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in a Dense-Medium Cyclone**



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WASHING FINE-SIZE COAL IN A DENSE-MEDIUM CYCLONE

by

Albert W. Deurbrouck¹

ABSTRACT AND CONCLUSIONS

Dense-medium cyclone tests in 4- and 8-inch-diameter units have shown the ability of cyclones to make sharp separations down to 100 mesh when washing coals of a finer top size than normally fed to dense-medium cyclones. The reduced top size of the feed apparently allows the finer size particles to report to the proper product by reducing the effect of very coarse particles in the congested separation zone of the dense-medium cyclone.

INTRODUCTION

The current emphasis on fine-coal cleaning is the result of new mining techniques and equipment which produce a finer size run-of-mine product and the need to further reduce the size of the coal prior to washing to liberate coal-associated impurities. Only through the liberation of such impurities as pyrite can an acceptable final product be provided at the maximum yield. As fine-coal processing is inherently more difficult, preparation costs will increase; however, the higher quality final product is required to meet environmental regulations.

The Bureau of Mines has undertaken a study of dense-medium cycloning of coal of finer size than is normally considered applicable. Some advantages of extending the lower size range of dense-medium cyclone feed include (1) Possibility of sharper separations in the finer sizes than would be possible with other coal washers. Performance of dense-medium cyclones is characteristically very sharp when washing plus 35-mesh (1/2 mm) material;² however, published data indicate³ cyclone performance deteriorates quite rapidly when washing material finer than 35 mesh; (2) elimination of the coarsest size material from froth flotation circuits. It is known that froth flotation performance is maximized by reducing the size range of the material to be treated. Coarser

¹ Research supervisor, process technology.

² Fontein, F. J., and C. Krijgsman. Recent Developments in the Cyclone Washer System. Second Internat. Coal Preparation Cong., Sept. 20-25, 1954, Essen, Germany, Paper A-IV-9, 7 pp.

³ Sokaski, M., and M. R. Geer. Cleaning Unsized Fine Coal in a Dense-Medium Cyclone Pilot Plant. BuMines RI 6274, 1963, 25 pp.

material generally requires excessive agitation which adversely effects the flotation of the finer size material.

To determine the performance potential of dense-medium cyclones when washing fine-size coal, tests were conducted using both a true heavy liquid and magnetite as the separating medium. Presumably, the true heavy liquid medium should provide optimum cyclone performance against which the performance of the magnetite medium separation could be compared.

TEST APPARATUS

Two closed circuit test facilities were used for this work, both of which included a cyclone, sump, mixer, and pump.

The true-liquid media work was done using a rubber lined 4-inch-diameter Heyl & Patterson, Inc. (H & P)⁴ cyclone having a 20° included angle. The pyramidal-shaped sump had a capacity of 10 gallons. A small single-bladed mixer was used in the sump to insure that a uniform slurry was fed to the cyclone. A closed-impeller type centrifugal pump delivered the feed slurry from the sump to the cyclone.

The magnetite media tests were done with an 8-inch-diameter H & P cyclone having a 12° included angle. The sump for this facility was a 55 gallon drum fitted with a conical bottom out of which the cyclone feed slurry was pumped. The sump was baffled to eliminate the formation of a vortex during mixing with a single-bladed mixer, thus insuring a thorough mix. A recessed open-impeller type centrifugal pump was used for this circuit.

EXPERIMENTAL RESULTS

The first series of tests was conducted in a 4-inch-diameter cyclone using a true heavy liquid, zinc chloride, as heavy media to separate a 48-mesh by 0 coal. The results of four of these tests are summarized in table 1. The operating conditions are shown in table 2.

The 48- by 100-mesh size fraction was separated quite sharply, as typified by error area values ranging from 28 to 51 and probable error values ranging from 0.040 to 0.065. The error area and probable error values for the 100- by 200-mesh material were reasonably good; however, the sharpness of the separation decreased quite rapidly for the minus 200-mesh material.

Following the completion of these tests, a second series of tests was conducted in an 8-inch-diameter cyclone using a magnetite and water suspension for the heavy media. The top size of the feed was increased to 6 mesh and the minus 200-mesh material was removed by dry screening on a 30-inch-diameter Sweco vibrating screen prior to washing. No attempt was made to determine the amount of misplaced fines in the 6- by 200-mesh product. The medium used for these tests was grade E magnetite (96 percent finer size than 325 mesh).

⁴Reference to specific brands is made for identification only and does not imply endorsement by the Bureau of Mines.

