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Flotation Study of Refractory Coals

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Flotation Study of Refractory Coals

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UNITED STATES DEPARTMENT OF THE INTERIOR
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FLOTATION STUDY OF REFRACTORY COALS

by

Kenneth J. Miller[1]

ABSTRACT

The Bureau of Mines conducted an investigation to improve the flotation response of coals that are difficult to wash by froth flotation. A literature survey and experimentation showed that, for the most part, refractory coals can be floated with oily collectors and frothers. Collector reagent consumption can be minimized and the selectivity of the flotation enhanced by assuring adequate, but not prolonged, reagent conditioning. Where flotation selectivity is especially poor, two-stage rougher-cleaner flotation is recommended.

It was concluded that a major problem with refractory coals is predicting when they will appear in a flotation circuit so that supplementary flotation collectors can be added. Coal losses due to variation in the floatability of the feed might be reduced if a nonpolar collector such as kerosine or fuel oil is used along with a frother as general coal flotation practice.

INTRODUCTION

There is a wide difference in the floatability of coals of different rank, and even of the same rank, depending on whether they have been freshly mined or allowed to oxidize. Also, differences in floatability, presumably due to oxidation, may occur within a particular seam because of ground water percolating through the coalbed or because of the proximity of the coal to the surface. Strip-mined coals are typically more difficult to float than deep-mined coals from the same seam.

The higher rank deep-mined coals found in the Appalachian region of the Eastern United States are usually floated with only a frother reagent such as methylisobutyl carbinol (MIBC). However, when oxidized or low-rank coals are treated, oily flotation collectors are needed and reagent consumption is high. In any case, proper treatment demands a knowledge of the flotation properties of the coal so that the correct amount and type of reagents can be added. This knowledge is not easily obtained in many coal preparation plants, where

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coals are arriving from surface as well as deep-mining operations, and perhaps even from different coalbeds.

This paper reviews the work of others and recommends methods by which flotation might be improved to minimize coal losses owing to the presence of refractory coals in the flotation circuit.

LITERATURE SURVEY

From the considerable amount of work that has been done on the flotation of oxidized and low-rank coals, one might conclude that practically any coal, except possibly lignitic or subbituminous coals, can be floated with the proper reagents and flotation-circuit design. However, whether it is economical to do so in some cases is subject to question. The high reagent consumption by refractory coals has been ascribed by Grounds (5)[2] to absorption into the highly porous surfaces of the coal, by Jowett (9) to the presence of clay slimes that might coat the coal particles and adsorb reagent and by Hindmarch (6) to the oxygenated hydrophilic groupings composing the surface of the coal particles.

The advantages of good slurry conditioning have been pointed out by many. Allum (1) proposes a simple two-stage conditioning method that he says cuts reagent costs 50 percent or more. Rogers (12) recommends a more complex method of intensive conditioning using a multistage conditioner instead of the standard mixing tank. Meniovich (10) suggests using conditioning hydrocyclones to prepare coal slurries for flotation, and Horsley (7) suggests emulsifying the oil to achieve maximum dispersion through the pulp. Any of the preceding methods would doubtless contribute to better flotation and reagent economy when treating refractory coals.

In the U.S.S.R. much effort is directed toward improving coal flotation efficiency. Soviet coal experts have designed pulp preparation-distribution units to assure intimate mixing of the slurry and reagent and, according to Deurbrouck (3), they employ reagent stage addition methods as routine procedure. Furthermore, Simonov (13) describes a method whereby instrumentation is used to meter the reagents (frothers and collectors) according to the solids concentration and flow rate of the slurry entering the flotation cells.

Despite the obvious advantages of reagent conditioning, many researchers have shown that too much conditioning can result in poor flotation and excessive reagent consumption. In Australia, for example, Jowett (8) found that cresylic acid is removed rapidly from solution by low-rank coals during conditioning. Eveson (4) showed similar absorption of phenol from aqueous solution by coals. These researchers suggest reducing to a minimum the conditioning time during which absorption or adsorption can take place.

Flotation with nonpolar collectors and frothers is advocated by Burdon (2) and Zimmerman (14). In fact, Allum (1) suggests that the frother quantity

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[2]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

be the same for all coals; only the collector need be varied. Plaksin (11) states that the combined use of collectors and frothers is the most rational way to conduct flotation.

