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Progress Report for Research on

HEAT TRANSFER TO TUBES
IN FREEBOARD SPACE OF FLUIDIZED-BED COMBUSTORS

Period of

August 1, 1981 to January 31, 1982

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SCOPE OF THE PROJECT

The objective of the research is to carry out an experimental study of heat transfer characteristics for tubes located in the freeboard region of fluidized beds. The heat transfer coefficients will be measured and experimental techniques for determining solid-contact behavior on the surface of horizontal tubes will be evaluated. Data will be obtained for various bed particles over a range of fluidization air flow rates, and for a range of tube elevations. Tests will be performed in room temperature beds and in high temperature beds. The anticipated results are:

- (a) Experimental data for heat transfer in freeboard region for single tubes, at room temperature and at FBC operating temperatures;
- (b) Determination of effect of operating variables (gas velocity, tube elevation, particle size, particle density, etc.) on heat transfer coefficients;
- (c) Indication of possible experimental method for determination of dominant heat transfer mechanisms in freeboard region, from solid contact measurements, in room temperature bed;
- (d) Derivation of phenomenological models and correlations.

PROGRESS IN THE PROJECT

This is the third progress report covering the period of August 1, 1981 to January 31, 1982.

Task 1 Low Temperature Heat Transfer Experiments

The objective of this task is to obtain heat transfer data on a horizontal tube in the freeboard region of a fluidized bed, operating at room temperature. The results of these experiments will help in filling some of the informational gaps on developing a phenomenological model.

As mentioned in previous reports, the new fluidized bed and the new heat transfer probe has been manufactured and assembled. During this

progress report period, the heat transfer experiments and data reduction were completed. A schematic of the test setup is shown in Figure 1. The static bed height was held constant at 36 cm, except for the experiments for the effects of static bed height. The heat transfer tube was placed to the heights of 1.25, 19, 58, 147 and 224 cm above the bed. The 1.25 cm tube elevation was the one when the lower side of the tube just touched the top of the static bed. Immersed tube heat transfer coefficients were also measured (for glass beads of $\bar{d} = 300, 850 \mu\text{m}$) to compare with the heat transfer coefficients in freeboard region. Glass beads with 300, 850 μm mean diameters and sand with 285, 465 μm mean diameters were used as fluidizing particles. High gas velocities were reached up to 3.5 m/sec. The heat transfer probe was capable to measure local heat transfer coefficients at eight locations that are 45° apart from each other. The average heat transfer coefficients were then calculated by integrating the local values.

A sample of experimental results for the variation of local heat transfer coefficient around the heat transfer tube for glass beads with mean diameter 300 μm is shown in Figures 2a and 2b for low and high air flow rates. These experiments were also carried out for 850 μm mean diameter glass beads and 285 and 465 μm mean diameter sand.

Average heat transfer coefficients were calculated from above mentioned local experimental data. Effects of tube elevation and gas flow rate on average heat transfer coefficient is shown in Figure 3 for glass beads with mean diameter of 300 μm . Experimental results for average heat transfer coefficient versus tube elevation are shown in Figures 4 and 5 for two different gas flow rates.

Effect of static bed height on heat transfer coefficient was also investigated by changing the static bed height. These experiments were carried out with only sand particles with mean diameters of 465 μm . Three different static bed heights were used which were 18, 36 and 72 cm. The heat transfer tube was 19 cm above the static bed for each of these bed heights. The results are shown in Figures 6 and 7 which indicate that heat transfer coefficients do not vary much after 36 cm bed height for all the gas flow rates.

Task 2 Dynamic Contact Experiments

The capacitance probe technique was utilized in order to obtain measurements of dynamic contact of bed particles on the tube surface. These tests were carried out at three different angular positions, $\beta = 0^\circ$, 90° and 180° , for GT-5, $d = 850 \mu\text{m}$, particles. The information will be used on developing a phenomenological model for the heat transfer process, for horizontal tubes in freeboard region of FBC's.

The capacitance sensed by the probe is proportional to the dielectric constant of the fluidized medium local to the probe electrodes. The dielectric constant in turn depends on the local void fraction. Thus, a capacitance trace versus time can be directly related to the variations in local solids density at the tube surface. The measured capacitance signals were calibrated relative to an upper bound corresponding to the capacitance measured when the probe is immersed in a loosely packed static bed of particles, and a lower bound corresponding to the capacitance sensed when the probe is fully exposed to air. This calibration process was repeated at least for air (lower bound) before each experiment.

Examples of typical capacitance signals obtained with an instrumented horizontal tube immersed in a fluidized bed are shown in Figures 8a, 8b, and 8c. These data were obtained for fluidization at atmospheric pressure. Figure 8a shows periodic particle contact at the bottom of the tube, for a gas flow rate corresponding to just above the fluidization flow rate. When the flow rate is increased, particles reach higher elevations and the bottom surface contact behavior is shown in Figure 8b. The particle surface contact behavior at the side of the tube is shown in Figure 8c.

Samples of the reduced data are shown in Figures 9 and 10. Figure 9 shows the variation of local voidage as a function of gas velocity, for different tube elevations and angular positions. Local residence times of particles on the tube surface is shown in Figure 10 as a function of gas velocity for different tube elevations and angular positions.

Task 3 High Temperature Heat Transfer Experiments

An instrumented heat exchanger has been designed and fabricated to measure the average heat transfer coefficients at different elevations in

the freeboard region. The heat exchanger will be assembled into the high temperature fluidized bed facility and the tests will be carried out during the next report period.

Figure 1 Flow diagram for the fluidized bed test unit

Figure 2a Local heat transfer coefficient around the tube in freeboard region for $U_{sg} = 0.166 \text{ m/sec}$

Glass beads, $\bar{d}_p = 300 \mu\text{m}$
 $\square$ 0 cm Tube elevation
 $\circ$ 58 cm "
 Δ 147 cm "
 $+$ 224 cm "

$$U_{sg} = 2.50 \text{ m/sec}$$

Figure 2b Local heat transfer coefficient around the tube in freeboard region for $U_{sg} = 2.50 \text{ m/sec}$

Figure 3 Freeboard heat transfer coefficients for glass beads with 300 μm mean diameter

Figure 4 Variation of average heat transfer coefficient in the freeboard, at superficial gas velocity, $U_{sg} = 1.5 \text{ m/sec}$

Figure 5 Variation of average heat transfer coefficient in the freeboard, at superficial gas velocity, $U_{sg} = 2.5 \text{ m/sec}$

Figure 6 Effect of static bed height on heat transfer coefficients

Figure 7 Effect of static bed height on heat transfer in freeboard region of the bed

Figure 8a Capacitance signal at $U_{sg} = 0.53$ m/sec gas velocity for GT-5, $d_p = 850$ μm , at the bottom of the tube, $\beta = 180^\circ$. Tube just touches to the bed, $H = 1.25$ cm

Figure 8b Capacitance signal for GT-5, $\bar{d}_p = 850 \mu m$ at gas velocity $U_{sg} = 2.55$ m/sec, at the bottom of the tube, $\beta = 180^\circ$. Tube is 19 cm above the static bed

Figure 8c Capacitance signal for GT-5, $\bar{d}_p = 850 \mu\text{m}$. At the second tube elevation, $H = 19 \text{ cm}$

Figure 9 Local bed voidage as a function of gas velocity

Figure 10 Local residence times of particles on the tube surface