DOE/MT/95013--04

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

Semi-Annual Report
September 30, 1996 - March 29, 1997

By:
Seong W. Lee

RECEIVED

AUG 10 1998

OSTI

Work Performed Under Contract No.: DE-FG22-95MT95013

For
U.S. Department of Energy
Office of Fossil Energy
Federal Energy Technology Center
P.O. Box 880
Morgantown, West Virginia 26507-0880

By
Morgan State University
School of Engineering
Baltimore, Maryland 21239

SWL
MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owed rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

**Portions of this document may be illegible
electronic image products. Images are
produced from the best available original
document.**

ABSTRACT

This technical report summarizes the research conducted and progress achieved during the period from October 1, 1996 to March 30, 1997.

The system tests were conducted by the bench-scale CFB system. Pressure drops of the distributor plate and the cyclone were measured. 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. The millet particles were tested by the modified CFB system.

The computer-assisted data acquisition system was developed to measure the pressure of different locations along the riser wall. Seven pressure transducers were connected to the pressure taps on the riser wall. Before using the pressure transducers, each transducer was carefully calibrated by the specially designed pressure calibration system. The aeration flow rate was adjusted to change the solid feed rate. The differential pressures were recorded by the data acquisition system. The pressure drop along the riser column was the function of the riser column height. The pressure drop decreased as the riser column height increased.

TABLE OF CONTENTS

	PAGE
ABSTRACT.....	ii
EXECUTIVE SUMMARY.....	1
SECTION	
1. SYSTEM TEST OF CFB COLD FLOW MODEL	
1.1 Experimental Apparatus and Procedures.....	2
1.2 Results and Discussion.....	3
2. DEVELOPMENT OF THE INSTRUMENTATION FOR PRESSURE MEASUREMENT	
2.1 Pressure Measurement System for CFB Riser.....	9
2.2 Pressure Transducer Calibration.....	9
2.3 Test Results and Discussion.....	12
3. CONCLUSIONS.....	17
REFERENCES.....	18

EXECUTIVE SUMMARY

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 NO_x 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 and to study the bed-surface heat transfer phenomena on the wall of the CFB riser. Auxiliary subsystems tests of the CFB were conducted and included the their characteristics. The computer-assisted data acquisition system was developed for the systematic instrumentation of flow measurements in CFB system. Pressure drops of the distributor plate/the cyclone were measured. The system tests were conducted with/without the feeding solids into the riser under different test conditions. The instrumentation will be continuously developed for measuring flow/local heat transfer rate effectively.

SECTION 1

SYSTEM TEST OF CFB COLD FLOW MODEL

1.1 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.

1.2 Results and Discussion

(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 m³/s to 0.038 m³/s, as shown in Figure 2. The maximum primary air flow rate was about 0.038 m³/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

Gas Flow Rate vs. Pressure Drop of Pitot Probe

(for 2 -inch diameter pipe)

Figure 1

Figure 2 Air Flow Rate vs. Primary Air Temperature

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 maximum solid feed rate was about 6.5 ft³/min. 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.

Figure 3

Solid Feed Rate vs. Aeration Air Flow Rate

Figure 4

Pressure Change of Riser Column vs. Solid Feed Rate

SECTION 2

DEVELOPMENT OF THE INSTRUMENTATION FOR PRESSURE MEASUREMENT

2.1 Pressure Measurement System for the CFB Riser

In order to conduct the experimental tests with millet particles and to determine the bed average structure in the riser of CFB system, a pressure transducer system was designed to measure the pressure and differential pressure at seven points along the riser wall as shown in Figure 5. Seven pressure transducers, 26 PC series of Honeywell Micro Switch were used for this system.

The pressure transducers were connected to pressure taps by a 1/4" OD x 0.175" ID vinyl tube. The pressure tabs were installed on the riser wall in the vertical direction: tap #1 (or Pt 1) at 1.27 cm from the bottom; (Pt2) at 40.64 cm; tap #3 (Pt 3) at 101.6 cm from the bottom; tap #4 (Pt 4) at 162.56 cm; tap #5 (Pt 5) at 223.52 cm from the bottom; tap #6 (Pt6) at 284.48 cm; and tap #7 (Pt 7) at 386.84 cm. The pressure at Pt 7 is measured by a straight style pressure transducer. The pressures are recorded by a PC with a RTI-800 ADC board from the Analog Device, and Paragon 500 software from Intec Controls Corporation.

