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Technical Progress Report No.5

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

to

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Pittsburgh Energy Technology Center
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for

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SUMMARY

This technical report summarizes the research work performed and progress achieved during the period of October 1, 1993 to December 31, 1993.

Measurement of particle-tube collision frequency was conducted by an electrostatic impact probe in the bench-scale FBC model. Two series of tests were conducted, in one test the probe traversed vertically along the bed axis. The other test conducted that the probe traversed from the center position to the quarter point of bed diagonal and the wall region.

The specific weight loss at different tube circumferential was examined to understand the effect of superficial fluidizing velocity. The bottom section of the test tube was found to be more serious erosion than that of the top section. In order to study the effect of tube orientations on in-bed tube erosion, the sample tubes along with four different angles were used. The sample tubes were also placed horizontally and vertically at the center, and vertically near the wall to quantify the effect of the tube location.

The project has been progressing well. Measurement of the particle-probe collision frequency will be continued to explore particle flow pattern/maximum erosion point by electrostatic impact probe. In order to simulate the erosion phenomena of the in-bed tubes in FBC, carbon steel as a target material will be used at elevated temperature condition by FBC bed material particles.

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SECTION 1

Measurement of Particle-Probe Collision Frequency

1.1 Particle-Probe Collision Frequency by Point Probe

Measurement of particle-probe collision frequency in the fluidized bed was conducted to understand major parameter characterizing the tube erosion. Two series of tests were conducted by a point probe [1], in one test the probe traversed vertically along the bed axis. The other test conducted that the probe traversed from the center position to the quarter point of the bed diagonal and the wall section.

The particle-probe collision frequency of the lateral moving particles at center (position 1) was much lower than that of near the wall (position 12). When the probe was close to the distributor, the collision frequency was increased as shown in Figure 1. The particle-probe collision frequency of outward flowing particles was shown in Figure 2. The collision frequency of near the wall showed similar trend of declining particle-probe collision frequencies.

Since the collision frequency indicates the total number of particle impacts per unit time through the probe tip area (or called particle number flux), which is directly related to the product of local particle velocity and particle phase density (concentration). In the dense fluidized, the averaged particle phase density remained as a constant [2]. The measured collision frequency indicated that the particle velocity varies with bed

Figure 1 Particle-Probe Collision Frequency by an Impact Point Probe at Different Heights/Positions

height, bubble velocity and bubble distribution.

The measured collision frequency generally represented the particle phase density, which decreased rapidly with increasing of the height. The averaged particle flow pattern and distribution in the fluidized bed could be explored by measured collision frequency along the different flow directions in the bed. In general, the mean particle flow pattern revealed by the present measurements is in agreement with the results of the radioactive particle tracking techniques [3].

Figure 2 Particle-Probe Collision Frequency by an Impact Point Probe for Wall Region in the Bench-Scale Fluidized Bed System

SECTION 2

Erosion Measurements and Discussions

2.1 Effect of Superficial Fluidizing Velocity at Different Tube Circumferential Section

It is commonly known that the wastage of ductile tube by impinging particles depends on impact particle direction and angles [4,5]. The erosion measurement was designed to explore this effect. The specific weight loss at different tube circumferential locations was examined to understand the effect of superficial fluidizing velocity. The superficial fluidizing velocity is defined as the mean air velocity in the fluidized bed in the absence of particles [6]. The measured minimum fluidizing velocity was 19 cm/s.

The target tube was consisted of six (6) circular wax segments, which was placed horizontally in the center of the fluidized bed with 5 cm of tube-to-distributor clearance. The sample tube was tested with bed materials of 0.55 mm glass beads. The test was continued for three(3) hours at a superficial fluidizing velocity of 67 cm/s. Results of specific weight losses for horizontal tube segments were plotted against excess air velocity as shown in Figure 3.

The results on specific weight loss versus excess air velocity diagram indicated a characteristic jump at threshold velocity (26 cm/s) slightly above the minimum fluidization velocity. It was increased with increasing superficial velocity.

Figure 3 Effect of Superficial Fluidizing Velocity at Different Tube Circumferential Section

The specific weight loss was found to be symmetrical about the vertical plane passing through the tube axis (i.e. results of segment nos. 2 and 6 are the same). The bottom section (section 1) of the test tube was found to experience a weight loss about 483% of that of top section (section 4) at excess air velocity of 62 cm/s (or superficial fluidizing velocity; 81 cm/s) as shown Figure 3. The weight loss of the side section (section 2) was found to be less than that of bottom section under same test condition. The trend of these results generally agree with other observations [6].

The observation was found that the upward movement of the solid particles was relatively rapid and the downward movement was slow. The particles spent most of their time moving downward slowly but occasionally are swept up to the top of the bed. A lateral pulsating movement of particles could be observed during downward flow, which was less pronounced during upward flow. Depending on the amount of solid in the bed and the fluidizing velocity, the averaged circulatory pattern [3] exhibited a upward flow at the center and downward flow near the wall; or multi-region flows of different combinations of the above cases.

For a shallow bed as in our bench-scale model, particles generally ascended rapidly in the central region and descended slowly along the wall region. As presented in previous technical report [1], the weight loss of an in-bed tube at low velocity (less than 26 cm/s for 0.55 mm glass beads) is effectively negli-

gible. In a shallow bubbling fluidized bed, tube erosion by downward-flow particles carried by fast moving air bubbles in core region.

2.2 Effect of Tube Orientation and Location

In order to study the effect of tube orientations on in-bed tube erosion, the experiments were conducted with wax cylinders mounted at the bed center. The test tube was arranged at four different inclined angles (0° , 30° , 60° , and 90°). For successive test runs, the sample tubes were also placed horizontally and vertically at the center, and vertically near the wall to quantify the effect of the tube location.

Figure 4 shows the averaged specific erosion rate for embedded tube in a bed with 0.55 mm glass beads at superficial fluidizing velocity of 67cm/s. The sample tubes were tested at the above bed conditions for 3 hours for different tube locations and orientations. The averaged specific erosion rates for 0° , 30° , 60° , and 90° , were found to be 0.58, 0.49, 0.34 and $0.27/\text{cm}^2 \text{ hr}$, respectively. Horizontal tubes were found to experience a weight loss about 215% of that of vertical tubes under same conditions. The specific erosion rate of the vertical tube near the wall as found to be only $0.15 \text{ mg}/\text{cm}^2 \text{ hr}$, being 55% of that of the tube in the core region. These results agree with other observations that the erosion rate of the horizontal tubes is more serious than the inclined and vertical tubes [7].

Figure 4 Effect of Tube Orientation and Location on In-Bed Tube Erosion Tube Size $1.7\phi \times 18 \text{ cm}$, T-to-D Clearance Measured based on the Bottom of Tube Center)

Results of the single tube erosion test were also plotted against the angular orientation as shown in Figure 4. The specific weight loss of a horizontal tube was 1.74 mg/cm^2 , which is about two times of that of a vertical tube near the wall. An influence of the tube orientation and location was more pronounced for the horizontal tube than for the inclined tube.

SECTION 3

Research Continuation

The project has been progressing well. Measurement of the particle-probe collision frequency will be continued to explore particle flow pattern/maximum erosion point by an electrostatic impact probe. In order to simulate the erosion phenomena of the in-bed tubes in FBC, carbon steel will be used at elevated temperature condition by FBC bed material particles.

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