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with 28 Micron 1600°C Fired ThO₂ Spheres
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LOW ATTACK RATES OBSERVED IN TOROID TESTSWITH 28 MICRON 1600°C FIRED ThO_2 SPHERES

D. G. Thomas

I. EXPERIMENTAL RESULTS

On March 22, 1957, the slurry corrosion group reported toroid tests with 28 micron ThO_2 spheres which had been fired at 1600°C and which gave essentially zero attack.¹ These results were confirmed in a duplicate test reported on May 3, 1957.²

The experimental conditions in these tests were:

1. Slurry concentration, 500 g Th/kg H_2O .
2. Mean particle diameter (after firing at 1600°C), 28 microns.
3. Rotational speed, 960 rpm (solution velocity 26 ft/sec).
4. Tube diameter, 1/2 in.
5. Toroid diameter, 8 in.
6. Duration of test, 300 hr.

The experimental results were:

1. Pin wear less than 1 mill per year.
2. No attack at base of pin.
3. Iron pickup from wall less than 1 mill per year.
4. No degradation of sphere particles compared with almost complete degradation observed with unfired spheroids.

These results indicate that the oxide particles were either not striking the pins or that their impact was cushioned in some manner and that they were not sliding over the tube wall.

II. ANALYSIS OF RESULTS

It has been suggested that there would be essentially zero attack on toroid pins at velocities of 26 ft/sec only if the particle diameter was less than 3 microns.³ Dr. W. O. Milligan has pointed out⁴ that erosion with fluidized solid catalysts in the petroleum industry has been virtually eliminated by the adoption of spherical catalyst particles.^a

There are at least four possible explanations for the essentially zero attack rates observed in the toroid tests:

- A. The analysis giving a limiting (velocity)(particle-diameter)² product below which attack will not take place presented in reference 3 is quantitatively incorrect. This may be because of the peculiar motion of the toroids or unknown wall effects since the analysis in reference 3 is based on flow in an infinite medium.
- B. The existence of rotational hydrodynamic forces of sufficient magnitude to cushion the impact of particles in the pins. There are at least four different forces acting on a ThO_2 particle as it approaches an obstacle:
 1. Inertial forces tending to cause the particle to continue in its path toward the obstacle.³

^a Application of the principles of reference 3 to fluidized catalyst systems of 100 micron particle diameter show that velocities of the order of 600 ft/sec are required to initiate attack on bodies having dimensions of the order of 0.1 inch. (The critical velocity is inversely proportional to particle diameter squared and directly proportional to body diameter.) The high critical velocity required is believed to be the principal reason for the low attack rate observed.

2. Viscous forces tending to cause the particle to follow the flow lines around the particle.³
 3. Attractive forces arising from the acceleration of the fluid between the particle and the obstacle and causing the particle to move toward the obstacle.⁵
 4. Rotational hydrodynamic forces arising from the velocity gradient around the obstacle. The velocity next to the obstacle is zero but rises quickly to a maximum and then decreases to the mean velocity of the surrounding medium.⁸ The latter velocity gradient, acting on the opposite sides of the spherical ThO_2 particle, could cause a rotational motion which might cushion or eliminate the impact of the particle with the obstacle surface and thus minimize the attack rate.
- C. The bed was not in suspension and was not sliding over the walls of the toroid. Centrifugal forces do not appear large enough compared with inertial forces to immobilize the particles. The nominal velocity was well above the 6 ft/sec resuspension velocity calculated from the Newitt and Richardson relations.⁶ However, one phenomenon that may be controlling is the dilatant⁷ character of the settled bed that can be observed as the vigor of shaking is increased; i.e., the harder the container is shaken the more resistant the settled bed is to being suspended.
- D. Round particles are not as erosive to oxide film surfaces as sharp pointed particles. Rosenberg¹⁰ has observed that small sharp particles of sand were about four times as erosive to steel as larger more rounded sand. There were several reasons advanced¹¹ for this observation:

1. The surface condition of the sand,
2. The greater surface area of the target scoured by the smaller sand per unit weight of sand impinging on the target,
3. The greater acceleration of the smaller particles.

III. PROPOSED TESTS

The desirability of circulating non-interacting thorium oxide particles has been pointed out by R. N. Lyon.⁹ The 28-micron diameter 1600°C fired spheres used in the toroid tests would appear to fulfill these requirements admirably. Therefore it is necessary to have further tests in toroids in order to understand the mechanism which allows essentially zero attack under the test conditions. In addition tests should be conducted in 100A pump loops to determine the resistance of particles to degradation while being circulated through the pump, since the low attack appears to be associated with the spheroidal nature of the particles.

