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Technical Progress Report No.1

Development of the Instrumentation
and Modeling for Heat Transfer
Characteristics in CFBC

to

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SUMMARY

This technical report summarizes the research performed and progress achieved during the period of October 1, 1995 to March 31, 1996.

The bench-scale circulating fluidized bed (CFB) system was carefully designed and fabricated to study gas/particle flow and heat transfer characteristics on the wall of the CFB riser. Design and fabrication of the major components such as gas distributor, cyclone, wind box, surge tank, solid control valve, and riser were summarized in this report. The air supply subsystems including blower, control valve, PVC piping, and air flow measuring devices are arranged and described.

The advanced data acquisition system and instrumentation will be developed/applied to measure pressure changes along the CFB riser height, gas/particle velocities, local heat transfer coefficient on the wall of CFB, and mass flux of the solid particles. The heat transfer probe will be designed to measure the bed-surface heat transfer coefficient on the wall of the CFB riser. In addition, an electrostatic probe will be designed to measure the local mass flux of the solid particles in the CFB.

The progress of this project has been on schedule. The arrangement of the auxiliary subsystems for the bench-scale CFB will be completed for the system test.

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SECTION 1

Bench-Scale Circulating Fluidized Bed (CFB) Test Facilities

1.1 Design and Fabrication of the Bench-Scale CFB System

The bench-scale circulating fluidized bed (CFB) system was carefully designed/fabricated to better understand the fluid dynamics of gas/particle flow and to study the bed-surface heat transfer phenomena on the wall of the CFB riser. Design of the major components in the bench-scale CFB system is summarized as follows;

Gas Distributor:

The design of the gas distributor is an important factor in determining the overall performance of fluidized bed process. The quality of bubbling fluidization, the system pressure drop, and the degree of solid-gas contact are strongly influenced by the type of gas distributor [1].

A simple flat perforated plate, as shown in Figure 1.1 was chosen for this study. This type of gas distributor is widely used for industrial and laboratory-scale operations because it retains the advantages of the single plate such as ease of design and construction, and is combined with good gas distribution.

An actual hole size of the distributor is 0.0625". The opening rate is 3.03 % with total 152 holes. The pressure drop from the gas distributor is 3.94 inches of water which is about 10 % of the total riser pressure drop.

Figure 1.1 Schematic Diagram of the Gas Distributor (Flat Perforated Plate)
(All dimensions are inches.)

Cyclone:

The cyclone system achieves particulate removal by centrifugal, inertial, and gravitational forces. The cyclone depends on the centrifugal separation of the particulate phase to the walls, as a result of the turn of the gas/solids stream as it enters. The efficiency is thus a function of the velocity of the stream entering the cyclone and turning angle, which is related to the diameter of the barrel section of the cyclone [2].

As shown in figure 1.2, the cyclone is designed and fabricated by plexiglass. The gas flow turns downwards from the cylindrical barrel section into the lower conical section. At the bottom, the gas flow turns upwards, forming a central ascending vortex. The separation between the exit clean gas flow and the inlet dirty gas stream can sometimes be improved by a central cylindrical tube, which forms a downward extension of the exit duct.

The design of cyclone was referred to the ASME standard design criteria and other reference [3]. The gas inlet velocity is an important design factor in deciding the cyclone inlet diameter D_1 . The gas inlet velocity is determined by the solid load/density and particle mean size. The cyclone inlet diameter was determined by the gas inlet flow rate Q and gas inlet velocity u_g to the cyclone. In our design case, solid load is 20-50 lb/h of glass beads with 2.5 g/cc of density. The mean particle diameter is 0.04 mm. The inlet gas flow rate Q to the cyclone is 250 m³/h. The cyclone inlet diameter D_1 is given by

$$D_1 = \sqrt{\frac{4Q}{\pi u_g}}$$

Figure 1.2 Schematic Diagram of the Cyclone System
(All dimensions are inches.)

The clean gas outlet diameter D was employed as the same dimension of D_1 . This dimension was used to find to other dimensions of the cyclone components such as upper pipe length H_1 , lower pipe length of clean gas outlet H_4 , cyclone chamber diameter D_2 , chamber height H_2 , and solid outlet diameter D_3 .

