Temperature Distribution Around Heated Horizontal Jet in Fluidized Bed

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The introduction of reactant gas into a fluidized bed as a jet is a common design practice. The rate at which the reactant gas disperses into bed field gas can have a significant effect on selectivity, yield and local catalyst temperature. Therefore, a description of the shape and extent of the coherent jet or void within the bed as a function of the jet inlet properties would be a useful design tool.

In a previous study (Chen and Weinstein, 1993) in which the literature was reviewed, the authors determined the shape and extent of the void formed by a horizontal jet using X-ray imaging. The void fraction distribution around the jet and the tracks of the bubbles formed by the jet gas leaving the void were described. In the present study using the same experimental facility, the horizontal jet was heated and temperature surveys were obtained in the bed. These data provide a comparison of the picture of the jet structure obtained from the spread of the heated gas with that previously obtained from the spread of the jet momentum. In addition, in the present study the superficial velocity of fluidizing gas (through the grid) was varied to determine its effect on the jet penetration and dispersion.

Experimental Studies

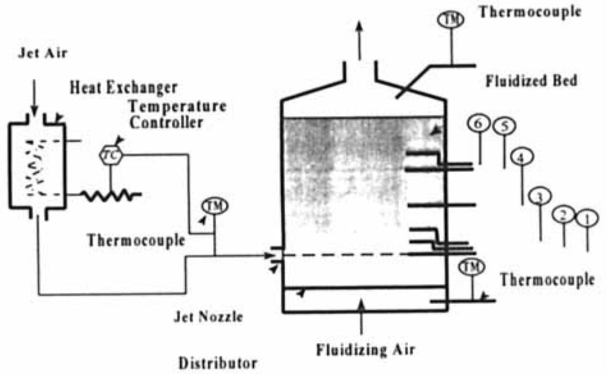
The experimental work was conducted in the CCNY jet penetration studies facility, which was described in detail in the previous study (Chen and Weinstein, 1993). The supplementary apparatus employed in the present work is a temperature measurement system, as shown in Figure 1. The jet air, which was discharged horizontally through a circular nozzle into the bed, was heated by two independent heating coils. A temperature controller, responding to a thermocouple placed upstream of the jet nozzle, maintained the heated jet at a desired temperature. Thermocouple (TC) probes were also positioned in the windbox and the freeboard of the bed to track air temperatures at the inlet and the outlet.

A set of traversable TC arrays [copper-constantan, 1/16 in. (1.6 mm) diameter], located through the wall opposite to the jet nozzle along the height of the bed, was used to measure the temperature distribution in the jet flow region. The locations of the thermocouples are shown in Figure 2. Three TC arrays were mounted horizontally along the bed vessel at elevations of 0, 2 and 4 in. (0, 50.8 and 101.6 mm) from the axis of the jet nozzle. The arrays at 0 and 4 in. elevations were rotatable about their axes so that measurements across the bed thickness could also be made to demonstrate bed uniformity in the transverse direction.

Data were obtained with each of two circular jet nozzles of 0.64 cm and 1.27 cm diameter. Three jet velocities were investigated with each nozzle and the fluidizing gas superficial velocity was also varied from 0.03 m/s to 0.21 m/s. The solid was an FCC cracking catalyst with a density of 1.45 g/cm^3 and a mean diameter of 60 μm.

Results and Discussion

The measurements made with the thermocouple traverses provided the temperature field in a vertical plane containing the jet axis. Measurements made by rotating the lower and upper TC arrays 90° demonstrated that there were no temperature gradients across the plane of the temperature map. A typical map of normalized temperature is shown in Figure 3. The normalized temperature $\overline{T}$ is the local measured temperature minus the windbox temperature divided by the ini-



