DRY SEPARATION OF PYRITE FROM COAL

By

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ABSTRACT

A dry separation process for removing pyrite from fine coal utilizing centrifugal and electrostatic methods removed 35 to 55 percent of the total pyritic sulfur (amounting to 70 to 100 percent of available pyritic sulfur) in rejects of 10 to 15 percent. Both separation methods are benefited by restricting the particle-size range and keeping the pyrite particles as large as possible. Removal efficiency is increased, therefore, by integrating the separation and grinding operations, as in stage grinding.

INTRODUCTION

Relatively coarse coal can be cleaned quite effectively at the mine by wet processes. However, the removal of fine pyrite cannot be completed until the coal is finely pulverized. Because of transportation losses, this final pulverization is usually carried out at the point of use rather than the mine. Furthermore, if these fines were to be cleaned by wet methods, problems of coal drying and wet waste disposal would be introduced.

In the dry process reported here and shown in figure 1, the coal is ground then subjected to centrifugal separation for removal of the fines as light, pyrite-depleted fractions leaving a heavy, pyrite-enriched fraction. The light fractions amounting to 10 to 50 percent of the feed are taken as a clean product. The heavy fraction is passed to an electrostatic separator that concentrates the pyrite in a reject fraction of about 10-15 percent.[1]

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[1] Minutes of the "Removal of Pyrite from Coal" Conference, U. S. Bureau of Mines, Pittsburgh Coal Research Center, Bruceton, Pa., April 22, 23, 24, 1968, pages 69-91.

Centrifugal Separation

A cross section of the centrifugal separator is shown in figure 2. Particles of coal drop down the hollow drive shaft onto the spinning spreader disk and are thrown off into the rising stream of recirculated air. Particles that are too heavy to become entrained drop into the tailings cone and out the heavy product exit. Particles whose density and shape allow entrainment are carried into the swirl of air created by the centrifugal fan and are classified according to particle mass. The lighter particles are carried into the annular space between the inner and outer cones from where they drop out the light product exit. The heavier particles are thrown to the walls of the chamber where they fall in the stagnant air layer near the wall and leave the separator via the heavy product exit. The size of fines carried into the air swirl of the classifying fan can be limited by adjusting the velocity of the recirculated air. Starting at the lowest setting of recirculated air velocity and refeeding the heavy fraction with each increase in air velocity, a series of fine cuts may be obtained.

Electrostatic Separation

Electrostatic separations utilize the difference in conductivity or dielectric properties of coal and associated material, such as pyrite, to maintain or adequately lose an induced charge under dynamic conditions. Figure 3 shows the separation section of a "high intensity" electrostatic separator. A sufficiently dispersed layer of feed is maintained on the electrically grounded rotor for individual particle contact. The feed passes under an active electrode for exposure to ionic bombardment. Subsequently the particles either become of equipotential with the rotor, as would a conductor, and are released, or if a dielectric material such as coal, remain attached to the rotor. All particles are also subjected to centrifugal and gravitational forces. The splitters are used to divide the stream of released material for the most effective concentrations of reject, middlings, and product.

Dry feed materials subjected to "high intensity" or a corona field of dissociated gas molecules are momentarily attracted to the rotor. This high intensity band is relatively narrow and depends on the proximity of the active electrode and the intensity of the rectified transformer current. A range of 18 kilovolts to 30 kilovolts was found adequate for particle attraction, although the unit had a range up to 40 kilovolts. Generally, fine particles separate more efficiently with higher rotor speeds and lower voltages, while larger particles give better separation at lower rotor speeds and high voltages. For these reasons the size of particulate is best kept within narrow ranges for a single pass unit. However, multipass units with provisions for sizing of reject and/or middlings at 50 mesh would give higher concentration of product than multipass units alone.

Other factors are also involved in making efficient separations, such as atmospheric humidity, moisture and fines content of the coal. Humidity affects ionization and separations are improved at a mid-range. Moisture and fines content affect the extent of balling of fines and coating of the larger particles. Neither of these factors enhances separation efficiency, and both must be controlled for efficient separation.

Grindability Aids Separation

Figure 4 demonstrates that coal is ground to 70 percent below 200 mesh in one-seventh of the time required for pyrite. While the spread is less in the early stages of Hardgrove milling (a ball and race mill), it increases rapidly as milling proceeds. Since both centrifugal and electrostatic separation remove larger particles of pyrite more efficiently than fine particles, the advantage of pulverizing in a manner that minimizes pyrite grinding is apparent. Thus, if the proper grinding process is incorporated as staged steps of the removal system, pyrite could be removed as it is released from the coal matrix.

