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Technical Progress Report No.4

Analysis/Control of In-Bed Tube Erosion
Phenomena in the Fluidized Bed
Combustion (FBC) System

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To

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by

Dr. Seong W. Lee, Principal Investigator

Morgan State University
School of Engineering
Baltimore, MD 21239
(Phone) 410-319-3082/3137

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SUMMARY

This technical report summarizes the research work performed and progress achieved during the period of July 1, 1993 to September 30, 1993.

Design and fabrication of the electrostatic impact probe were continued for measuring particle-tube collision frequency in the bench-scale FBC model. To verify the working principle of the electrostatic impact probe and to establish the reliability of probe readings, several readings were performed. The number of impact particles can be conveniently read from the frequency counter by the impact probe, which was reproducible and consistent data.

The erosion measurement was conducted under different superficial fluidizing velocity in the bench-scale FBC model. Results of specific weight loss versus excess air velocity (air velocity above the minimum fluidization velocity) show the dominant effect of the fluidizing velocity on the tube erosion.

The project has been progressing well. Measurement of the particle-tube collision frequency will be conducted under different tube location by the electrostatic impact probe. Instrumentation for the measurement of the in-bed tube erosion will be continued under various operating conditions. In addition to that, the relationship between the results of particle-tube collision frequency and the measurement of in-bed tube erosion will be predicted.

TABLE OF CONTENTS

	<u>PAGE</u>
SUMMARY.....	ii
 <u>SECTION</u>	
1. Design/Calibration Test of the Impact Probe.....	1
1.1 Working Principle of Electrostatic Impact Probe.....	1
1.2 The Characteristics of the Electrostatic Impact Probe.....	1
2. Erosion Measurements and Discussions.....	8
2.1 Effect of Superficial Fluidizing Velocity.....	8
3. RESEARCH CONTINUATION.....	11
REFERENCES.....	12

SECTION 1

1 Design and Calibration Test of the Impact Probe

Design and fabrication of the electrostatic impact probe were continued for measuring particle-tube collision frequency in the fluidized bed under various experimental conditions.

1.1 Working Principle of Electrostatic Impact Probe

The working principle of electrostatic impact probe for measuring tube-particle collision frequency in a fluidized bed is based on the charge transfer due to the triboelectric effect as outlined below.

Solid surfaces of different materials normally have Fermi energies and distinct work functions [1]. The work function is the potential barrier that an electron must overcome to leave the solid material. The energy-level diagram and the resultant contact potential of two bodies before and after contact are schematically shown in Figure 1.

The Fermi energies of the materials are denoted as E_{F1} and E_{F2} . When two uncharged bodies (for instance, particle and probe sensor tip) with different work functions ϕ_1 and ϕ_2 are brought into contact for a period of time, so that the equilibrium condition is established. Therefore, the contact potential difference $V_1 - V_2$ will be arranged to compensate $E_{F1} - E_{F2}$, as shown in Figure 1. The charge transfer phenomena between two bodies follow the triboelectric process [1]. When glass beads in the fluidized bed strike the impact copper-probe sensor, the

(a) After Contact

(b) Before Contact

Figure 1 Schematic Diagram of Energy Levels and Contact Potentials for Two Bodies in Contact

probe may carry the negative charge as well as the glass beads will be positively charged.

1.2 The Characteristics of the Electrostatic Impact Probe

The electrostatic probe was designed/fabricated which could be served as the input transducer to generate impact charge signals. The series of converting/amplifying network circuit was built to count the number of charge signals, as shown in Figure 2. The power supply was also built in the laboratory to supply appropriate voltages to IC components/signal processing unit. A center tap transformer was used to step down 120 volts to 36 volts which is installed at ground potential along with connection of ground-circuit. The positive and negative unregulated voltages across the capacitor are applied to the input of the positive and negative IC regulator respectively [2].

The charge signals are first converted into a voltages signals by means of a charge-to-voltage (Q-to-V) converter, which is combined by an operational amplifier (TL084 CN), two resistors, and a feedback capacitor (100 pf) as shown in Figure 2. A simple amplifier circuit was used to apply the converted signals and forward to the pulse sampler at the downstream. The analog voltage signals are transformed into the digital signals by the pulse sampler, which is correspond to particle-sensor collision. The digital signals are recorded and displayed by a digital frequency counter.

