interval.

In an axial direction, 6 taps were mounted on the wall of the riser column with an equidistant spacing of 3 feet. Pressure differences over these sections were measured using two-foot-tall water manometer and two-foot-tall mercury manometer. The solid mass flow rate of the circulating solids could be determined by measuring the accumulated height of the solids in the measuring pipe during a certain period of time.

The local and the overall solids average solid concentrations (bed voidage) were determined by the differential pressure drop and solid weight. Solid particles used for the CFB cold test were organic millet particles with an average of 1.826 mm, a particle density of 1369 kg/m3, and bulk density of 620 kg/m3.

3 RESULTS AND DISCUSSION

3.1 Results and Discussion for the Experimental Study

(a) Test Results without Feeding Solids into the Riser

Pressure drops of the distributor plate and the cyclone are a function of the gas flow rate [3]. The primary air flow rate was measured by the specially designed pitot probe. The air flow rate was a function of the pressure drop. These results are shown in Figure 1. There was some pressure potential energy loss in the wind box which is used to generate thermal energy and heat up the primary air. When the temperature of primary air increased from 80 F to 190 F in twenty minutes, the total primary air flow rate was reduced from 0.046 m/s to 0.038 m/s, as shown in Figure 2. The maximum primary air flow rate was about 0.038 m/s which was responded to the superficial velocity of 4.6 m/s. The terminal velocity and the minimum fluidization velocity of the glass beads were 1.15 m/s and 0.023 m/s respectively.

(b) Test Results with Feeding Solids into the Riser

The test conditions for the tests with feeding millet particles into the riser included (i) fully opening the primary air inlet valve, (ii) fully closing the bypass controlling valve, and (iii) stable running condition. When the system reached to its stable running condition, the aeration air valve was slowly opened and the solid particles were fed into the riser. The solid feed rate was a function of the aeration air flow rate as shown in Figure 3. The solid feed rate was set at 12 ft3/hr of aeration air flow rate for starting feeding point, and it increased as the aeration flow rate increased. When the solid feed rate increased, the total pressure drop of the riser column increased. That indicated the bed void fraction was reduced or the bed density was increased. The maximum solid feed rate was about 0.075 kg/s and the total riser pressure drop was 380 mm-water as shown in Figure 4. Under this condition, the most important cold flow hydrodynamics can be calculated. The bed void fraction was about 0.6, and total solid accumulated in the riser was about 30.25 kg. The average solid residence time in the riser column was about 6.72 minutes, and the average solid particle velocity was 0.544 m/s. The gas velocity through the column was about 7.67 m/s. So, the relative slip velocity between the gas and solid particles was about 7.12 m/s, which was about 6.2 times of the terminal velocity.

(c) Test of Solid Particles

The CFB system was modified to use millet particles by changing the cloth filter of the gas distributor to a metal screen in order to reduce the pressure drop of the gas distributor, and to increase the primary air flow rate. With these system modifications, the CFB system was tested with the millet particles. The primary air flow rate was 0.0866 m3/s which was responded to a riser column superficial velocity of 10.68 m/s. It was slightly greater than the particle terminal velocity.

3.2 Results and Discussion for the Numerical Simulation

Numerical Simulation of the typical gas flow patterns in the CFB system is conducted using the computational fluid dynamics (CFD) code, Fluent [4]. The system was configured in 3-D cylindrical coordinates with uniform mesh grids [4]. Since the flow with a larger Reynolds number has a strong turbulence flow with unisotropic behaviors, the standard k-e turbulence model was not significant for our test case [5]. The renormalization group (RNG), k-e turbulence model was applied for the numerical simulation. This RNG model provided a more general and fundamental model and improved predictions of near wall flow, transitional flow, and vortex shedding behavior.

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Figures 5 and 6 show a 2-D velocity vector in slide plate I=4 and I=24. The pressure profiles in the same 2-D slides are shown in Figure 7. In the vertical direction, the lower velocity was found at the two ends of the probe, and along the riser wall at the aeration air input side as shown in Figure 5. The flow profiles below the probe were relatively uniform at the center region of the chamber. When the air flow reached the probe, the uniform flow was split to two parts and the velocity of the center region was reduced as shown in Figure 6.

4. CONCLUSIONS

(1) It is evident from the system test results that our bench-scale CFB system is very effective to control air flow rate and solid feeding rate.

(2) The air flow rate was a function of pressure drop in the CFB riser. The solid particle feed rate increased as the aeration flow rate increased.

(3) The void fraction was reduced with an increasing pressure drop in the CFB riser column.

