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HYDRAULIC CYCLONES FOR THORIUM OXIDE PARTICLE SIZE CLASSIFICATION

L. L. Bennett and D. G. Thomas

I. SUMMARY

Results are reported concerning studies of hydraulic cyclones (hydroclones) for application to particle size classification of thorium oxide. Tests were run with a 0.50-inch diameter hydroclone obtained from the Chemical Technology Division of ORNL.

It was shown that a single pass through this hydroclone would reduce the material greater than 10 microns from 12 wt. per cent to less than 1% while the mean diameter was reduced from 1.7 to 0.9 micron. When the overflow (fine) fraction was again pumped through the hydroclone, the overflow solids from the second pass were 98 wt. per cent less than 2 microns in diameter. The mean diameter was reduced from 0.9 micron to about 0.7 micron by the second pass.

A yield of 5 - 7 wt. per cent of solids (to the overflow stream) and a ratio of overflow to feed volume of 0.25 - 0.30 were observed during the hydroclone tests. Although this low yield is undesirable, recommendations are made that would increase the yield sufficiently to make desirable the incorporation of hydroclones in the ThO_2 production flow sheet.

II. INTRODUCTION

Results from various toroid and loop tests indicate that only those thorium oxide particles larger than some critical diameter (3 - 10 microns) are effective in causing abrasive attack for velocities less than 30 ft/sec. Even the most careful quality control in the precipitation and calcination steps cannot insure that there will not be an occasional batch of ThO_2

containing large particles. It seemed desirable, therefore, to select and test a simple, durable apparatus for inclusion in the ThO_2 production process to reduce the possibility of particles larger than about 3 - 5 microns appearing in the product.

The possibility of using small hydroclones was suggested by their simplicity, durability, high capacity, and their successful development and operation by the Chemical Technology Division as liquid-solid separators. The hydroclone has no moving parts and is especially suited for continuous process use. No cleaning problems are involved as opposed to use of a centrifuge or continuous filter. Any material which will withstand the pressure requirement may be used for fabrication of the units. Corrosion and erosion problems will be of the order of those associated with slurry velocities of 20 ft/sec.⁹ The results from corrosion studies can be used in consideration of materials to be used.

Many experimenters^{6, 10, 12} believe that the high shearing forces in the cyclone will break up flocs of particles and prevent them from reforming. These high shear forces arise as follows: The fluid in a cyclone does not move at constant angular velocity, since the fluid spirals from the wall toward the axis of the cone. The tangential velocity (and angular velocity) increases to a maximum at some distance from the axis,^{10, 11} and then decreases sharply as the axis is approached more closely. According to Fitch and Johnson,⁶ this velocity gradient will break up any but the most tightly bound flocs.

III. EQUIPMENT

Figure 1 shows a sketch of a typical hydroclone, and Figure 2 is a photograph of the test set-up.

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FIGURE 1 - Typical Hydroclone⁹

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FIGURE 2 - Hydroclone Test System

Dimensions of the hydroclone used in this study^a are listed in Table 1; the unit was constructed of type 347 stainless steel. The feed enters tangentially at the top of the conical section. The coarse, heavy particles are thrown centrifugally to the wall and make their way down to the underflow port where they are discharged. The lighter fine particles are swept into the upward flowing vortex stream which exits as overflow through the vortex finder.

A three-stage Eastern^b pump developing 50 psi head at 5 gpm flow rate was used to supply the energy required for the separation process.

TABLE 1

HYDROCLONE DIMENSIONS

Item	Symbol	Size, inches
Hydroclone Inside Length	L	3.00
Hydroclone I.D. at Feed Port	D _c	0.50
Feed Port Size	D _f	0.10 W x 0.15 H
Underflow Port Diameter	D _u	0.125
Overflow Port Diameter, Vortex finder I.D.	D _o	0.100
Vortex Finder O.D.	OD _c	0.125
Vortex Finder Length, extension into hydroclone	L _o	0.250

^a The hydroclone was kindly loaned by P. A. Haas of the Chemical Technology Division.

^b Model 3-J centrifugal pump, Eastern Industries, Inc., Hamden, Connecticut.