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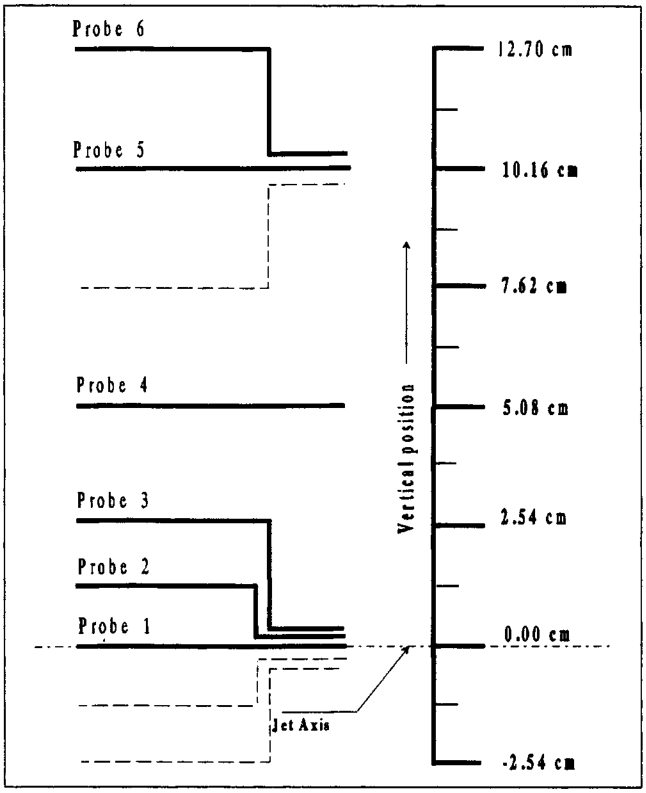

Figure 2. Vertical positions of the thermocouple probes (1)–(6) in Figure 1.

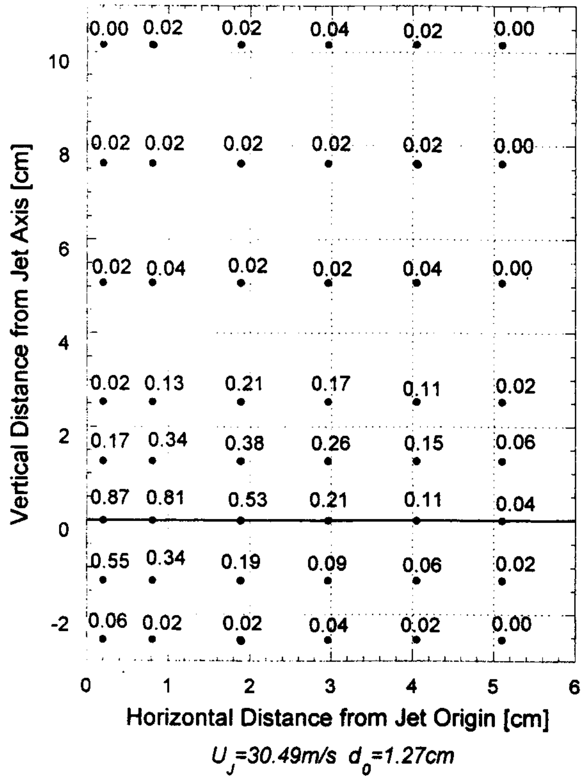

Figure 3. Normalized temperature distribution from a heated jet in a fluidized bed with a superficial velocity of 0.03 m/s.

tial jet temperature minus the windbox temperature. Even with a jet velocity of over 30 m/s, the jet begins to bend upward a few centimeters from the nozzle.

This temperature map shows considerable agreement with the flow field described in Chen and Weinstein (1993). There is a region of high temperature above the jet which marks the bubble train leaving the upper surface of the jet at about 2 cm from the jet entry wall. This confirms that bubbles do not typically leave from the horizontal end of the jet which is about 7 cm from the wall. Also, the zone below the jet is heated to relatively high temperature which is consistent with the existence of a fairly stagnant catalyst compaction zone below the jet which is formed by the gas entrained through the zone into the jet.