(4) The simulation results could predict valuable information on the velocity vector and pressure profiles in the different locations of CFB riser column.

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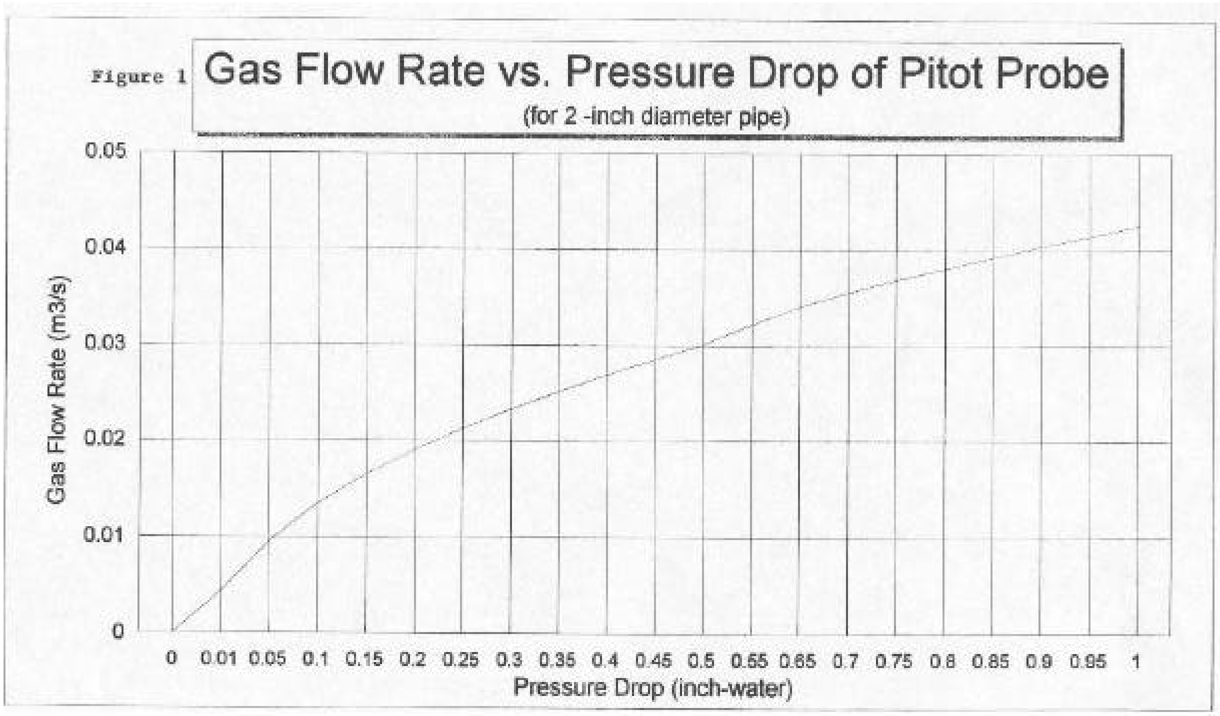
Figure 1
Gas Flow Rate vs. Pressure Drop of Pitot Probe
(for 2 -inch diameter pipe)
Gas Flow Rate (m3/s)
0.05
0.04
0.03
0.02
0.01
0
0 0.01 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5 0.55 0.65 0.7 0.75 0.8 0.85 0.9 0.95 1
Pressure Drop (inch-water)

