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DYNAMIC SEPARATION OF SUSPENDED SOLIDS

Allen T. Hjelmfelt, Jr., Ph. D.

University of Missouri
Columbia, Missouri, U. S. A.

Jae Duk Lee, M. S. C. E.

Leo A. Daly Co.

San Francisco, California, U. S. A.

Summary

A pilot study of a dynamic means of separating suspended solids from a two-phase flow is described. The separation is achieved by passing the two-phase flow through an orifice. The difference in mass between the suspended solids and the fluid causes the path lines of the solids to deviate from the fluid streamlines when flowing through the abrupt contraction. Withdrawal of the center portion of the jet issuing from the orifice results in a primary separation of the solids from the fluid. The utility of this separation technique is indicated.

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NOMENCLATURE

C = concentration of solids at a point in the flow.
$\bar{C}_i$ = average concentration inside a core of diameter d_i.
$\bar{C}_o$ = average concentration outside a core of diameter d_i.
$\bar{C}_t$ = average concentration of total flow.
d_i = diameter of core region under consideration.
d_o = diameter of orifice.
d_t = diameter of jet at vena contracta.
M = mass flow rate of solids.
M_o = mass flow rate of solids outside a core of diameter d_i.
V = velocity of flow at vena contracta.

1. INTRODUCTION

A discrete particle transported by a fluid with a density different from that of the particle will not follow the fluid streamlines at all times. The forces causing convective acceleration of the fluid act equally on the fluid and the discrete particle, but the particle response is different in magnitude than the fluid response due to the difference in mass. Flow through a contracting section is an example of a boundary geometry resulting in convective acceleration.

Forcing a homogenous two-phase flow through a contraction can be expected to result in the fluid and the particle pathlines being noncoincident and producing a nonhomogenous mixture. Extraction of an appropriate portion of the flow downstream from the contraction should yield a portion with a solids concentration different from that of the original homogenous mixture.

To test the validity of the separation concept outlined above, an experimental investigation was initiated at the University of Missouri-Columbia, Missouri, U.S.A.

2. EXPERIMENTAL STUDY

The concentration distribution in the jet resulting from passing a two-phase flow through a contraction was investigated experimentally. A sand-water mixture flowed through a two-inch plastic pipe which terminated at an orifice with a 0.76 inch diameter. A schematic diagram of the test system is shown in Figure 1.

The inner portion of the jet was separated from the outer portion by inserting a probe, shaped like a truncated cone, into the jet at the vena contracta (see Figure 2). The portion of the jet flowing through the probe was captured and the concentration of solids determined. The process was repeated using eight different probe diameters to give a measure of the concentration distribution across the jet.

The concentration was determined by measuring the volume of the trapped mixture and by drying and weighing the sand. The flow velocity was measured using an orifice. Three different flow velocities were tested.

The results of the tests are summarized in Table 1. Each tabulated result is the average of at least five replicate tests. The average concentration of the total flow was maintained at 0.00660 gm./c.c.

3. ANALYSIS OF TEST RESULTS

A quick scan of the test results given in Table 1 indicates that the average concentration in the inner portion of the jet is greater than the average concentration for the total jet. It does not, however, give an indication of the utility of the process for separation of the solid phase from the fluid phase of the flow. In the material that follows two measures of the separation achieved and one measure of the utility of the system will be presented.

A diagram of the concentration at a point in the flow as a function of radius from the jet centerline is desirable. Point concentrations were not measured, however. The solids concentrations given in Table I are average values for central portions, or cores, of various diameters. The average concentration of an annular region can be determined from the measurements. Let $\bar{C}_i$ be the concentration of a core of diameter d_i and let $\bar{C}_{i+1}$ be the concentration of a core of diameter d_{i+1}. The material flowing through the two cores is

$$M_i = V\pi \frac{d_i^2}{4} \bar{C}_i \tag{1}$$

$$M_{i+1} = V\pi \frac{d_{i+1}^2}{4} \bar{C}_{i+1} \tag{2}$$

The material flowing through the region contained by d_{i+1} but outside of d_i is

$$\Delta M = M_{i+1} - M_i = (d_{i+1}^2 \, \bar{C}_{i+1} - d_i^2 \, \bar{C}_i) \frac{\pi}{4} V \qquad (3)$$

The point concentration distribution determined in this manner is indicated in Figure 3.