Wind Box:

The wind box is an important part of the CFB system. Fluidizing air from high pressure blower at desired pressure and flow rate is delivered to the wind box through a PVC pipe. The gas kinetic energy is transferred into the potential energy.

The wind box is designed to damp out the small flow of unsteady fluidizing air and to provide an uniform air for the distributor and the riser. The gas velocity at the top of wind box is reduced to $1/4$ of the velocity at the wind box inlet. The pressure is increased four times because the diameter of the wind box is increased from 2 inches to 4 inches as shown Figure 1.3. The increased pressure provided uniform gas velocity through the small holes of the gas distributor plate. The maximum pressure of the wind box is 200 inches of water, which could match with the high pressure blower. The wind box is made of $1/16$ " thick stainless steel plate with a top bolted flange to the distributor as shown Figure 1.3.

Surge Tank:

The surge tank achieves the solid particle storage and feeding of solid particles into the riser. In addition, the surge tank also stores enough solids in the system to ensure smooth opera-

Figure 1.3 Schematic Diagram of the Wind Box (All dimensions are inches.)

tion of the system. The schematic diagram of the surge tank, which is made of 1/16" carbon steel plate, as shown in Figure 1.4. The total volume of the surge tank is about 2.7 ft^3 , can store 80 kg of solid particles. The solid level in the tank can be measured through the attached glass view window.

Solid Control Valve:

The solid control valve is used to measure the solid flow rate through the system, which is installed to the pipe between the cyclone and the surge tank. The solid control valve as the butterfly valve is designed and fabricated as shown in Figure 1.5. The solid particles are accumulated in the pipe when the valve is closed. The solid circulation rate C can be calculated by solid bulk density ρ_s , accumulating time t , and volume of the measuring vessel V , as expressed below:

$$C = \frac{\rho_s V}{t}$$

Riser:

The riser is the fast fluidized bed regime of CFB combustion chamber where all chemical reactions take place. Solid particles are entrained by the primary gas the riser tube. The riser tube is made of 4" ID plexiglass. Under normal operating conditions, the superficial gas velocity is 5 to 10 times of the particle terminal velocity [4]. The total pressure drop in the riser tube is about 39.4 inches of water. The optimizing operating condition will be determined by further experiments.

Figure 1.4 Schematic Diagram of the Surge Tank (All dimensions are inches)

Figure 1.5 Schematic Diagram of the Solid Control Valve

1.2 Auxiliary Subsystems for the Bench-Scale CFB Model

The bench-scale CFB model and supporting auxiliary subsystems are schematically shown in Figure 1.6, which included air supply system, instrumented riser, gas-solid separation system, solid return/storage tank.

The air supply subsystem consists of blower, control valves, PVC piping, and flow measuring devices as shown in Figure 1.6. Primary air is supplied by a 7.5 hp ROTRON Model DR808AY72MX, regenerative blower of 116-in. of water and 345 scfm. Two 1-hp, two-speed centrifugal blowers will be used to supply secondary air separately during the test. Primary air is controlled by the primary inlet valve and the bypass valve. Secondary air is controlled by the aeration valve.

Pressure transducer with a data acquisition system will be used to measure the pressure change along the different height of the riser. A five-point, 3-dimensional probe with pressure transducer will be used to measure gas axial, tangential, and radial velocities. The heat transfer probe will be developed to measure the bed-surface heat transfer coefficient on the wall of the CFB riser. The probe will be consisted of two major components, heating component and heat flux sensing unit. The output of the thermocouples will be recorded on a computerized data acquisition system consisting of a direct-current amplifier, an A/D converter, and a personal computer.

In order to determine the local mass flux of the solid particles, the electrostatic probe will be designed and fabricated along with a signal processing system.

Figure 1.6 Schematic Diagram of the Bench-Scale CFB System

SECTION 2

Research Continuation

The progress of this project has been on schedule. The arrangement of the auxiliary subsystems for the bench-scale CFB model will be completed for the system test.

The advanced data acquisition system and instrumentation will be developed/applied to measure pressure changes along the CFB riser height, gas/particle velocities, local heat transfer coefficient on the wall of CFB, and the mass flux of the solid particles.

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