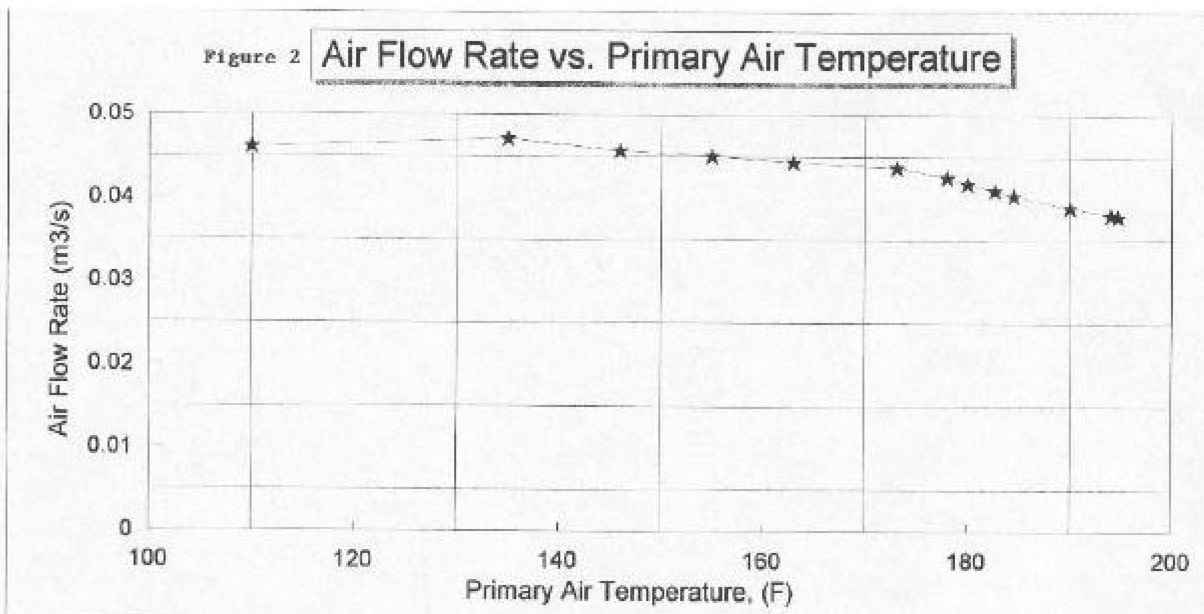
Figure 2
Air Flow Rate vs. Primary Air Temperature
Air Flow Rate (m3/s)
0.05
0.04
0.03
0.02
0.01
0
100 120 140 160 180 200
Primary Air Temperature, (F)

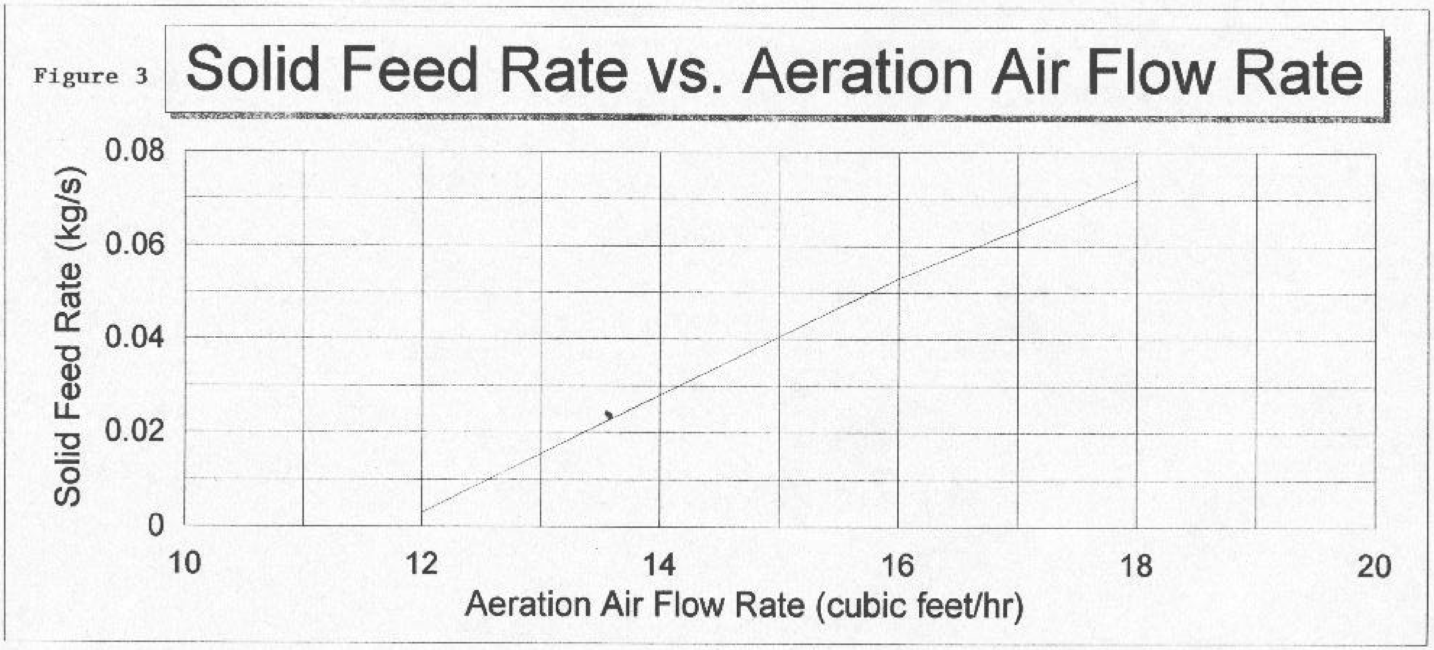
Figure 3
Solid Feed Rate vs. Aeration Air Flow Rate
Solid Feed Rate (kg/s)
0.08
0.06
0.04
0.02
0
10
12
14
16
18
20
Aeration Air Flow Rate (cubic feet/hr)