The figure indicates that the concentrations are generally higher toward the center of the jet than near the edges. The maximum concentration does not, however, occur at the centerline in all cases. Use of an orifice as the contraction device is assumed to be the cause. To go through the orifice the flow must first bend toward the centerline. The flow then curves away from the centerline as it approaches the vena contracta. This results in two separations, one causing the particles to move toward the boundaries and the other to move the particles toward the centerline. If this explanation is correct there should be a better geometry for the contraction which will provide better separation.

An alternative indication of the separation is to compare the average concentration in the core to the concentration in the outer portion of the jet. The material flowing through the outer portion is

$$M_o = \bar{C}_t \pi \frac{d_t^2}{4} V - \bar{C}_i \pi \frac{d_i^2}{4} V \qquad (5)$$

and the average concentration in the outer portion is

$$\bar{C}_o = \frac{M_o}{\frac{\pi}{4} V (d_t^2 - d_i^2)} = \frac{C_t d_t^2 - C_i d_i^2}{d_t^2 - d_i^2} \qquad (6)$$

Thus, the concentration ratio is

$$\frac{\bar{C}_o}{\bar{C}_i} = \frac{\frac{\bar{C}_t}{\bar{C}_i} - \left(\frac{d_i}{d_t}\right)^2}{1 - \left(\frac{d_i}{d_t}\right)^2} \qquad (7)$$

This concentration ratio as a function of core diameter is shown in Figure 4.

The object of separation processes is to separate one phase from the other. With the process described herein one can capture all of the solids by capturing the whole jet. No separation is achieved in this case. One can capture none of the fluid by capturing none of the jet, but no particles are trapped in this case. A measure of the utility must measure the rate at which separation is achieved. Such a measure is given by

$$\text{Separative Capacity} = \left[\frac{\bar{C}_i}{\bar{C}_t} - 1.0\right] \left(\frac{d_i}{d_t}\right)^2 \qquad (8)$$

This quantity will be zero if a very small region at the center of the jet is all that is retained, because no flow will be saved. It will also be zero if the entire jet is caught, as there will be no separation. The separative capacity is graphed in Figure 5 as a function of the diameter of the core. The maximum separation rate is achieved by capturing a core with a diameter almost 0.8 that of the total jet.

4. CONCLUSIONS

The results of the experimental program indicate that separation does occur as hypothesized. Concentrations exceeding twice the initial concentration were measured, indicating a significant migration of solid material toward the centerline of the jet.

The tests indicate, as was initially assumed, that the orifice is not the optimal form of the contracting section. A carefully designed nozzle should result in greater separation.

5. ACKNOWLEDGEMENTS

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TABLE I

SUMMARY OF TEST RESULTS

d_t = 0.635(inch), C_t = 0.00660(gt/cc)

	d_i(inch)	$\bar{C}_i$(gr/cc)
Velocity = 13.7 ft./sec.	0.15	0.00980
	0.20	0.01005
	0.25	0.01034
	0.30	0.01058
	0.35	0.01041
	0.40	0.01032
	0.45	0.01002
	0.50	0.00971
Velocity = 14.6 ft./sec.	0.15	0.01148
	0.20	0.01115
	0.25	0.01132
	0.30	0.01150
	0.35	0.01125
	0.40	0.01093
	0.45	0.01040
	0.50	0.00980
Velocity = 16.0 ft./sec.	0.15	0.01362
	0.20	0.01310
	0.25	0.01273
	0.30	0.01235
	0.35	0.01101
	0.40	0.01143
	0.45	0.01076
	0.50	0.01010