TABLE 1. - Performance of 4-inch-diameter dense-medium cyclone washing 48-mesh by 0 coal using an inorganic solution as medium¹

Test	Weight-percent	Prob-able error	Error area	Specific gravity of sepa-ration	Weight-percent	Prob-able error	Error area	Specific gravity of sepa-ration
1.....	37.3	0.060	51	1.51	31.5	0.080	63	1.50
2.....	25.3	.055	47	1.51	33.0	.100	78	1.52
3.....	26.2	.040	28	1.51	33.1	.065	40	1.52
4.....	39.4	.065	43	1.57	31.8	.070	66	1.59
Average.....	-	.055	42	-	-	.079	62	-
	Minus 200 mesh				Composite			
1.....	31.3	.185	108	1.47	100.0	.110	79	1.49
2.....	41.7	.245	156	1.75	100.0	.130	100	1.53
3.....	40.7	.220	131	1.62	100.0	.110	79	1.52
4.....	28.8	.112	111	1.67	100.0	.075	77	1.61
Average.....	-	.190	126	-	-	.106	84	-

¹Specific gravity of medium for all tests was 1.50.

TABLE 2. - Operating conditions of 4-inch-diameter dense-medium cyclone washing 48-mesh by 0 coal using an inorganic solution as medium¹

Test	Feed inlet pressure, psi	Orifice, inches		
		Feed	Overflow	Underflow
1.....	5	1	1/2	3/8
2.....	10	1	9/16	1/4
3.....	6	1	1/2	1/4
4.....	10	1	1/2	3/8

¹Ten percent solids in feed.

A number of preliminary tests were conducted to assure proper operation of the cyclone and the ancillary equipment. A detailed performance study was then made with the cyclone operating under the following conditions:

Orifice	Orifice sizes, inches	Medium specific gravity
Overflow..	3	1.28
Underflow.	2	1.67
Feed.....	1-1/2	1.30

Cyclone pressure - 10 psi

Feed rate, solids - 3.3 tons per hour

Feed rate, slurry - 110 gallons per minute

Solids in feed - 12 percent

Table 3 is a specific gravity analysis of the feed to the cyclone. The high percentage (84.0) of float 1.30 specific gravity material assured a high percentage of near-gravity material at a low density of separation in the cyclone washing test.

TABLE 3. - Specific gravity analysis of feed to 8-inch-diameter dense-medium cyclone

Specific gravity fraction	Direct, percent		Cumulative, percent	
	Weight	Ash	Weight	Ash
Float - 1.30.....	84.0	1.2	84.0	1.2
1.30 - 1.35.....	5.5	7.1	89.5	1.6
1.35 - 1.40.....	2.1	11.4	91.6	1.8
1.40 - 1.45.....	1.3	15.0	92.9	2.0
1.45 - 1.50.....	.9	17.4	93.8	2.2
1.50 - 1.60.....	1.1	21.1	94.9	2.4
Sink - 1.60.....	5.1	56.5	100.0	5.1

Table 4 summarizes the washing performance of the cyclone on the 6- by 200-mesh material. Although there is the normal deterioration in washing performance with a decrease in size increment, the sharpness of the separation was excellent down to 65 mesh and quite acceptable for the 65- by 100-mesh size fraction. As expected, the specific gravity of separation increased as the size consist of the separated material decreased, but the increases were more pronounced than those commonly found in dense-medium-cyclone washing of coarser coal. The recovery of the lightest specific-gravity material was somewhat impaired. Approximately 30 percent of the refuse product of the composite 6- by 100-mesh product was misplaced material; however, this was a very difficult separation in that it contained 94 percent of ± 0.10 near-separating-gravity material. Very little high-specific-gravity material was misplaced into the clean coal product. The 6- by 100-mesh material was separated at 1.35 specific gravity, at a probable error of 0.028 and an error area of 26 even though such a high percentage of near-separating-gravity material was present. The quality of the clean coal products remained high and reasonably constant throughout the range of size fractions, increasing to only 2.0 percent ash in the 100- by 200-mesh fraction where the feed ash was 15.4 percent.

DISCUSSION OF RESULTS

The separations effected in a 4-inch-diameter dense-medium cyclone, using a true liquid, were excellent even though the raw feed was approximately one-third minus 200-mesh material and two-thirds minus 100-mesh material.

TABLE 4. - Summary of performance data for 8-inch-diameter dense-medium cyclone washing 6- by 200-mesh raw coal