Centrifugal Separator Performance

The capability of centrifugal separation for removing pyrite from closely sized feed material is shown in table 1 and figure 5. The portion of total pyritic sulfur concentrated in a 10-percent reject increased as the particle size decreased until nearly 60 percent was concentrated from the 270 x 400 mesh cut. The accompanying bar at each size fraction in figure 5 shows the pyritic sulfur which is available. Available pyritic sulfur is defined as pyritic sulfur in the sink portion from float-sink separation at a specific gravity of 1.6. The size and chemical analysis of the coal from which these closely sized fractions were taken is shown in table 2. It is significant that the 400 x 0 mesh fraction underwent reverse enrichment when subjected to centrifugal separation. This demonstrated the breadth of particle-size range of this fraction containing extremely fine pyrite. The amount of the fine pyrite probably resulted from grinding in an air-swept mill in which the particles are returned to the mill until fine enough to be carried out by the air sweep.

Electrostatic Separation Performance

The effectiveness of electrostatic separation for concentrating pyrite is shown by table 3. Blends consisting of 90 percent coal and 10 percent pyritic material were submitted to the electrostatic separator. Each component of the blend had been previously cleaned by float-sink separation, i.e., the coal floated at 1.6 specific gravity while the pyritic material reported to sink at 2.89 specific gravity. With closely sized fractions of these blends, the separation was very sharp. As shown in table 3 with the 80 x 100 mesh fraction, nearly 98 percent of the pyrite was rejected while 97 percent of the coal went to the product bin. Treatment of the 270 x 400 mesh fraction placed 98 percent of the pyrite in the reject bin, 92 percent of the coal in product bin, and about 6 percent of the coal in the middling bin.

Combined Centrifugal-Electrostatic Separation Performance

The float-sink behavior of ground Pittsburgh-seam roof coal at 1.6 specific gravity is shown in figure 6. The upper curve shows the portion of these consists below 200 mesh. The results of combined centrifugal-electrostatic separation treatment of this same coal are given in table 4 and shown in figure 7. While only about 35 percent of the total pyritic sulfur was removed, this amounted to nearly 70 percent of the available pyritic sulfur. Where grinding time is shown as a variable in the process the initial size of the coal feed is 16 x 30 mesh.

Figure 8, which shows the data of table 5, demonstrates the improvement in separation efficiency when cleaning is carried out between stages of grinding. Grinding of this same Pittsburgh-seam roof coal was accomplished in three 15-minute stages followed by one 30-minute stage. As shown in figure 8, over 40 percent of the total pyritic sulfur was removed after the first stage, with an additional 12 percent removed after the remaining grinding stages. While only about 53 percent of the total pyritic sulfur was removed, this amounted to virtually all the available pyritic sulfur as shown by the upper curve of figure 8. The fact that more than 100 percent of the available pyritic sulfur was removed from the 15- and 30-minute grinds was due to considerable size reduction occurring in centrifugal separation of these relatively coarse consists.

A third coal was chosen for testing because its sulfur content was highly pyritic, much of which occurred as a larger, more available particulate. The results of combined separation tests on this coal are shown in table 6 and in figure 9. Over 50 percent of the total pyritic sulfur was removed from the 90-minute ball-mill product in a reject of about 13 percent. With staged grinding, i.e., pyrite removal steps between grinding stages, this removal could probably be increased to more than 70 percent of total pyrite. Float-sink results on this coal are not yet completed.

CONCLUSIONS

Wet cleaning methods currently in practice effectively remove available pyrite from relatively coarse coal. Removal of fine pyrite, however, requires crushing the coal to very fine size. If these fine coals are cleaned by wet methods, problems of drying and wet waste disposal are introduced.

An integrated dry process was investigated that involved grinding followed by centrifugal and electrostatic separation, using three coals that are burned for power generation in the Appalachian region. Centrifugal separation removed the light, pyrite-poor portion of the crushed coal, after which the heavy fraction was submitted to electrostatic separation that concentrated the pyrite in a relatively small reject portion.

From 35 to 55 percent of the total pyritic sulfur (amounting to 70 to 100 percent of available pyritic sulfur) was removed in rejects of 10 to 15 percent. Since both centrifugal and electrostatic separation are benefited by restricting particle-size range and by maintaining the pyrite particles as large as possible, the efficiency of pyrite removal is improved by integrating grinding with the dry process.

When integrated with the grinding operation, the dry process was equally as effective as the wet process, and because of its potential advantages may warrant further research on a larger scale.