The following section gives flotation results with several U.S. coals to show the advantage, or sometimes the necessity, of using nonpolar collectors with frothers to float refractory coals.

FROTH FLOTATION EXPERIMENTS

Appalachian Coals

A sample of minus 28-mesh coal was dry-screened from the feed to a coal preparation plant in northern West Virginia and riffled into 200-gram increments. The coal is a mixture of Pittsburgh and Redstone bed coals mined in an area where the two seams converge. The Redstone bed coal had somewhat poorer floatability than the Pittsburgh bed coal and had a detrimental effect on the flotation process.

A number of flotation experiments were performed with the coal sample in the laboratory flotation cell (fig. 1). An oily collector and several different frothers were used in the work. Tap water from the laboratory was compared with clarified water taken from the static thickener overflow at the preparation plant where the coal was collected.

All flotation tests were run at 1,800 rpm with 0.33 cfm of air delivered to the flotation cell from a compressed air source. Each 200-gram coal sample was conditioned in the cell for 15 minutes prior to reagent addition. Each reagent was conditioned in the pulp for 1 minute before aeration was begun; the collector was always added first. The froth was scraped from the surface of the pulp until it was barren of coal (usually 1 to 1-1/2 minutes).

Table 1 shows that a nonpolar collector such as kerosine along with a conventional frother such as MIBC was necessary for good recovery of clean coal. The table also reveals that recovery was better with tap water than with the preparation plant water, especially at lower levels of reagent addition.

These results indicate that kerosine or similar nonpolar collectors must be used when floating this coal. Neither MIBC nor 2-ethylisohexanol (2-EIH) by itself provided an acceptable recovery with good selectivity, although 2-EIH provided better recoveries than MIBC. Also, the ratio of Pittsburgh bed to Redstone bed coal changes from time to time at the plant. Therefore, a collector such as kerosine in the flotation feed should minimize the suppressive effect of too much of the refractory Redstone bed coal in the circuit.

TABLE 1. - Flotation of Pittsburgh-Redstone bed coal blend in laboratory tap water and preparation plant clarified water

Product	Tap water		Plant water		Reagents added, lb/ton		
	Weight-percent	Ash, percent	Weight-percent	Ash, percent	Kerosine	MIBC[1]	2-EIH[2]
Clean coal.......	61.4	7.1	49.2	6.3	-	0.25	-
Reject...........	38.6	26.5	50.8	24.9			
Feed........	100.0	14.6	100.0	15.7			
Clean coal.......	68.7	7.0	48.0	6.6	-	.35	-
Reject...........	31.3	33.0	52.0	23.1			
Feed........	100.0	15.1	100.0	15.2			
Clean coal.......	69.8	6.9	67.2	7.3	-	.50	-
Reject...........	30.2	33.4	32.8	29.9			
Feed........	100.0	14.9	100.0	14.7			
Clean coal.......	87.1	7.6	85.4	7.6	0.50	.25	-
Reject...........	12.9	63.8	14.6	59.6			
Feed........	100.0	14.8	100.0	15.2			
Clean coal.......	89.2	8.3	87.0	7.3	1.00	.25	-
Reject...........	10.8	70.5	13.0	64.9			
Feed........	100.0	15.0	100.0	14.8			
Clean coal.......	79.3	7.5	76.8	7.0	-	-	0.25
Reject...........	20.7	42.3	23.2	40.0			
Feed........	100.0	14.7	100.0	14.7			
Clean coal.......	80.3	7.4	79.3	7.2	-	-	.35
Reject...........	19.7	47.4	20.7	44.6			
Feed........	100.0	15.3	100.0	14.9			

[1]Methylisobutyl carbinol.
[2]2-Ethylisohexanol.

Two other Appalachian region coals were tested--Waynesburg and Lower Freeport bed coal. These coals were collected as run-of-mine samples and returned to our laboratory to be dried at ambient temperature and crushed to flotation size in a high-speed hammermill. The pulverized coals were then riffled into 200-gram samples for laboratory-scale batch flotation tests using the procedure outlined earlier.

FIGURE 1. - Laboratory flotation cell used in tests.

The Waynesburg bed sample (table 2) was a strip mined coal from eastern Ohio that could not be floated well without a collector such as kerosine in the pulp. Even an MIBC addition of 1.0 lb/ton failed to float more than 61.4 percent of the material, leaving a tailings product containing only 25.5 percent ash. With kerosine and MIBC, however, nearly 90 percent was recovered, leaving a tailings product that contained over 50 percent ash.