2.2 Pressure Transducer Calibration

Before using the transducers for pressure measurement, each transducer was carefully calibrated with a specially designed pressure calibration system as shown in Figure 6. The pressure is generated by pressing the plastic bottle and setting a pressure valve, which is connected to the stop valve. The pressure

Figure 5 Arrangement of Pressure Measurement in the Bench-Scale Circulating Fluidized Bed System

Figure 6 Instrumentation for Pressure Transducer Calibration System

was measured by the manometer and the PC. The results were recorded on the PC and calculated with LOTUS program. For each transducer, the pressure change was a linear function.

In order to prevent the falling millet particles into the pressure tap and plugging up the pressure measurement tube, a metal screen was placed at the inlet of the pressure tap.

2.3 Test Results and Discussion

After warming up about 20 minutes, the system reached the steady state. The changes of temperature and pressure at the wind box were recorded. The gas density was the function of pressure/temperature, which could be calculated by using the ideal gas law [4]. The primary air flow rate was measured by the modified pitot probe. The superficial gas velocity in the riser column was calculated from the following equation [5]:

$$U_g = \frac{Q_g}{A_{riser}}$$

where, U_g = is the gas superficial velocity in the riser column, in m/s. Q_g is the primary air flow rate under operation conditions, measured in m^3/s . A_{riser} is the cross-sectional area of the riser tube in m^2 . The test conditions for the lower superficial velocity test case included the setting of gas superficial velocity in the riser column at 9.7 m/s. The aeration (secondary air) flow rate was adjusted to change the solid feed rate at three values for the three test cases; 3391 g/min. for case 1, 2848 g/min. for case 2, and 2153 g/min. for case 3. For each of the

test cases, the differential pressures were recorded by the computer-assisted data acquisition system. The pressure drop along the riser column was a function of the riser column height, as shown Figures 7(for case 1), Figure 8 (for case 20, and Figure 9 (for case 30). The pressure drop decreased as the riser column height increased. Cases 1 and 3 showed more gradually changes. However, the change of case 3 is more linear region between Pt2 and Pt 6.

Figure 7 Differential Pressure vs Column Height

Figure 8 Differential Pressure vs Column Height

Figure 9 Differential Pressure vs Column Height

SECTION 3

CONCLUSIONS

The system tests were conducted with and without the feeding solids into the CFB riser by the bench-scale CFB system. The primary air flow rate was measured by the specially designed pitot tube. The air flow rate was a function of the pressure drop. The solid feed rate increased as the aeration flow rate increased. The void fraction was reduced with the increase of total pressure drop in the CFB riser column.

The computer-assisted data acquisition system was developed to measure the pressure of the different locations along the riser wall. Seven pressure transducers were connected to the pressure taps on the riser wall. Before using the pressure transducers, each transducer was carefully calibrated by the specially designed pressure calibration system. The pressure drop along the riser column was a function of the riser column height. The instrumentation will be continuously developed for measuring the gas/particle flow and local heat transfer effectively in CFB system.

REFERENCES

- [1] Singer J.G., Combustion; Fossil Fuel System, 3rd Ed., Combustion Engineering, Inc., Chapter 24, 1981.
- [2] Lee, S.W., Technical Progress Report, No. 1, U.S. DOE, Pittsburgh Energy Technology Center (PETC), April 1996.
- [3] Lee, S.W., Technical Progress Report, No. 1, U.S. DOE, Pittsburgh Energy Technology Center (PETC), November 1996.
- [4] Moran, M.J. and H.N. Shapiro, Fundamentals of Engineering Thermodynamics, Chapt. 13, 3rd Ed. John Wiley & Sons, Inc. 1995.
- [5] Hetsroni, G., Handbook of Multi-Phase Systems, McGraw-Hill Book Co., New York, Chapter 8, 1982.