TABLE 1. - Dry removal of pyrite from closely sized fractions of finely ground Pittsburgh-seam coal via centrifugal separation

	Light fraction					Heavy fraction					
Feed size, U.S. sieve	Percent of feed	Sulfur, pct	Pyritic sulfur, pct	Portion of total sulfur, pct	Portion of total pyritic sulfur, pct	Percent of feed	Sulfur, pct	Pyritic sulfur, pct	Portion of total sulfur, pct	Portion of total pyritic sulfur, pct	Adjusted portion[1] of total pyritic sulfur, pct
60-80	89.4	2.30	0.98	86.1	81.8	10.6	3.12	1.84	13.9	18.2	17.2
80-100	91.0	2.65	1.00	89.8	87.1	9.0	3.04	1.50	10.2	12.9	14.3
100-140	93.5	2.70	1.20	91.5	88.6	6.5	3.60	2.23	8.5	11.4	17.5
140-200	86.1	2.77	1.15	81.5	71.6	13.9	3.89	2.83	18.5	28.4	20.4
200-270	89.4	2.44	0.96	80.0	68.1	10.6	5.14	3.79	20.0	31.9	30.1
270-400	91.6	2.32	0.72	72.7	50.6	8.4	9.51	7.65	27.3	49.4	58.8
400-0	88.6	3.47	1.31	91.2	95.9	11.4	2.59	0.43	8.8	4.1	3.6

[1] The percent of total pyritic sulfur contained in a 10% coarse cut of same composition as the actual coarse cut.

Note: Analyses of feed fractions are given in Table 2.

TABLE 2. - Analysis of Pittsburgh-seam coal

Fraction, U. S. sieve	Portion of feed, pct	Sulfur, pct	Portion of total sulfur, pct	Pyritic sulfur, pct	Portion of total pyritic sulfur, pct	Ash, pct	Portion of total ash, pct
16 x 60	0.8	2.03	0.7	0.75	0.6	7.91	0.9
60 x 80	2.4	2.02	2.1	.65	1.7	6.27	2.2
80 x 100	3.1	2.06	2.8	.66	2.2	6.04	2.7
100 x 140	10.1	2.27	10.0	.90	9.8	5.99	8.9
140 x 200	12.6	2.34	12.9	.97	13.2	6.20	11.4
200 x 270	10.3	2.59	11.7	1.14	12.7	6.27	9.4
270 x 400	11.9	2.60	13.5	1.18	15.1	6.20	10.8
400 x 0	48.8	2.17	46.3	.85	44.7	7.53	53.7
COMPOSITE	100.0	2.35	102.6	.97	104.3	6.94	101.3

TABLE 3. - Electrostatic separation of closely-sized blends consisting of 90 percent coal, 10 percent pyritic material

Component	Distribution of each component, percent		
	Reject	Middling	Product
	80 x 100 mesh blend		
Coal [1]	2.7	0.3	97.0
Pyritic material [2]	97.8	0.4	1.8
	270 x 400 mesh blend		
Coal [1]	1.8	6.2	92.0
Pyritic material [2]	97.9	2.0	.1

[1] Coal from Kittanning seam, comprising 90% of blend, previously cleaned by removing sink @ 1.6 sp gr.
[2] Pyritic material from Pittsburgh seam, comprising 10% of blend, previously cleaned by removing float @ 2.89 sp gr.

TABLE 4. - Combined centrifugal-electrostatic separation of pyrite from a Pittsburgh seam roof coal

Feed		Centrifugal separation				Electrostatic separation				Product of combined separations				Reject of combined separations		
Ball milling time, minutes	Pct of total pyritic sulfur in sink @ 1.6 sp gr [3]	Yield, pct of feed	Analysis of product, pct [2]		Pct of total pyritic sulfur	Yield, pct of feed	Analysis of product, pct [2]		Pct of total pyritic sulfur	Yield, pct of feed	Analysis of product, pct [2]		Pct of total pyritic sulfur	Pct of feed	Pct of total pyritic sulfur	Pct of total available pyritic sulfur
			Total sulfur	Pyritic sulfur			Total sulfur	Pyritic sulfur			Total sulfur	Pyritic sulfur				
15	28.9	50.1	4.07	1.90	52.3	42.1	3.45	1.30	30.0	92.2	3.78	1.62	82.3	7.8	17.7	61.2
	28.9	25.8	3.84	1.68	23.6	63.4	3.49	1.34	46.5	89.2	3.59	1.44	70.1	10.8	29.9	103.5
30	45.7	30.3	3.54	1.39	22.1	60.1	3.47	1.32	42.0	90.4	3.49	1.34	64.1	9.6	35.9	78.6
	45.7	44.9	3.77	1.61	39.5	44.7	3.37	1.22	29.8	89.6	3.57	1.42	69.3	10.4	30.7	67.2
60 [1]	52.8	45.2	3.54	1.39	32.3	48.8	3.65	1.49	37.1	94.0	3.59	1.44	69.4	6.0	30.6	57.9
	52.8	24.2	3.40	1.25	15.5	61.7	3.68	1.56	49.1	85.9	3.63	1.47	64.6	14.1	35.4	67.0
	52.8	11.4	3.27	1.13	6.6	77.8	3.48	1.33	52.8	89.2	3.45	1.30	59.4	10.8	40.6	76.9
	52.8					90.7	3.51	1.36	62.9	90.7	3.51	1.36	62.9	9.3	37.1	70.2

