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SUBJECT: ATMOSPHERIC PRESSURE SYSTEM FOR DETERMINING
RESUSPENSION VELOCITY OF THORIUM OXIDE SLURRIES
IN ROUND HORIZONTAL PIPES

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I. Introduction

Settled beds of particles may be resuspended by the exertion of hydrodynamic forces on the particles. Analysis of the action of these forces is complicated because the bed may have formed from either a flocculated or deflocculated system.^a The particles in a bed settled from a deflocculated system form a dense closely packed array that is resuspended one particle layer at a time. The particles in a bed settled from a flocculated system form a loosely packed array from which clusters of particles are removed by shear forces.³

II. Literature Review

Newitt, et al.¹ studied the hydraulic conveying of non-interacting solids particles in horizontal pipes and summarized similar work through 1954. Five distinct types of flow were observed for suspensions of 60 micron glass beads in 3/4-inch glass pipe:

- a. Fully suspended flow - all particles were in a fully suspended state.
- b. Suspended flow with a moving bed - in the upper part of the pipe the material was in suspension, while a bed of solids moved at a uniform rate in the lower part.
- c. Suspended flow with a layer of particles sliding over a stationary deposit - the upper part of the pipe contained suspended material and the lower part a deposit, the surface layers of which were moving in saltation.

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^aIn a flocculated slurry, the particles stick together in the form of a loose irregular clusters in which the original particles can still be recognized. In a deflocculated slurry, the particles repel each other and the original particles are not in contact.³

- d. Stationary deposit with superimposed ripples - only a small quantity of material was in suspension, but the particles constituting the ripples were moving in the direction of flow.
- e. Isolated deposits - lenticular deposits were distributed along the pipe and travelled slowly as in d.

These different types of flow are shown as a function of concentration for the glass beads (particle specific gravity 2.8) flowing in 3/4 ID glass pipe in Fig. 1. The effect of pipe diameter and particle diameter on the first three types of flow are shown in Fig. 2, where type "a" flow has been further divided into that for homogeneous and heterogeneous suspensions.^a The velocities corresponding to the transitions between these different types of flow are given by:

Homogeneous and heterogeneous flow

$$v_{hh}^3 = 1800 g_c D U_T \quad (1)$$

Heterogeneous flow and moving bed (types a and b)

$$v_{ab} = 17 U_T \quad (2)$$

Moving bed and stationary bed (types b and c)

$$v_{bc} = F_L \sqrt{2 g_c D \left(\frac{\rho_p - \rho}{\rho} \right)} \quad (3)$$

^a Homogeneous and heterogeneous flow may be differentiated by plotting pressure drop against velocity. If flow is homogeneous the characteristic curve will diverge from the water curve as the velocity increases due to the mean density being a linear combination of the fluid and particle densities. If flow is heterogeneous the characteristic curve will converge toward the water curve as the velocity increases, due to the increase of the mean fluid velocity relative to the particle settling velocity.

Perret has studied the resuspension of thorium oxide particles settled in 3/4 ID glass pipe.⁴ Those studies were made with one particular slurry at different concentrations. The first three types of flow listed were observed, and a plot (similar to Fig. 1) of the data for the critical velocity at different concentrations for the different types of flow is shown in Fig. 3. No data were given for the rheologic properties of the slurry or for the particle size distribution.

Wichner has proposed⁵ that the onset of type "b" flow can be correlated with the yield stress of the settled bed and that the onset of type "a" flow is a function of the Hedstrom number, N_H and the ratio of particle to pipe diameter. An apparatus containing 21 ft. lengths of glass pipe and a concentration probe was proposed to study resuspension velocities.

III. Discussion of Literature

The observations of Newitt et. al. provide a qualitative basis for understanding resuspension tests of non-interacting (deflocculated material) particularly when the particle size is greater than 30 microns. The data of Durand² indicate that the pipe diameter may enter Newitt's correlation raised to the 3/2 power (perhaps only for tests with rough pipe).⁶

The data of Perret indicate that a flocculated thorium oxide slurry may exhibit several types of flow in common with a deflocculated slurry. No data are available to indicate the effect of the rheological properties of the settled bed on the onset of different types of flow.