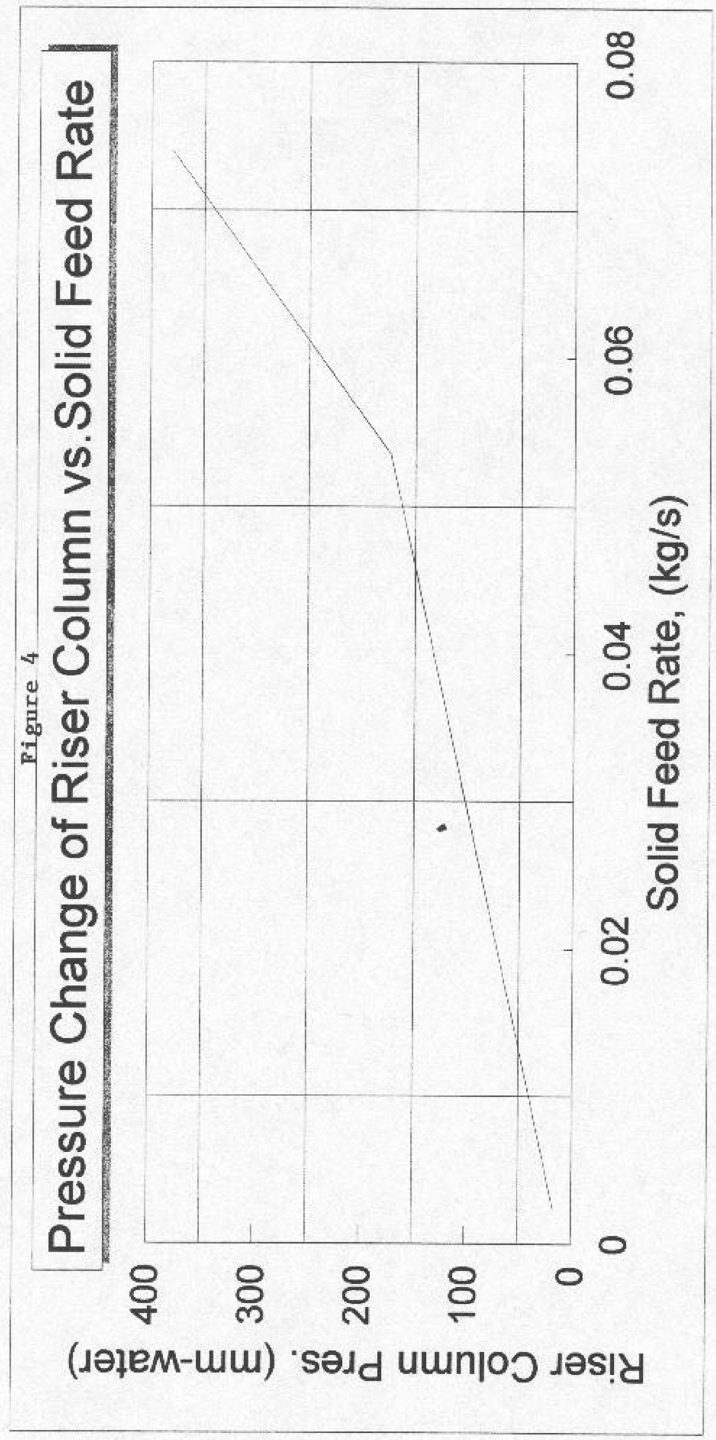
Figure 4
Pressure Change of Riser Column vs. Solid Feed Rate
Riser Column Pres. (mm-water)
400
300
200
100
0
0
0.02
0.04
0.06
0.08
Solid Feed Rate, (kg/s)