A. Toroid Tests

Many of the following tests are either being made or are planned so that the following comments are directed largely toward discussion of the results in the light of the various proposed mechanisms.

1. Variable Rotational Speed

a) Application of the concepts of a limiting (velocity)-(particle-diameter)² product below which attack will not take place yields a value of about 0.3 ft/sec for 28 micron particles below which attack will not take place. Thus for the range 0.3 to 26 ft/sec the velocity effect should be proportional to some power of the velocity greater than 1, the major effect

being that the pin would "see" the particles more frequently as the velocity is increased.

b) Application of the concepts of a rotational hydrodynamic force indicates that as the velocity is increased the attack rate should decrease since at higher velocities the particle should have more spin and be less likely to strike to the surface.

c) Application of the concept of a dilatant settled bed indicates that as the velocity is increased the attack rate should decrease since the greater the agitation the greater the apparent viscosity of the settled bed and the more difficult the resuspension of the particles in the settled bed could be. It should be pointed out that although the speed of a slug of liquid circulating in a toroid is essentially constant, its direction of motion and hence its velocity is constantly changing. Thus the immobilized bed of particles would be subjected to the continuously changing rate of shear which is necessary for the maintenance of high apparent viscosity in a dilatant material.

2. Variable Concentration (constant velocity)

a) Application of the limiting (velocity)-(particle-diameter)² concept indicates that the attack rate should be proportional to the concentration since the greater the concentration the more particles a pin will "see".

b) Application of the rotational hydrodynamic force concept indicates that the greater the concentration the greater the attack since the greater the concentration the more particles a pin will "see".

c) Application of the dilatant settled bed concept indicates that there would be a limiting value of the total concentration above which there would be little attack. This is because a certain amount of material is needed to maintain a continuous layer of solid which would not tear away from the wall. Thus at high concentrations the ThO_2 particles are essentially immobilized whereas at sufficiently low concentrations they would at least slide over the surface. With sufficiently high velocities and low enough concentration the particles should be in suspension and attack the pins uniformly.

The critical concentration below which attack should take place should be of the order of 50 - 100 g Th/kg H_2O .

The discussion of the preceding paragraphs are summarized in Table 1. Inspection of this table shows that the proper selection of toroid test conditions could possibly differentiate between the different mechanisms proposed. If mechanism (c) is found to be true then a considerable disintegration of particles should also be observed at concentrations below the threshold.

The proposed tests can thus be summarized as:

1. Choose three velocities, such as 5, 15 and 26 ft/sec, and make tests at four concentrations such as 10, 25, 200, and 500 g Th/kg H_2O using the 28 micron 1600°C fired spheroids. Comparison of the results with those predicted in Table 1 could perhaps establish the mechanism of attack.

B. Jet Impingement Tests

It was pointed^a out that the McBride-Pattison jet impingement test

^aR. N. Lyon, personal communication, May 16, 1957.

TABLE 1

EFFECT OF PARTICLE SIZE AND VELOCITY ON ATTACK RATE OF
28 MICRON ThO_2 PARTICLES IN PINS IN TOROID TESTS FOR
THREE DIFFERENT PROPOSED MECHANISMS

Mechanism	Increasing Velocity (Concentration Constant)		Increasing Conc. (velocity constant and >0.3 ft/sec)
	<50 to 100 g Th/kg H_2O	>50 to 100 g Th/kg H_2O	
A. Limiting (Vel.)(Part. Dia) ²	I ^a	O ^b	I
B. Rotational Hydrodynamic Force	D ^c	O	I
C. Dilatant Settled Bed	I	O	I up to 50 to 100 g Th/kg H_2O then O

- a. I = attack rate increases
b. O = attack rate unaffected
c. D = attack rate decreases

appeared to be ideal for comparing the abrasiveness of round and sharp pointed particles. In further discussions McBride agreed that these would be very interesting tests but pointed out that in early attempts to test a 40 micron spheroidal catalyst particle, the jet would not pick up these large particles. Therefore sized fractions of high fired spheroids will be prepared for McBride to test and compare with the abrasiveness of low temperature precipitated oxide which is nearly cubic in gross appearance.

C. Loop Tests

If the results of the toroid tests indicate that the spheroids were circulating and that indeed the attack was very low, then it becomes imperative to study the rate of degradation of the fired spheres under circulating loop conditions. Several kilograms of "Standard Oxide" having about 15 micron particle diameter have been fired at 1400°C and at 1600°C for 2 hours and will be tested for stability against degradation in loop run S-100 scheduled to be started about the 4th week in June.

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