IV. EXPERIMENTAL RESULTS

The study was made with a 1600°C fired oxide (LO-25-1, B Part), which had a mean diameter of 1.7 microns and 10-12 wt. per cent greater than 10 microns diameter. Feed concentration of the slurry was 300 - 500 g. ThO_2 /liter of water. Feed pressures used were 25 and 60 psig.

Table 2 gives a comparison of throughput and recovery rates for the high- and low-pressure tests.

TABLE 2
COMPARISON OF RESULTS OF HIGH- AND
LOW-PRESSURE HYDROCLONE TESTS

Feed Pressure	25 psig	60 psig
Volume Throughput	3 L/min	5 L/min
Weight Percent of Feed Solids Recovered in Overflow	6.9%	5.5%
Volume Percent to Overflow	28%	31%
Rate of Solid Recovery from Overflow (single pass)	6 kg/hr	4.5 kg/hr

Results from particle size determinations are listed in Table 3 and Table 4, and curves of cumulative weight per cent versus particle size are shown in Figures 3 through 7. In runs 5 through 11 (Table 4) a dispersed slurry was used as the test material. Sodium silicate solution was added to the slurry in a ratio of 10 ml/liter of slurry.

TABLE 3

PARTICLE SIZE ANALYSIS OF THORIUM OXIDE FROM HYDROCLONE
TEST USING FLOCCULATED MATERIAL - LO-25-1, B PART

Run	Sample No.	Sample Source	Particle Size Analysis - Wt. per cent								Remarks
			> 10 μ	< 5	< 3	< 2	< 1.5	< 1	< .7	< .5	
1	LO-25-1-1	Feed	12	87	80	62	37	19	5	1	(60 psig feed pres.;
	-2	U.F.-1*	11	82	75	59	44	30	10	1	10 psig U.F. pres.
	-3	O.F.-1*	2	97	96	84	54	35	15	3	for runs 1 and 2)
2	-----	Feed	See Remarks								Run No. 2 is 4th
	-4	U.F.-2	8	89	80	55	31	22	6	1	pass of LO-25-1-1
	-5	O.F.-2	2	97	95	86	65	35	11	1	through hydroclone; U.F. is used as feed for each pass
3	-6	Feed	11	86	78	60	40	20	11	7	(60 psig feed pres.;
	-7	U.F.-3	11	86	77	55	35	16	6	1	0 psig U.F. pres.)
	-8	O.F.-3	3	96	94	83	61	29	11	2	
4	-----	Feed	U.F.-3 used as feed material								(60 psig feed pres.;
	-9	U.F.-4	6	90	84	66	50	24	7	1	0 psig U.F. pres.)
	-10	O.F.-4	-	98	94	82	56	27	10	2	

*
U.F. designates underflow stream; O.F. designates overflow stream.

TABLE 4

PARTICLE SIZE ANALYSIS OF THORIUM OXIDE FROM HYDROCLONE

TEST: SLURRY LO-25-1, B PART: DISPERSED WITH SODIUM SILICATE

Run No.	Sample No.	Sample Source	Particle Size Analysis - Wt. per cent								Remarks	
			> 10 μ	< 5	< 3	< 2	< 1.5	< 1	< .7	< .5		
5	LO-25-1-19	Feed	6	88	80	56	31	14	4	1	Runs 5 through 9 were made with 60 psig feed pres.; 0 psig U.F. pres.	
	-15	U.F.-5	9	84	76	51	35	16	7	1		
	-16	O.F.-5	1	97	94	87	73	50	30	14		
6	-----	Feed		U.F.-5 used as feed material								
	-17	U.F.-6	10	85	77	58	39	22	7	3		
	-18	O.F.-6	-	96	90	83	72	42	19	8		
7	-24	Feed	10	87	80	60	40	22	10	3		
	-25	U.F.-7	7	91	87	63	39	24	10	3		
	-26	O.F.-7	-	99	97	90	80	63	29	14		
8	-----	Feed		U.F.-7 used as feed material								
	-27	U.F.-8	8	90	85	62	45	22	11	3		
	-28	O.F.-8	2	-	-	93	85	68	41	27		
9	-----	Feed		O.F.-7 and O.F.-8 used as feed material								
	-36	U.F.-9	-	-	99	94	80	60	32	12		
	-38	O.F.-9	-	-	-	97	91	81	55	35		
10	-40	Feed	11	86	78	69	38	22	11	3	(25 psig feed pres.; 0 psig U.F. pres. in runs 10 and 11)	
	-43	U.F.-10	12	86	82	62	37	18	6	4		
	-44	O.F.-10	1	-	98	95	85	53	24	11		
11	-----	Feed		O.F.-10 used as feed material								
	-----	U.F.-11		No sample submitted								
	-46	O.F.-11	-	-	-	98	91	81	53	20