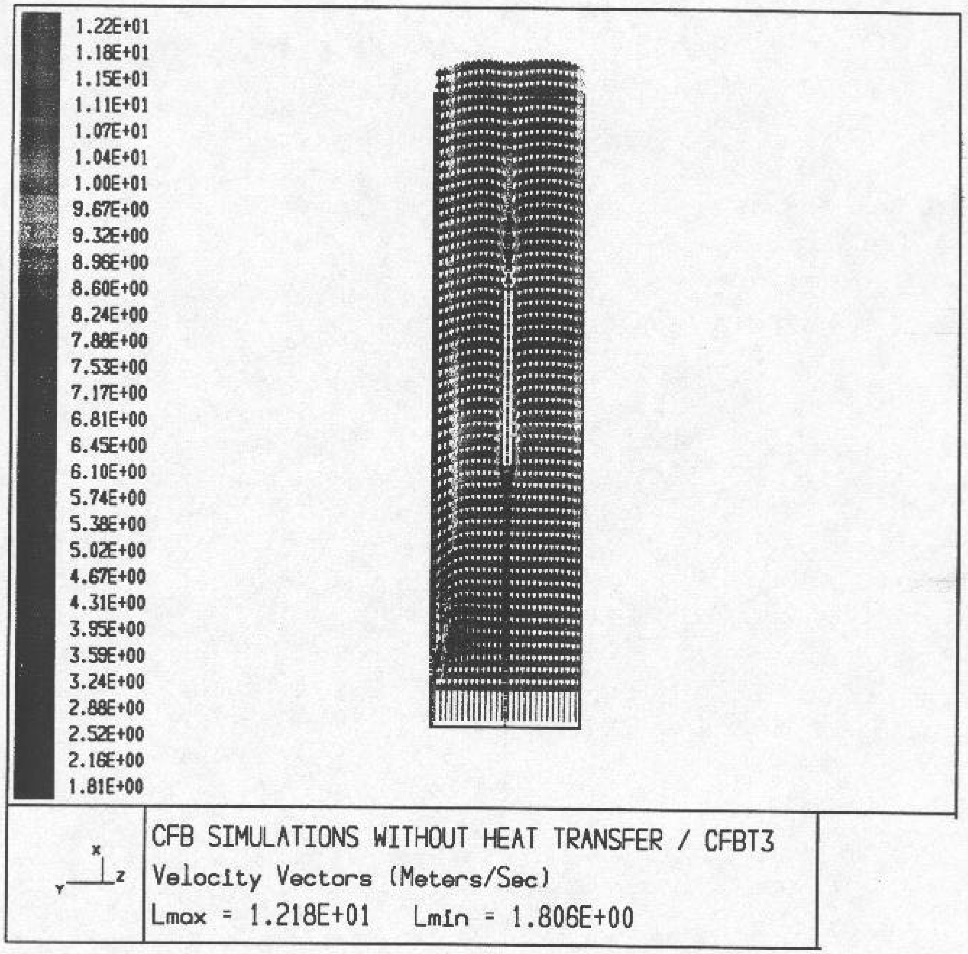

Figure 5 Velocity Vectors along the CFB Riser

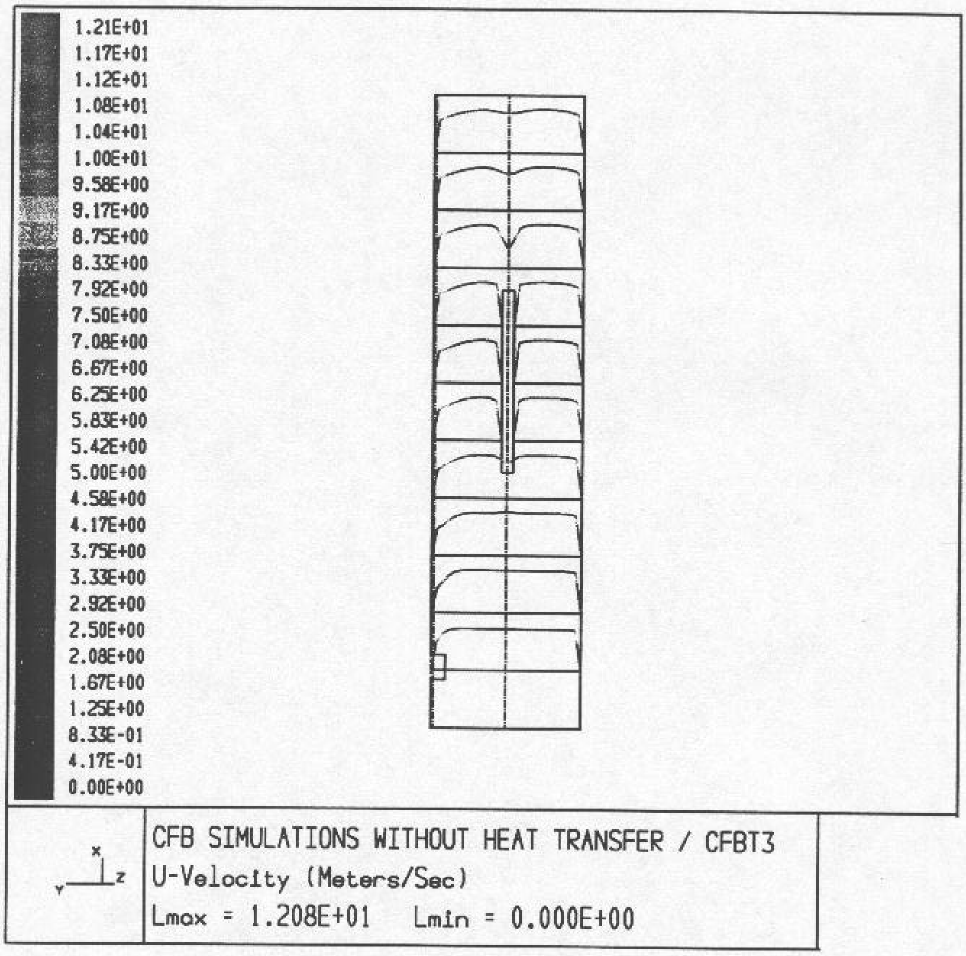

Figure 6 Velocity Profiles