TABLE 2. - Flotation of Waynesburg bed coal

Product	Weight-percent	Ash, percent	Reagents added, lb/ton Kerosine	Reagents added, lb/ton MIBC[1]
Clean coal	29.2	11.4		
Reject	70.8	20.1	-	0.30
Feed	100.0	17.6		
Clean coal	44.5	11.4		
Reject	55.5	22.3	-	.50
Feed	100.0	17.5		
Clean coal	61.4	12.6		
Reject	38.6	25.5	-	1.00
Feed	100.0	17.6		
Clean coal	62.7	10.7		
Reject	37.3	33.3	0.50	.20
Feed	100.0	19.1		
Clean coal	81.6	12.9		
Reject	18.4	43.5	.50	.30
Feed	100.0	18.5		
Clean coal	85.8	13.4		
Reject	14.2	46.9	.50	.50
Feed	100.0	18.2		
Clean coal	79.6	12.7		
Reject	20.4	41.4	1.00	.20
Feed	100.0	18.6		
Clean coal	88.6	15.1		
Reject	11.4	51.2	1.00	.30
Feed	100.0	19.2		
Clean coal	89.8	13.8		
Reject	10.2	50.8	1.00	.50
Feed	100.0	17.6		

[1]Methylisobutyl carbinol.

Table 3 shows results of flotation tests with a deep-mined Lower Freeport bed coal from central Pennsylvania that can be floated easily with MIBC alone. However, collector was added in most of the tests to see if better selectivity could be obtained with kerosine and lower MIBC dosages. As the table shows, selectivity was not improved when kerosine was added; in fact, it was impaired. Apparently, there is no advantage in adding a collector when floating this coal. However, if its floatability were unknown or variable, neither would there be a strong disadvantage.

TABLE 3. - Flotation of Lower Freeport bed coal

Product	Weight-percent	Ash, percent	Reagents added, lb/ton Kerosine	Reagents added, lb/ton MIBC[1]
Clean coal	79.9	6.8		
Reject	20.1	63.5	-	0.20
Feed	100.0	18.2		
Clean coal	84.8	8.5		
Reject	15.2	74.3	-	.30
Feed	100.0	18.5		
Clean coal	86.4	9.3		
Reject	13.6	77.7	-	.40
Feed	100.0	18.6		
Clean coal	83.9	7.5		
Reject	16.1	64.3	0.50	.20
Feed	100.0	16.6		
Clean coal	86.9	9.3		
Reject	13.1	70.5	.50	.30
Feed	100.0	17.3		
Clean coal	79.5	7.8		
Reject	20.5	67.3	1.00	.20
Feed	100.0	20.0		
Clean coal	87.5	10.3		
Reject	12.5	70.5	1.00	.30
Feed	100.0	17.8		

[1]Methylisobutyl carbinol.

