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

to

U.S. Department of Energy
Pittsburgh Energy Technology Center
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for

Project No: DE-FG22-92MT92021

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April 1994

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SUMMARY

This technical report summarizes the research work performed and progress achieved during the period of January 1, 1994 to March 31, 1994.

The metal wastage mechanisms and rate that occur in 1018 carbon steel used in in-bed tube of the bubbling fluidized bed combustor (BFBC) are discussed with particle-surface collision frequency around tube. The distribution of particle-surface collision frequency around tube was affected by the location of tube and bed height. A series of material wastage tests was carried out using 742 μm , quartz silica (SiO_2) on 1018 steel at elevated temperature (300°C) which occurs in-bed locations of BFBC.

The morphologies of the specimens were examined and analyzed by scanning electron microscopy (SEM) and energy-dispersive spectroscopy (EDS). The maximum collision frequency around the periphery of the tube was found at 45° , 315° from bottom center, 0° , which was correlated with maximum material wastage rate of the specimens.

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1. Introduction

Fluidized bed combustors (FBCs) are of continuously increasing interest as an attractive alternative to conventional stoker-type boilers because of their attractive operation efficiencies and reliable method for direct combustion of high-sulfur, low grade coals in an economically and environmentally acceptable manner. In bubbling fluidized bed combustor (BFBC), in-bed tubes and components are widely used to enhance the heat and mass transfer, and to control the combustion temperature and bubble size [1]. Material wastage of surfaces by impingement of bed materials has been gradually recognized as one of the major areas of uncertainty in transplanting the FBC technology to actual power and heat generation processes. The underside of horizontal in-bed tube bundle and lower tube bends of slanted or vertical bundles usually experience the heaviest erosion in the fluidized [2-4].

In general, the extent of surface wastage by the impingement of abrasive particles depends on the nature of target tube material (such as material properties, tube orientation and curvature, and surface condition), properties of the impacting particles (such as particle type and grade, mechanical properties, size and sphericity), and system operation conditions (such as particle impinging velocity, collision frequency, impact angle, and operation temperature and pressure). Experimental results in a room-temperature fluidized-bed wear test rig found that the major mechanism of metal wastage of in-bed tube was that of solid particle impact erosion at low particle velocities (less than or

equal to 2 m/s) with a relatively small amount of three-body abrasion occurring [5]. Besides the material properties of target tubes and impinging particles, the flow particles, such as, particle impinging velocity and angle, and number of impacts per unit time (or collision frequency) are the primary factors. In order to explore the effect of collision frequency of flowing particles on material wastage of in-bed tube, a new electrostatic probe was designed and tested in this study.

In order to simulate material wastage of in-bed tube of BFBC, laboratory tests focused on wastage of tube material (AISI 1018 steel), using quartz silica (SiO_2) at elevated temperature (300°C) under generally oxidizing conditions. Since 1018 steel is commonly used in in-bed tubes of BFBC.

2. Experimental test conditions

2.1 Instrumentation for particle-tube collision frequency measurement

For the measuring of particle-tube collision frequency, a bench-scale cold fluidized bed system was used [6]. The instrumented tube probe was designed to simulate the embedded tube for measuring the maximum wastage loss as discussed previous reports [6]. The aluminum tube used as shielding and supporting stem. One 0.7 mm copper sensor tip was glued on tube surface. This design is to provide measurement of particle-tube collision frequency at peripheral location of the tube. The working principle of impact probe was tested and the measurement error assessed. No signals were generated when there were not direct contacts between the probe and the particles. When pressurized air jet from a compressor was suddenly directed to the probe sensor tip, no electrical signals were generated by this impulse force, either. This demonstrated that the vibration of probe tip caused by particles impact will not result in signals. Three different types of impact probes were also used to measure the collision frequencies along the major flow directions at various locations in the fluidized bed.

2.2 Instrumentation for metal wastage measurement

In order to simulate material wastage of in-bed tubes in the BFBC [7], the tests were carried out in the elevated temperature blast nozzle type of tester as shown in Figure 1. Air was utilized as the carrier gas for the particles, creating a generally oxidizing atmosphere. Erodent particles flow down a vibrating

Fig. 1 Schematic diagram of elevated temperature material wastage tester.

tube into a chamber where they are mixed with incoming heated air. The velocity of the heated air propels the particles down a nozzle where they impact the specimen. Temperatures from 20°C to 850 °C were achievable with a temperature variation not exceeding 10 °C over the test range. Particle velocity was established by setting a pressure drop across the nozzle using a meeting system that was connected to an air compressor. The air pressures were determined by using a calculation program of two-phase particulate flow [8].