A plot of normalized temperature along the jet centerline vs. distance from the nozzle for 6 runs at a single gas superficial velocity, 0.03 m/s, is shown in Figure 4. The profiles exhibit a generally similar shape, but it is clear that $\overline{T}$ at a given distance is strongly dependent on both parameters, jet diameter, and jet velocity. A collapse of all these profiles was obtained by dividing the distance by the initial jet velocity to give a "time of flight" variable and plotting the product of the natural logarithm of $\overline{T}$ and the jet nozzle diameter against it. The fit of these six profiles to a single straight line is shown in Figure 5. The fit is quite good.

The correlation extended to data for the other two superficial gas velocities is shown in Figure 6. The agreement for the 0.03 m/s data and the 0.09 m/s is again quite good, while that for the 0.21 m/s data is poor. This can be explained to some extent by the observation that the bubbles in the 6-in

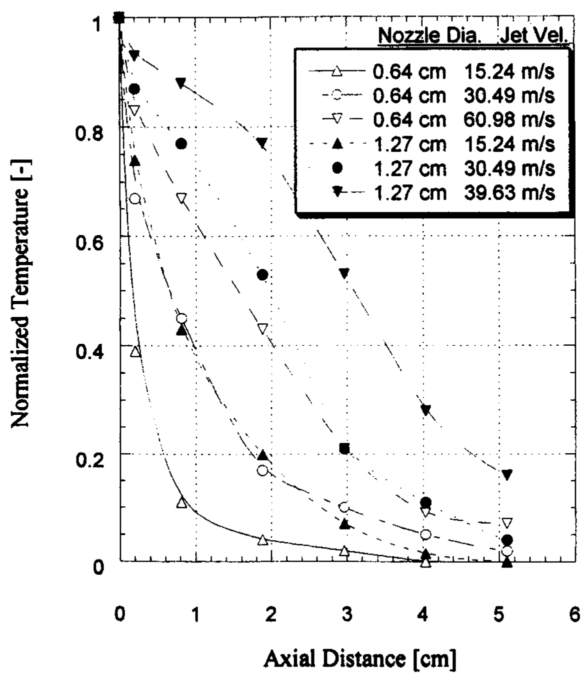

Figure 4. Normalized temperature profiles for horizontal jets in a fluidized bed with a superficial velocity of 0.03 m/s as a function of distance from the nozzle wall.

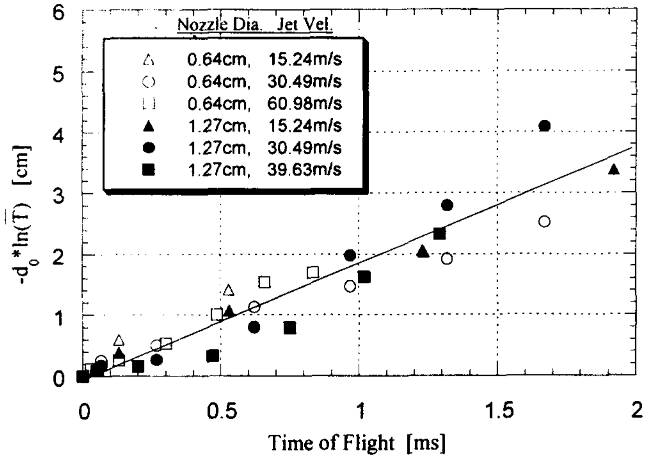

Figure 5. Correlation between $-d_0 \times \ln[\bar{T}]$ and time of flight for a horizontal jet in a fluidized bed with a superficial velocity of 0.03 m/s.

(152.4-mm)-thick bed exhibited wall controlled behavior at 0.21 m/s superficial velocity. The correlation can be expressed as $\bar{T} = \exp[-1.75 \times 10^3\ t_f/d_0]$ for superficial gas velocities of 0.03 and 0.09 m/s.