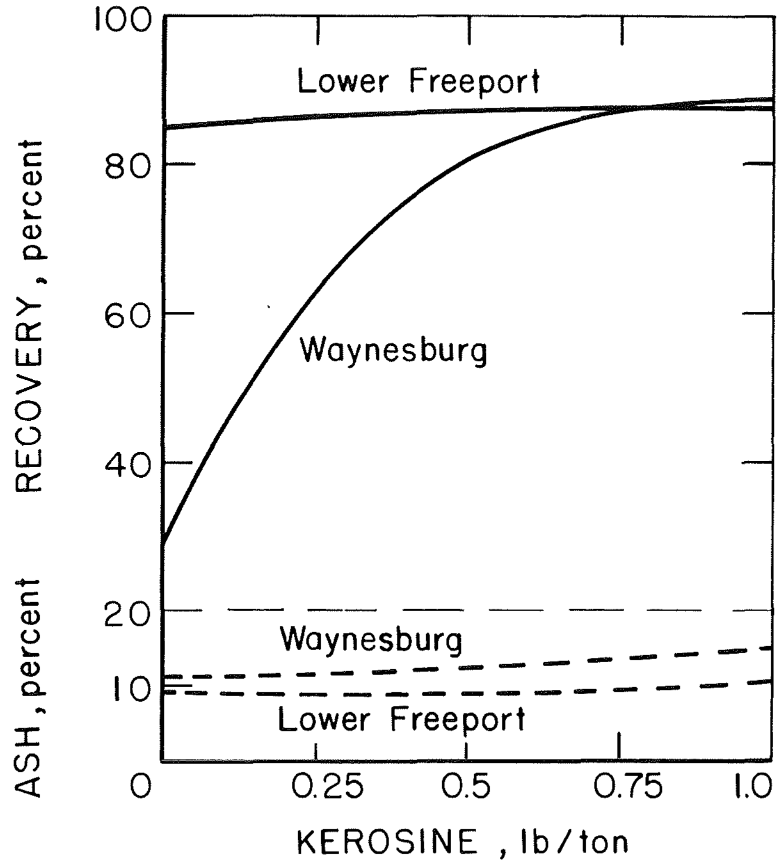

FIGURE 2. - Clean coal recovery and ash content from flotation of Waynesburg bed and Lower Freeport bed coals in the presence of 0.3 lb/ton MIBC and various quantities of kerosine.

The results (fig. 2) of floating the aforementioned coals using the same collector and frother additions show the need for oily collectors in the flotation of certain refractory coals. The curves demonstrate the importance of collectors when dealing with coals of variable floatability.

Midwestern Coals

A number of flotation tests were run with coals from the midwestern coalfields. These lower rank coals frequently require large quantities of oily collectors along with frothers to get good flotation recovery and, as a result, the froth concentrate sometimes contains large amounts of entrained, high-ash material. Tables 4 and 5 provide results of some flotation tests with two of these coals; these results show the need for a collector as well as a frother when treating low-rank midwestern coals.

In addition to the single-stage tests, several two-stage rougher-cleaner coal flotation tests were run with a few of these midwestern coals. These results are shown in tables 6 and 7. A significant reduction in final clean coal ash resulted from these second-stage coal flotation tests. Sulfur analyses are also given to show the reduction in sulfur as well. Similar ash and sulfur reduction would undoubtedly occur if two-stage rougher-cleaner flotation were applied to some Appalachian coals that are particularly difficult to wash.

TABLE 4. - Flotation of West Kentucky No. 9 bed coal from Camp No. 2 mine

Product	Weight-percent	Ash, percent	Reagents added, lb/ton	
			Kerosine	MIBC[1]
Clean coal...........	45.6	10.1	0.50	0.20
Reject...............	54.4	38.3		
Feed...........	100.0	25.4		
Clean coal...........	71.2	10.9	.75	.30
Reject...............	28.8	59.9		
Feed...........	100.0	25.0		
Clean coal...........	68.9	10.5	1.00	.20
Reject...............	31.1	58.0		
Feed...........	100.0	25.3		
Clean coal...........	75.5	10.6	1.00	.30
Reject...............	24.5	66.5		
Feed...........	100.0	24.3		
Clean coal...........	79.1	11.9	1.00	.50
Reject...............	20.9	69.4		
Feed...........	100.0	23.9		

[1]Methylisobutyl carbinol.

TABLE 5. - Flotation of West Kentucky No. 9 bed coal from Camp No. 1 mine

Product	Weight-percent	Ash, percent	Reagents added, lb/ton	
			Kerosine	MIBC[1]
Clean coal...........	74.5	9.1	1.00	0.30
Reject...............	25.5	41.1		
Feed...........	100.0	17.3		
Clean coal...........	85.9	11.2	2.00	.35
Reject...............	14.1	62.9		
Feed...........	100.0	18.5		
Clean coal...........	79.4	10.0	3.00	.20
Reject...............	20.6	52.6		
Feed...........	100.0	19.0		
Clean coal...........	86.0	10.8	3.00	.30
Reject...............	14.0	63.9		
Feed...........	100.0	18.2		
Clean coal...........	86.0	11.6	3.00	.35
Reject...............	14.0	71.7		
Feed...........	100.0	20.0		

[1]Methylisobutyl carbinol.