Point probe and tube probe were designed to verify the

Figure 2 Schematic Diagram of the Associated Signal/Circuit Processing Unit

working principle. The diameters of the inner copper sensors of the impact probes were selected to be in the range of 0.7 mm to 10 mm for testing glass beads of 0.5 mm diameter. A copper wire of 0.7 mm diameter in a shielded coaxial was used for the sensor. Under this condition, the probability of having two or more particles striking on the sensor at the same time will be very small and rare. Problems of false counting and electronic noises can be minimized during the tests. An aluminum tube with 19 mm OD is used as shielding and supporting tube is made with same dimensions of target tubes in the erosion tests.

The tube probe was designed to simulate the embedded tube for the erosion tests in the bench-scale FBC system [3] as shown Figure 3. Two sensors tips were made in the opposite direction on the tube surface at the middle point. This design is to provide simultaneous measurements of the particle collisions at two opposite points of the target tube at the same testing condition. When the particle touch the probe sensor, an impact charge signal will be generated and stored by the associated electronic circuits.

To verify the working principle of the electrostatic impact probe and to establish the reliability of probe readings, several tests were performed. When compressed air jet was suddenly directed to the probe sensor tip, no electric charge signals were generated/detected by the impulse force. This indicates that vibration of the probe tip caused by the impact of moving particles won't affect the probe readings. When the fluidizing air increased, the readings of the impact probes increased with the

Figure 3 Schematic Diagram of the Electrostatic Impact Probes/Associated Signal Processing Unit

air velocity. The impact signals can not be generated without the particle-surface contact. The number of impact particles can be conveniently read from the frequency counter by the impact probe. Test results of collision frequency by using this probe were reproducible and consistent in the bench-scale fluidized bed system.

SECTION 2

Erosion Measurements and Discussions

2.1 Effect of Superficial Fluidizing Velocity

The erosion measurement was conducted under different superficial fluidizing velocity. The superficial fluidizing velocity is defined as the mean air velocity in the fluidized bed in the absence of particles. The air flow rate could be varied by controlling of the two blowers' speed. Twenty five data points, each requiring 5 hours of testing were obtained for in-bed tubes at 3 cm and 5 cm clearances. Results of specific weight loss were plotted versus the excess air velocity (air velocity above the minimum fluidization velocity, $u - u_{mf}$) in Figure 4.

The minimum fluidization velocity is defined at the onset of fluidization, which occurs when drag force exerted by upward moving gas equals the weight of the bed particles. It is of great interest to note that the erosion occurred at a velocity (26 cm/s) above the minimum fluidization velocity (19 cm/s), for 0.55 mm glass beads, and increased with increasing superficial velocity. This threshold velocity, causing an abrupt change, is believed to be related to the bubbling velocity of bed particles [4,5].

It was found that the bed particles may vigorously interact with each other and with the target tube specimen below the threshold velocity, but no apparent weight loss can be detected. Above the threshold velocity, the tube erosion was found to increase almost linearly with increasing fluidizing velocity. A

Figure 4 Effect of Superficial Fluidizing Velocity on In-Bed Tube Erosion

modified power law representation suggests that:

$$\Delta M/A \text{ (mg/cm}^2\text{)} = (\Delta A/A)_0 + C (u - u_{mf} \text{ (cm)})^m$$

where subscript o denotes the threshold condition. The least squares method [6] was employed to determine the power law constant C and exponent m in the above equation. In general, the exponent m ranges from 1.0 to 1.3, depending primarily upon the location of the target cylinder in the fluidized bed system.

SECTION 3

RESEARCH CONTINUATION

The progress of this project has been on schedule. Measurement of the particle-tube collision frequency in the bench-scale FBC model will be conducted under different tube location by the electrostatic impact probe. The improved electrostatic impact probe will be used to explore the effect of collision frequency of flowing particle on the in-bed tube erosion.

Instrumentation for the measurement of the in-bed tube erosion will be continued under the various operating conditions. In addition to that, the relationship between the results of particle-tube collision frequency and the measurement of in-bed tube erosion will be predicted.

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