The target material for the test was AISI 1018 plain carbon steel, which is commonly used in in-bed tubes of BFBC. Quartz silica (SiO_2) particles with an average 742 μm was used for erodent material, which is constituent of bed materials. Figure 2 shows an appearance of Si O_2 quartz particle and particle size distribution. All tests were carried out at test temperature of 300 °C and at impact angles of 30°, 45°, 90°. A test time of 96 hours was used at a particle loading of 9000 g at a particle velocity of 2.5 m/s. The material wastage of the specimen was predicted by weight measurements, which was weighed after test period on a balance with a resolution of 0.1 mg. The metal wastage of the specimen was also determined by microscopic dimensional measurements of cross-sections through the area of greatest metal loss to determine the thickness of the remaining sound metal. This experiment was conducted by collaborative efforts of private sector, which is Metallurgical Laboratory of Metal Spray, Inc. in Richmond, Virginia.

Fig. 2a Particles appearance of SiO_2 quartz.

Fig . 2b Particle size distribution of quartz .

3. Results and discussion

3.1 Particle-tube collision frequency

Measurements of particle-tube collision frequency were conducted in the fluidized bed with a static bed height of 11 cm, an active bed height of 18.5 cm, and a superficial fluidizing velocity of 64 cm/s. The experiment with the probe traversing vertically along the bed axis was conducted. Figure 3 shows the axial distribution of particle-probe collision frequencies of ascending particles, descending particles, and laterally moving particles at the center of the fluidized bed.

As seen in Figure 3, the ascending particles exhibited a minimum collision at 3.5 cm above the distributor and a minimum collision at 11.5 cm. The descending particles exhibited two peaks (minimum collisions) and one valley. It is evident that the ascending-particles curve and descending-particles curve exhibited almost opposite behavior. The particular interest is the finding that almost all peaks and valley appeared in a consistent way at near locations Nos. 1, 2, and 3. At location of No.1 of Figure 3, the measured highest count of particle collision frequency is for the ascending particles. Therefore, the mean local particle velocity at location No.1 should be upward. Similarly, the mean local particle velocity at the location No.2 should move sideward, and at location No.3, the mean local particle velocity should point downward. In the dense fluidized bed, the averaged particle phase density remained roughly constant. The measured collision frequency thus indicated the particle

Fig. 3 Results of particle-probe collision frequency measured by I-, J-, and L-shape impact probe at different heights along the bed axis.

velocity which varies with the location of the bed, bubble velocity, and bubble distribution.

In order to identify the effect of particle impacts on material wastage of in-bed tubs, a series of measurements was conducted to determine the peripheral distribution of the collision frequencies. Measurements of collision frequencies at different circumferential locations were made by rotating the instrumented tube. These data were averaged values taken over 50 seconds of measurements with 0.55 mm glass beads at 64 cm/s fluidizing velocity.

It can be seen in Figure 4 that more particles collided on the lower half of tube than the upper half of tube. In the dilute freeboard, the measured collision frequency generally represented the particle phase density, which decreased rapidly with an increasing of the height. The highest particle impact was found at about 45° , 315° apart from the bottom center of the target tube, 0° as shown in Figure 4.

3.2 Metal wastage

For the low particle velocity (2.5 m/s), the oxidation of surrounding surfaces after 96 hours test period was combined with very low erosion wastage rates accounted for the weight gain of specimens tested at particle impact angles of 30° and 90° . At the low particle velocity, the oxide scale-particle deposition layer developed at elevated temperature condition (300°C), which caused less wastage loss as shown in Figure 5.

Fig. 4 Particle collision frequency of a horizontal tube immersed at superficial velocity of 64 cm/s.

Fig. 5 Material wastage of 1018 steel eroded at low particle velocity

Figure 6 shows the surfaces and cross sections of the specimens at three different particle impact angles for low particle velocity (2.5 m/s). It can be seen that a thin, continuous scale layer formed on the surface of the AISI 1018 steel specimens at the 30° and 45° while a discontinuous scale layer formed on the surface at 90° as shown in Figure 6. A great amount of erodent particles was also embedded in the worn surface as proven energy-dispersive spectroscopy (EDS) analyses. Figure 6 shows the different morphologies of surfaces at three different impact angles. The maximum material wastage was occurred at 45° of impact angle. When the thickness loss at 90° compared with that at 30° , thickness loss was increased from 8 μm to 14 μm .

Comparing Figs 4 and 5, a meaningful correlation between particle-tube collision frequency and material wastage can be clearly seen. These consistent results indicate that the bottom tube surface had the higher wastage rate due to the frequent particle impacts; while the top tube surface had lower wastage rate due to less particle collisions. It is known that the mass removal process of an embedded tube is directly affected by the number of particle impacts per unit time and the particle impact velocity. It is also considered that the great particle impact force experienced at the bottom of in-bed tube. The distribution of particle-tube collision frequency was found to be quite similar profile with material wastage rate.

(A) Eroded surface.

tested at $V=2.5$ m/s and $\alpha=30^\circ$.

(B) Cross-section.

(A) Eroded surface.

tested at $V=2.5$ m/s and $\alpha=45^\circ$.

(B) Cross-section.

(A) Eroded surface.

tested at $V=2.5$ m/s and $\alpha=90^\circ$.

(B) Cross-section.

Fig. 6 Surface, cross-section and EDS peak analyses of 1018 steel material wastage at low particle velocity, 2.5m/s.

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