TABLE 6. - Two-stage rougher-cleaner coal flotation of West Kentucky No. 11 bed coal

Product and stage	Weight-percent	Analyses, percent: Ash	Pyritic sulfur	Total sulfur	Reagents added, lb/ton: Kerosine	MIBC[1]
TEST 1						
Clean coal 2..........	84.1	8.1	1.99	3.90	-	0.25
Reject 2..............	2.3	67.8	7.02	7.83		
Clean coal 1..........	86.4	9.7	2.12	4.00	2.00	.50
Reject 1..............	13.6	77.7	6.99	7.21		
Feed.............	100.0	18.9	2.79	4.44		
TEST 2						
Clean coal 2..........	79.7	7.0	1.41	3.55	-	.25
Reject 2..............	3.5	48.5	5.63	6.68		
Clean coal 1..........	83.2	8.8	1.59	3.68	1.00	.50
Reject 1..............	16.8	67.4	7.01	7.05		
Feed.............	100.0	18.6	2.50	4.25		
TEST 3						
Clean coal 2..........	82.0	7.1	1.76	3.72	-	.10
Reject 2..............	3.8	59.1	6.44	6.97		
Clean coal 1..........	85.8	9.4	1.97	3.86	2.00	.50
Reject 1..............	14.2	76.4	5.77	6.08		
Feed.............	100.0	18.9	2.51	4.18		
TEST 4						
Clean coal 2..........	77.0	6.2	1.17	3.44	-	-
Reject 2..............	8.8	38.2	4.15	6.44		
Clean coal 1..........	85.8	9.5	1.48	3.75	2.00	.50
Reject 1..............	14.2	80.3	4.71	6.08		
Feed.............	100.0	19.5	1.93	4.08		
TEST 5						
Clean coal 2..........	81.1	6.8	1.35	3.42	-	.05
Reject 2..............	4.8	51.3	4.43	6.49		
Clean coal 1..........	85.9	9.3	1.52	3.59	2.00	.50
Reject 1..............	14.1	79.6	5.02	6.46		
Feed.............	100.0	19.2	2.02	4.00		

[1]Methylisobutyl carbinol.

TABLE 7. - Two-stage rougher-cleaner coal flotation of West Kentucky No. 9 bed coal

Product and stage	Weight-percent	Analyses, percent			Reagents added, lb/ton	
		Ash	Pyritic sulfur	Total sulfur	Kerosine	MIBC[1]
TEST 1						
Clean coal 2..........	78.2	7.8	1.76	3.58	-	0.25
Reject 2..............	6.3	36.0	6.45	7.72		
Clean coal 1..........	83.5	10.0	2.13	3.94	1.00	.50
Reject 1..............	15.5	59.5	6.43	7.71		
Feed.............	100.0	17.6	2.78	4.48		
TEST 2						
Clean coal 2..........	85.2	8.2	1.89	3.80	-	.25
Reject 2..............	3.2	54.3	7.62	8.26		
Clean coal 1..........	88.4	9.9	2.10	3.96	2.00	.50
Reject 1..............	11.6	50.8	7.00	8.24		
Feed.............	100.0	14.6	2.67	4.46		
TEST 3						
Clean coal 2..........	83.4	7.9	1.83	3.67	-	.10
Reject 2..............	4.9	37.7	6.45	7.97		
Clean coal 1..........	88.3	9.6	2.09	3.91	2.00	.50
Reject 1..............	11.7	57.4	8.17	9.04		
Feed.............	100.0	15.2	2.80	4.51		
TEST 4						
Clean coal 2..........	82.9	7.8	1.47	3.55	-	.05
Reject 2..............	6.3	36.3	5.78	7.36		
Clean coal 1..........	89.2	9.8	1.77	3.82	2.00	.50
Reject 1..............	10.8	67.5	7.00	7.45		
Feed.............	100.0	16.0	2.34	4.21		

[1]Methylisobutyl carbinol.

CONCLUSIONS

1. Oily collectors plus frothers such as MIBC or 2-EIH are generally effective for floating refractory coals.

2. Emphasis should be placed on conditioning of the collector with the feed pulp: Too little conditioning results in poor dispersion of the collector in the pulp and incomplete particle coverage; too much conditioning allows excessive absorption and loss of the collector into the porous surface of the coal.

3. Adequate ash and sulfur reduction of some refractory coals can be achieved only by using two-stage rougher-cleaner coal flotation.

4. Coal losses due to the variable and unpredictable presence of refractory coals in a flotation circuit might be reduced if a collector such as kerosine or fuel oil is used along with a frother as standard flotation procedure in circuits where refractory coals are known to appear.

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