Fig. 3. Particle Size Distribution of ThO_2 from Hydroclone Test

Fig. 4. Particle Size Distribution of ThO_2 from Hydroclone Test

Fig. 5. Particle Size Distribution of ThO_2 from Hydroclone Test

Fig. 6. Particle Size Distribution of ThO_2 from Hydroclone Test

Fig. 7 Particle Size Distribution of ThO_2 from Hydroclone Test

V. DISCUSSION OF RESULTS

1. Size Separation

The particle size distribution obtained in the overflow product from a two-pass test (first overflow returned to feed) demonstrated that the hydroclone promised to give effective classification in the 2- to 3-micron range. As shown in Table 4 for runs 9 and 11, the overflow material was 98 wt. per cent less than 2 microns in diameter. The underflow stream carried a considerable quantity of fine material to the underflow receiver; however, this is mainly due to the design of this particular hydroclone and is not a characteristic of hydroclones in general. The hydroclone used in this test was obtained from the Chemical Technology Division, and it had been designed for induced-underflow operation in a liquid-solid separation system. (This system is described in detail in reference 9.) For induced-underflow operation the underflow port must be larger than that required for a hydroclone discharging to air at atmospheric pressure.

If this type of hydroclone is operated with atmospheric underflow discharge without induced underflow, an excessively large underflow ratio will result; in this study the underflow ratio was about 0.70. Solid particles which enter with the underflow liquid never pass through a classification zone in the hydroclone. Therefore, about 70 wt. per cent of the solids were carried to the underflow receiver without being subjected to the classifying action of the hydroclone. Methods of recovering this fine material are discussed in the following section on product yield.

2. Product Yield

With a feed concentration of 300 - 500 g ThO_2 /liter of water and a feed pressure of 25 - 60 psig, the hydroclone removed 5 - 7 wt. per cent of feed solids to the overflow. (About 60 wt. per cent of the feed material was smaller than 2 microns.) As indicated in the preceding paragraph, a large part (about 70 wt. per cent) of the feed material was carried to the underflow because of the high underflow ratio.

Some methods of increasing the product yield are:

- a. Series operation
- b. Decrease underflow port diameter
- c. Decrease feed pressure.

A series-connected hydroclone system is shown graphically in Fig. 8. The overflow from the first stage is the feed for the second stage; the overflow from the second feeds the third; the third stage overflow carries the final product. The underflow from the first stage is removed from the system for further reduction of coarse particles. The underflow from succeeding stages is returned to the feed tank. The only material which is removed from the system is the underflow from the first stage and the final product.

As shown in Tables 3 and 4, several runs were made using underflow slurry for feed material (Runs 2, 4, 6 and 8). The particle size distribution in the overflow from these runs was no coarser than for the runs using the as-received slurry for feed.