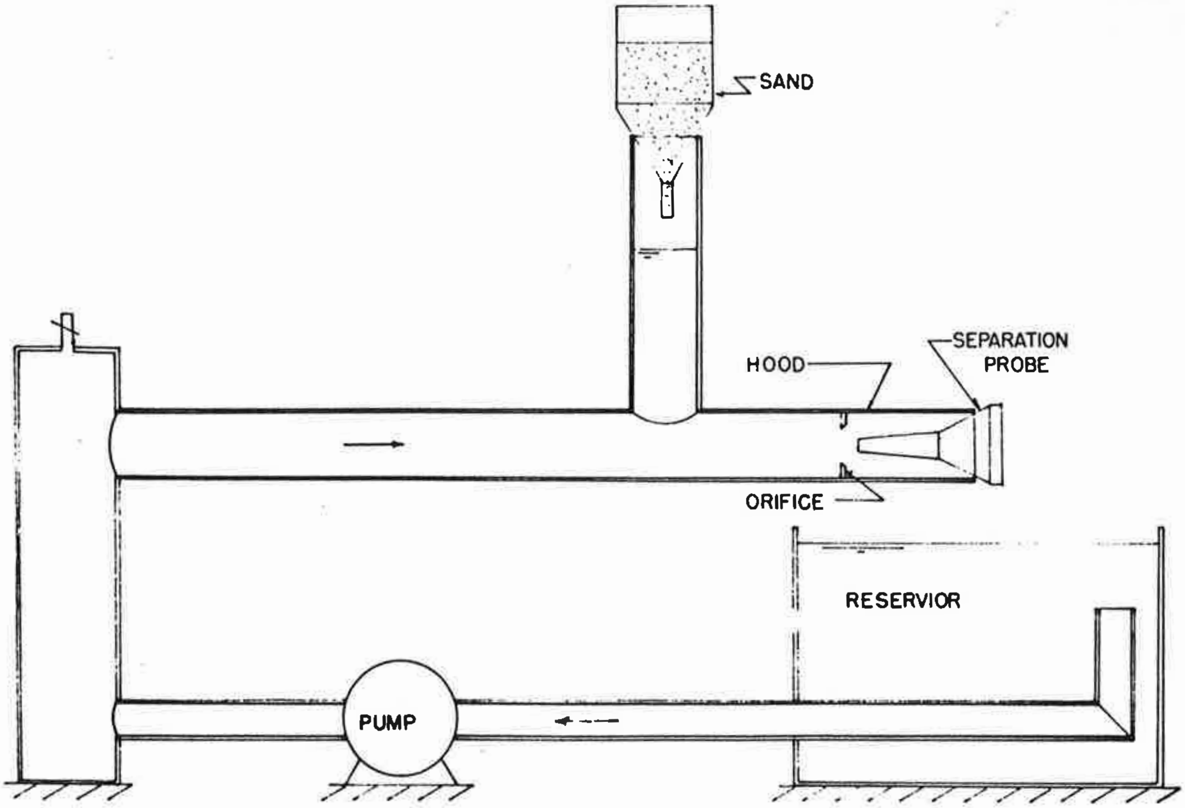

FIGURE 1: Schematic of test loop.

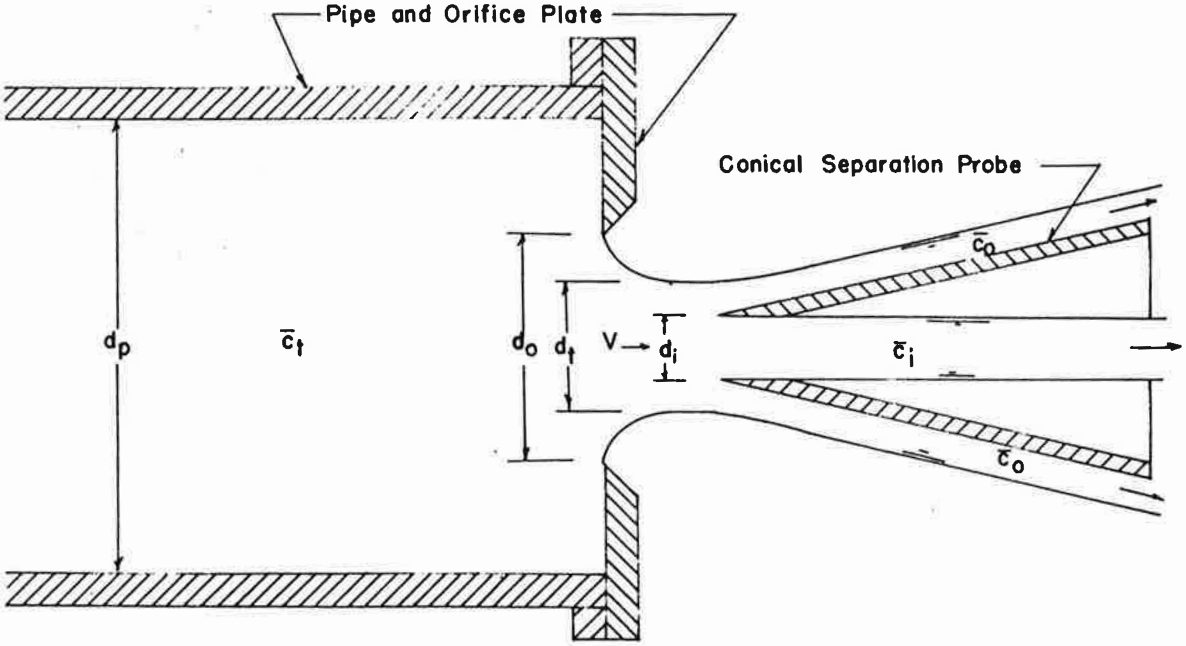

FIGURE 2: Diagram of pipe, orifice and separation probe.