Type of analysis	Size, mesh								
	6 by 14	14 by 28	28 by 48	48 by 65	65 by 100	100 by 200	6 by 200	6 by 100	6 by 65
Screen analysis, percent:									
Feed.....	29.6	29.2	23.5	5.8	6.2	5.7	100.0	94.3	88.1
Washed coal.....	27.9	30.2	24.7	5.9	6.3	5.0	100.0	95.0	88.7
Refuse.....	40.3	22.8	15.4	5.1	5.8	10.6	100.0	89.4	83.6
Ash, percent:									
Feed.....	4.5	4.0	4.2	5.7	6.4	15.4	5.1	4.5	4.3
Washed coal.....	1.7	1.6	1.5	1.4	1.7	2.0	1.6	1.6	1.6
Refuse.....	17.3	24.6	32.1	37.4	39.9	52.5	27.3	24.3	23.3
Recovery, percent:									
Actual.....	81.8	89.5	91.2	88.2	87.5	73.4	86.4	87.3	87.3
Theoretical.....	85.2	92.0	93.4	91.9	92.1	81.9	89.6	90.3	90.3
Efficiency.....	96.0	97.3	97.6	96.0	95.0	89.6	96.4	96.7	96.7
Misplaced material, percent:									
Float in refuse product.....	28.4	27.7	29.8	34.2	39.5	33.7	31.0	31.0	30.7
Sink in washed coal product.....	2.2	.5	.5	.4	.3	.8	1.2	1.1	.9
Total misplaced material.....	7.0	3.4	2.9	4.4	5.4	9.5	5.3	4.9	4.7
Near-gravity ± 0.10 material, percent of feed.....	92	94	7	4	<3	<3	93	94	94
Specific gravity of separation.....	1.33	1.36	1.41	1.44	1.53	1.57	1.35	1.35	1.35
Probable error, specific gravity.....	.024	.024	.034	.038	.064	.103	.030	.028	.026
Error area.....	12	15	24	36	55	74	29	26	22
Distribution, percent to washed coal:									
Specific gravity fraction:									
Float - 1.30.....	96.2	97.9	98.0	96.1	95.0	89.4	96.7	97.1	97.3
1.30 - 1.35.....	53.9	82.1	92.9	92.9	95.6	86.1	73.7	73.7	72.2
1.35 - 1.40.....	4.2	29.4	72.7	88.6	94.0	91.1	30.8	29.4	25.5
1.40 - 1.45.....	.8	4.3	37.5	60.2	85.5	89.0	17.5	15.6	11.5
1.45 - 1.50.....	.0	1.2	9.9	27.5	71.6	84.2	8.4	6.2	3.0
1.50 - 1.60.....	.0	.8	2.2	9.4	42.9	55.4	6.1	3.5	1.4
1.60 - sink.....	.0	.0	.4	.9	2.4	2.3	.7	.5	.3

The sharpness of the separation effected in the 8-inch-diameter dense-medium cyclone, using finely ground magnetite as medium, was excellent down to 65 mesh and, while obviously deteriorating, still very acceptable for the 65- by 100-mesh material. The large percentage of misplaced low-specific-gravity material that reported to the refuse product was disconcerting, however, the total misplaced material was not much greater than reported for dense-medium cyclones making separations at low densities in the presence of high percentages of near-gravity ± 0.10 specific gravity material.⁵

An earlier study on dense-medium cycloning a 3/8-inch by 0 feed⁶ showed significantly inferior results on the 48- by 200-mesh size material; however, it must be pointed out that the feed for this earlier study was 3/8-inch top size. For the current study, the feed top size was 6 mesh, or approximately one-twenty-third of the volume of the 3/8-inch top size particle used by Sokaski.

It is theorized that the sharpness of separation attained by dense-medium cycloning of fine-size material is directly related to the top size of the feed to the cyclone. The coarse-size particles, which separate quite sharply, are so disproportionately large as to misplace adjacent fine-size particles by physically driving or carrying them into the wrong product. Certainly the point of separation within the cyclone is confined and becomes quite congested near the apex (underflow orifice) with the result that many fine-size particles come in intimate contact with coarse-size particles at this "moment of decision" and are subsequently misplaced.

MAGNETITE RECOVERY

The inherent attractiveness of extending the bottom-size range of the dense-medium-cyclone feed down to 100 mesh to attain improved quality products is diminished by the known limitations of conventional magnetite recovery circuits.

Although no modifications on the magnetic recovery circuit were made to cope with such fine-sized feeds in the laboratory, discussions with coal preparation design engineers have indicated such circuits are within the scope of current technology. For example, the cyclone products could be put across sieve bends and the underflow products could be fed directly to magnetic separators. Or, the Derrick High Speed screens could be used to separate the cyclone products from the associated magnetite at 100 mesh. Further, there is work underway on the application of new magnetic field technology to the minerals preparation field.

The utilization of froth flotation for recovering magnetite from magnetic separator effluents has been proposed in a recent Bureau publication.⁷ Such a system would also reclaim any coal values lost to the nonmagnetic products from the magnetic separators.

⁵Deurbrouck, A. W., and J. Rudy, Jr. Performance Characteristics of Coal-Washing Equipment: Dense-Medium Cyclones. BuMines RI 7673, 1972, 34 pp.

⁶Work cited in footnote 3.

⁷Cavallaro, J. A., and A. W. Deurbrouck. Reclaiming Magnetite in Dense-Medium Circuits by Froth Flotation. BuMines RI 6821, 1966, 11 pp.