Decreasing the underflow port diameter (or increasing the overflow port diameter) will produce a decrease in the underflow ratio. According to Yoshioka and Hotta,¹² the ratio of D_u/D_o affects the underflow ratio, and the latter is approximately determined by this ratio. An equation is

Figure 8. Suggested Flow Diagram for a Three-Stage Hydroclone System.
(Dorr-Oliver, Inc., Bulletin No. 2502)

given for the calculation of the ratio, R_f , which is defined as the ratio of underflow volume to feed volume.

$$1 - R_f = k \frac{D_o^4}{D_u^4 + D_o^4} = \frac{k}{(D_u/D_o)^4 + 1} \quad (1)$$

When the inlet pressure is greater than 0.5 kg/cm^2 (about 7 lb/in.^2) the underflow ratio in the range $D_u/D_o = 0.3 - 0.8$ can be calculated approximately by using $k = 0.95$. The equation then becomes:

$$1 - R_f = 0.95 \frac{1}{(D_u/D_o)^4 + 1} \quad (2)$$

This equation was used to calculate the flow ratio expected for the hydroclone used in this test. The calculated value was $R_f = 0.72$; ratios actually obtained during the test varied from 0.69 to 0.80.

A decrease in the hydroclone feed pressure causes more material to report to the overflow. This decrease in pressure also causes larger particles to pass to the overflow, so it is important that the pressure be sufficiently high that operation will meet the product size requirement.

Haas⁹ gives the following equation for rough estimates of performance of hydroclones with diameters less than 1 inch:

$$d_{50} = 5 \times 10^3 \frac{D_c^{0.5} \mu^{0.5}}{(\Delta P)^{0.25} (\rho_s - \rho_l)^{0.5}} \quad (3)$$

where d_{50} = diameter of particles removed with 50% efficiency,*
microns

D_c = hydroclone inside diameter at feed port, in.

μ = liquid viscosity, lb/ft sec.

ΔP = feed-to-overflow pressure drop, feet of liquid

ρ_s = solid phase density, lb/ft³

ρ_l = liquid phase density, lb/ft³

3. Deflocculating Action of Hydroclone

Most of the hydroclone runs were made with a dispersed slurry (sodium silicate solution used as dispersing agent). However, results from two tests (Runs 1-4, Table 3) made with flocculated slurry indicated that the hydroclone is an effective dispersing device in itself. The differences in particle size distribution for flocculated and dispersed slurry tests could be attributed to experimental errors in analysis.

Fitch and Johnson⁶ stated that the velocity gradient inside the hydroclone sets up shear forces in the fluid which breaks up flocs of particles and prevents them from reforming. The hydroclone will, therefore, classify small particles without the requirement of added dilution or dispersing agents.

* Haas defined hydroclone efficiency as 100 times the ratio of the weight of underflow solids to the weight of feed solids.

VI. CONCLUSIONS

From the results of this study of the particle size classification characteristics of the hydraulic cyclone, it is concluded that:

1. The hydroclone is an effective tool for scalping operation, i.e., for removing the coarse fraction from a sample with a continuous particle size spectrum.
2. In order to reduce the possibility of coarse particles being in the product, it is necessary to arrange hydroclones in series; the overflow stream of each stage becomes the feed stream for the following stage. A three-stage hydroclone system is shown in Fig. 8.
3. Because of the low solid recovery ratio (overflow solids wt. divided by feed solids wt.), it would be necessary to increase the yield by returning the underflow material from each hydroclone stage to the feed stream for further processing.
4. It seems desirable to operate the hydroclones with 20 - 25 psi pressure drop between feed and overflow. This produces effective separation with fairly high solids recovery ratio.

VII. RECOMMENDATIONS

A. If a general program of hydroclone tests were to be continued, single-stage, two-stage and three-stage hydroclone systems should be tested with the following hydroclone dimensions and operating conditions:

1. One-half-inch diameter hydroclones with underflow port diameters of 0.10 inch and 0.063 inch;
2. Feed-to-overflow pressure drops (across each stage) of 15, 25 and 40 psi;
3. Slurry concentrations of 250, 500 and 750 g ThO_2 /liter of water;
4. All future tests should be made with flocculated feed material;
5. Multiple-stage systems should be connected as shown in Figure 8.

B. Of especial interest is the following combination of hydroclone dimensions and operating conditions:

1. Three-stage system of one-half-inch hydroclones as shown in Figure 8;
2. Underflow port diameter --- 0.10 inch;
3. Pressure at inlet to first stage --- 60 psig;
4. Feed concentration (flocculated) --- 500 g/liter.

The results of this study indicate that the above system would be very effective as a thorium oxide classifying system and should be the first system investigated in any future study.

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