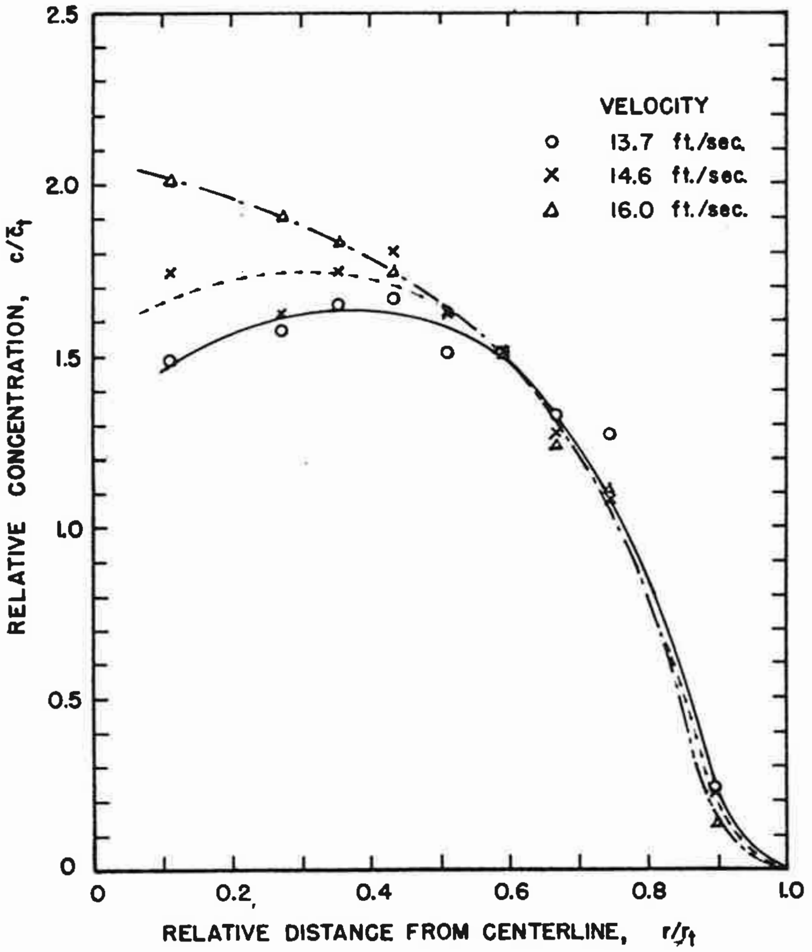

FIGURE 3:

Point concentrations in vena contracta as a function of radius.

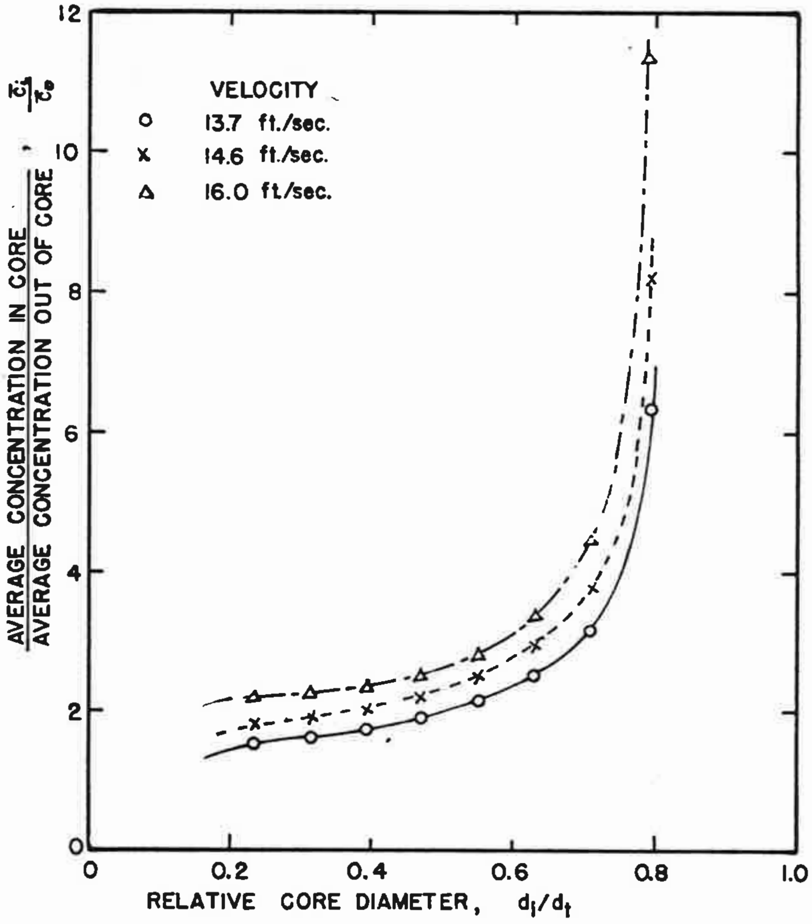

FIGURE 4:

Ratio of concentrations inside of core and outside of core for various core diameters.