in the Vertical Direction of CFB Riser

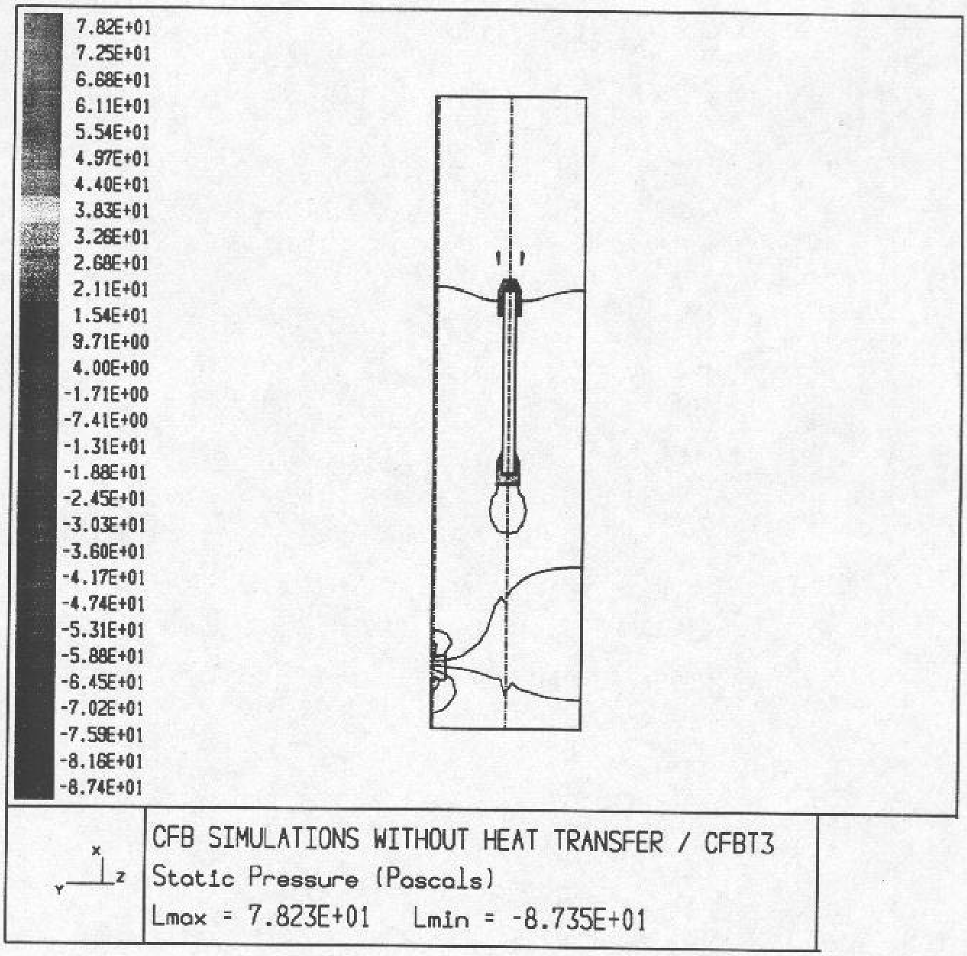

Figure 7 Static Pressure Profiles in the Vertical Direction of CFB Riser