The jet penetration length (L(m)) for the temperature data was defined by the horizontal distance from the jet origin at which $\bar{T}$ reached a value of 0.02. This is about equivalent to the definition of penetration length used for the X-ray data which was obtained with a superficial velocity of 0.04 m/s (Chen and Weinstein, 1993). The jet penetration lengths for

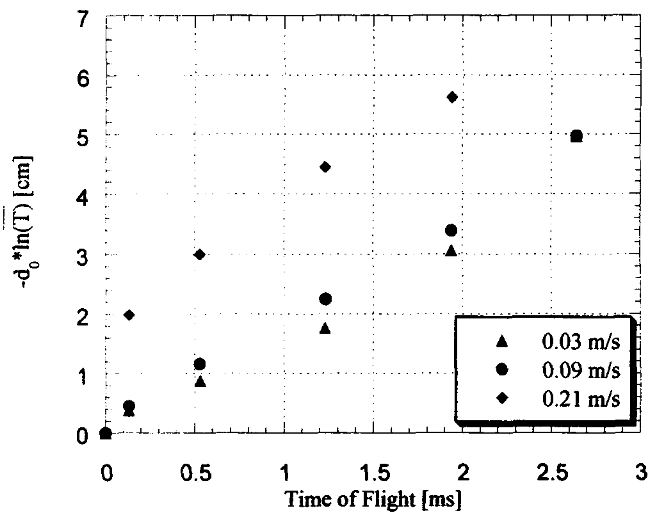

Figure 6. Correlation for $-d_0 \times \ln[\bar{T}]$ vs. time of flight with superficial velocity of as parameter.

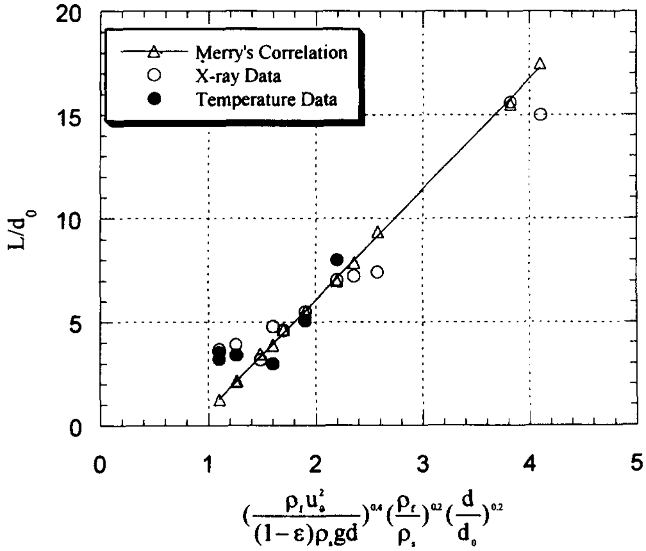

Figure 7. Comparison of experimental data for jet penetration length with the correlation of Merry.

the temperature data at 0.03 m/s superficial velocity and the X-ray data are compared to Merry's correlation (Merry, 1971) in Figure 7. [ρ_f is the density of the gas and ρ_s is the density of the solid particle. ϵ is the void fraction, d_0 is the jet diameter, and d is the particle diameter all in consistent units.] The agreement of all the data with the correlation is remarkably good. The conclusion, then, is that the correlation of Merry will give reasonable estimates of horizontal jet penetration lengths for bubbling fluidized beds and is applicable to both velocity and temperature fields.

Acknowledgment

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Notation

d_0 = jet diameter, cm
g = acceleration of gravity, m/s^2
t_f = time of flight, distance from the jet nozzle divided by the initial jet velocity, seconds
u_0 = superficial gas fluidizing velocity, m/s

Literature Cited

Chen, L., and H. Weinstein, "Shape and Extent of the Void Formed by a Horizontal Jet in a Fluidized Bed," *AIChE J.*, **39**, 1901 (1993).

Merry, J. M. D., "Penetration of a Horizontal Gas Jet into a Fluidized Bed," *Trans. Instn. Chem. Eng.*, **49**, 189 (1971).

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