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SUBJECT: Comments on the Angle of Repose of
Aqueous ThO_2 Slurries

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FROM: D. G. Thomas

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COMMENTS ON THE ANGLE OF REPOSE

I. ~~Summary~~

Questions about the angle of repose^a of settled beds of aqueous thorium oxide slurries have arisen in connection with the design of the lower portion of the blanket pressure vessel and its associated piping. The literature review on the angle of repose of various dry solids by Mrs. B. S. Neumann in J. J. Hermans' book on "Flow Properties of Dispersed Systems" is summarized. Mrs. Neumann points out that both a dynamic and static angle of repose have been observed with the angles for dynamic systems being larger than for static systems. Results are reported for two different types of experiments with slurry discharged⁴ from run 200A-14 which gave static angles of repose of 45 to 50° and dynamic angles of 65 to 75°.

^a All angles reported will be measured from the horizontal.

II. LITERATURE REVIEW

A. Static Angle of Repose

B. S. Newmann¹ reported results of measurements of the static angle of repose for a variety of powders; these are shown in Table 1. The tests were made by pouring the powder into a small funnel rigidly supported a known distance from a plane surface. The flow of powder was stopped when the top of the powder heap touched the bottom of the funnel. The bottom area of the pile was then outlined in pencil. The angle of repose was calculated from the diameter of the base and the height of the powder heap. Data in Table 1 also include the "tap density" of the settled bed and the external particle surface area as determined by air permeability methods. Apparently the static angle of repose increases as the particle size is decreased, with Mrs. Neumann believing that the scatter for materials g, h, and i, was due to the smooth faces and sharp edges of the often crystalline particles.

It is of interest to note that the determination of the amount of 60 - 100 mesh sand that had to be added to these powders to produce free flow through a 1/8-inch hole gave results that correlated rather well with the angle of repose. (Table 1). Apparently the mechanism involved in the production of the free flowing powder was the coating of the large particles with the fines, thus preventing the bonding of large flocs by these fines.

TABLE 1

STATIC ANGLE OF REPOSE FOR A VARIETY OF DRY POWDERS

Material	Tap Bed Porosity	Permeability Surface Area, $\frac{10^3 \text{ cm}^2}{\text{gram}}$	Per Cent Sand required to produce free flow	Angle of Repose ^a
a Microspheres	0.585	2.0	0	27.7
b TiO ₂	0.777	6.0	26	38.9
c Flour	0.555	7.0	30	41.0
d Natural fullers' earth	0.596	8.0	25	42.3
e Activated fullers' earth	0.756	17.5	60	43.9
f Refined Kaolin	0.880	24.0	1200	45.2
g CaF ₂	0.335	0.9	0	31.0
h Na ₂ CO ₃	0.688	2.5	23	42.6
i Cement	0.523	5.0	100	44.8

^a Measured from the horizontal.

B. Dynamic Angle of Repose

Brown and Hawksley² studied the efflux of particles through a hole in a plate by means of two-dimensional models and found four different flow regimes (Fig. 1).

Fig. 1 Flow Pattern for Free Flow of Sand Through a Hole

- A. Fast Moving Particles
- B. Slower Moving Particles
- C. Particles Moving Downward and inward, fed by region B.
- D. Tongue of intense movement

The top of surface A was inclined at a steeper angle than the static angle of repose and was defined as the dynamic angle of repose.

Brown³ showed that by fixing a few widely spaced horizontal rods inside the vessel described above the flow pattern became essentially slug flow with all the particles having similar velocities.

III. ANGLE OF REPOSE OF SETTLE BEDS OF ThO_2

The slurry discharged⁴ from run 200A-14 was allowed to settle for periods of 24 to 48 hours on a stainless steel plate 2 inches square. The settled bed depth was about 1 inch. The plate and the settled bed it supported was lifted vertically upward and, while still submerged, the included angle between the slurry remaining on the plate and the horizontal was found to be $68 \pm 12^\circ$. The submerged plate was tilted and the angle between the plate and the horizontal at which the slurry started to slide was found to be $47 \pm 6^\circ$.

In lifting the flat plate there was a movement of slurry from the top surface corresponding qualitatively to the definition of the dynamic angle of repose. Tilting the plate until movement was initiated corresponds most closely to the measurement of the static angle of repose. It is interesting to note that the value of 47 degrees agrees very well with the asymptotic static angle of repose of 45 degrees observed by Neumann on studies with dry powders.

One further observation related to the dump problem. A four-liter graduate containing four liters of 200A-14 slurry of concentration 2700 g Th/kg H_2O was thoroughly stirred and then the slurry was poured as rapidly as possible into a funnel containing a 1/2-inch spout, the graduate ultimately being held upside down and gently shaken. Of the order of 2 wt. per cent of the solids remained at the conclusion of the "dump." Thus, an additional problem beyond the application of the angle of repose is the determination of the residual slurry left on the walls of a container at the conclusion of a dump.

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