It appears that the important variables to study in attempting to generalize the results of Newitt for non-interacting particles are:

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1. Velocity
2. Particle diameter
3. Particle density
4. Pipe diameter
5. Liquid density
6. Liquid viscosity
7. Solid concentration
8. Particle shape
9. Pipe slope

In addition the effect of the rheological properties of the homogeneous suspension and the settled bed should be studied when working with a flocculated system.

IV. Proposed System for Studying Resuspension Velocities

The proposed resuspension velocity system is shown in Fig. 4 with details of the pressure tap shown in Fig. 5. The system is to be constructed of 1-inch ID copper tubing except for two 10-foot sections of the return line which are to be glass for visual observation. Pressure taps will be located at 10-ft. intervals along the 80 ft. of tubes, thus allowing pressure drop to be measured for many different length-to-diameter ratios. Diameter effects will be determined in succeeding series of tests with loops having different pipe diameters. A 100-gpm Moyno pump (from Y-12 salvage) with a steel rotor and medium-hard rubber stator will be tested for use in this system.

Calculations for a Newtonian slurry indicate that even at velocities as low as 0.1 ft. per second, there will be 1 cm. of mercury pressure drop over a ten-foot length of pipe. Non-Newtonian slurries can be expected to give appreciably higher pressure drops. Maximum velocity for turbulent flow in the 1-inch pipe will be about 25 ft/sec.

The particular advantages of the proposed system include:

1. The long lengths of pipe will allow accurate pressure drop measurements even at very low flow rates.

2. Two 10-foot long sections of glass pipe at either end of the 40-foot straight run of pipe will allow ample space for visual observation.
3. The weigh tank on the slurry stream will give an accurate measure of the velocity over the complete range of velocities to be studied.
4. Gamma surveys through the glass pipe with a well collimated counter should allow correlation of visual observations with experimental absorption profiles.

Settled bed characteristics will be studied in conjunction with the resuspension tests. Several different tests may prove useful in these studies. One test is to allow a slurry to settle into the bottom of a U-tube;⁸ the pressure required to flow the slurry out of the tube would be a measure of the average rheologic properties of the settled bed. These studies could be made at temperatures up to 300°C through use of an X-ray system similar to that being installed in the Chemical Technology Division for the study of slurry settling rates. Another test that appears to be significant is the force required to lift a rod around which slurry has been allowed to settle.⁷ These studies can be made in a modified dash-pot stirred autoclave with a more powerful solenoid coil and can be made at temperatures up to 300°C. Correlation of the force-time relationship observed in these tests with the resuspension measurements should allow generalizations on the effect of temperature on the resuspension characteristics of different slurry beds. A third test is to extrude the settled bed through an orifice in an extrusion rheometer.⁹ It does not appear easy to adopt this instrument for use at high temperatures.

NOMENCLATURE

D	=	Inside diameter of pipe	ft
F_L	=	Function of particle diameter given in Reference 2.	
g_c	=	Conversion factor	
N_H	=	Hedstrom number = $g_c \rho_s \tau_y D^2 / \eta^2$	Dimensionless
U_T	=	Terminal settling velocity of particle	ft/sec
V_{hh}	=	Transition velocity for flow either as a homogeneous or heterogeneous suspension	ft/sec
V_{ab}	=	Transition velocity for flow either as a heterogeneous suspension or flow with a moving bed	ft/sec
V_{bc}	=	Transition velocity for flow either as a moving bed or as a stationary bed	ft/sec
ρ_p	=	Particle density	lb/cu ft
ρ_l	=	Solution density	lb/cu ft
ρ_s	=	Suspension density	lb/cu ft
τ_y	=	Bingham plastic yield stress	lb/sq ft
η	=	Bingham plastic coefficient of rigidity	lb/(ft)(sec)

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Fig. 1 TYPES OF FLOW FOR 60 MICRON GLASS BEADS IN 3/4-INCH ID GLASS PIPE

Fig. 2 EFFECT OF SAND AND GRAVEL PARTICLE DIAMETER
ON FLOW CHARACTERISTICS IN 1 INCH AND 6 INCH
DIAMETER PIPES

Fig. 3 TYPES OF FLOW FOR AQUEOUS THORIUM OXIDE
IN 3/4 INCH ID GLASS PIPE

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Fig. 4 SYSTEM FOR SLURRY RESUSPENSION STUDIES

Fig. 5 SLURRY TRAP FOR MANOMETER LINES

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