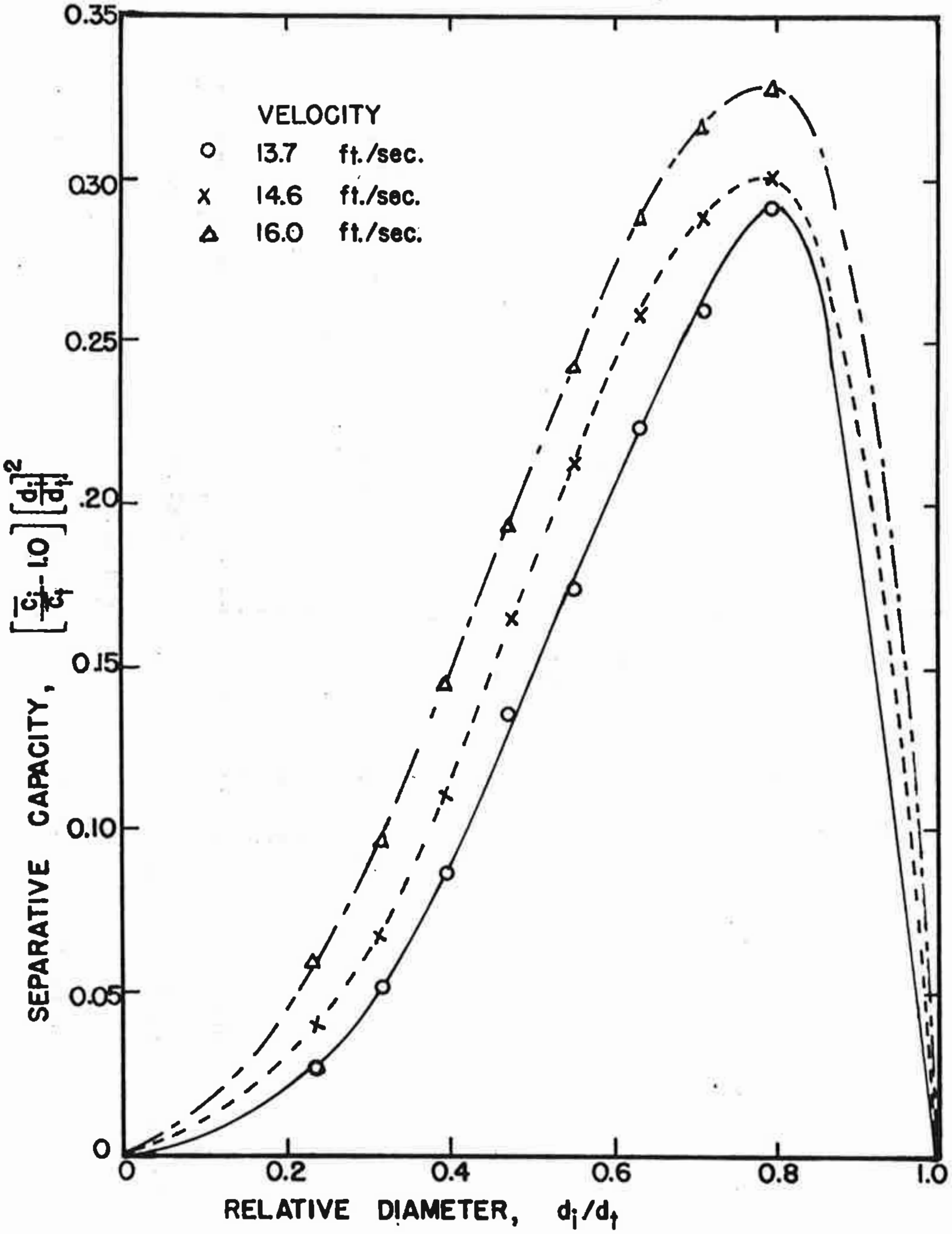

FIGURE 5: Rate of separation achieved by withdrawal of various portions of the jet.