[1] All 4 runs in the 60 minute consist were made by reconstituting electrostatic separation products and adding the last cut from centrifugal separation.
[2] Pyrite sulfurs were calculated from total sulfur using the relation P.S. = .96 (T.S.) - 2.01. This relation was determined experimentally for this coal.
[3] The percent of total pyritic sulfur reporting to sink @ 1.6 sp gr is taken as the percent of available pyritic sulfur.

TABLE 5. - Combined centrifugal-electrostatic separation of pyrite from a Pittsburgh seam roof coal utilizing staged grinding

Feed			Centrifugal separation product				Electrostatic separation reject				Cumulative product total				Cumulative reject total		
Sep'n Stage	Cumulative ball milling time, minutes	Pct of total pyritic sulfur in sink @ 1.6 sp gr	Yield, pct of feed	Analysis, pct [1] Total sulfur	Analysis, pct [1] Pyritic sulfur	Pct of total pyritic sulfur	Portion of feed, pct	Analysis, pct [1] Total sulfur	Analysis, pct [1] Pyritic sulfur	Total pyritic sulfur, pct	Yield, pct of feed	Analysis, pct [1] Total sulfur	Analysis, pct [1] Pyritic sulfur	Pct of total pyritic sulfur	Pct of feed	Pct of total pyritic sulfur	Pct of total available pyritic sulfur
1	15	28.9	19.9	3.83	1.67	18.7	9.4	9.98	7.57	40.5	19.9	3.83	1.67	18.7	9.4	40.5	140.1
2	30	45.7	3.3	3.33	1.19	2.2	3.2	5.61	3.38	6.1	23.2	3.76	1.60	20.9	12.6	46.6	102.0
3	45	49.0	1.7	3.18	1.04	1.0	3.1	4.92	2.71	4.7	24.9	3.72	1.56	21.9	15.7	51.3	105.0
4	75	55.0	5.6	3.06	0.93	3.0	1.2	4.72	2.52	1.7	30.5	3.59	1.44	24.9	16.9	53.0	96.4
							Electrostatic separation product										
							42.8	3.50	1.35	32.8							

[1] Pyritic sulfurs were calculated from total sulfur using the relation P.S. = .96 (T.S.) - 2.01. This relation was determined experimentally for this coal.
[2] The percent of total pyritic sulfur reporting to sink @ 1.6 sp gr is taken as the percent of available pyritic sulfur.

TABLE 6. - Combined centrifugal-electrostatic separation of pyrite from Pittsburgh seam strip mine

Feed		Centrifugal separation product				Electrostatic separation product				Product of Combined Separation				Reject of combined separation		
Ball milling time	Pct of total pyritic sulfur in sink @ 1.6 sp gr [2]	Yield, pct of feed	Analysis of product, pct [1] Total sulfur	Analysis of product, pct [1] Pyritic sulfur	Pct of total pyritic sulfur	Yield, pct of feed	Analysis of product, pct [1] Total sulfur	Analysis of product, pct [1] Pyritic sulfur	Pct of total pyritic sulfur	Yield, pct of feed	Analysis of product, pct [1] Total sulfur	Analysis of product, pct [1] Pyritic sulfur	Pct of total pyritic sulfur	Pct of feed	Pct of total pyritic sulfur	Pct of total available pyritic sulfur [2]
15	51.3	7.3	2.26	1.17	4.7	80.8	2.67	1.56	68.9	88.1	2.64	1.53	73.6	11.9	26.4	51.5
30	59.1	19.1	2.19	1.09	10.2	71.0	2.95	1.84	64.0	90.1	2.79	1.68	74.2	9.9	25.8	43.7
60	73.2	38.7	1.98	0.88	18.5	46.1	2.54	1.44	36.2	84.8	2.28	1.18	54.7	15.2	45.3	61.9
90	76.9	58.0	2.11	1.01	32.0	29.1	2.23	1.13	18.0	87.1	2.15	1.05	50.0	12.9	50.0	65.0

[1] Pyritic sulfur is calculated by the relation P.S. = 0.99 (T.S.) - 1.079. This relation was determined experimentally for this coal.

[2] The percent of total pyritic sulfur reporting to sink @ 1.6 sp gr is referred to as the available pyritic sulfur.

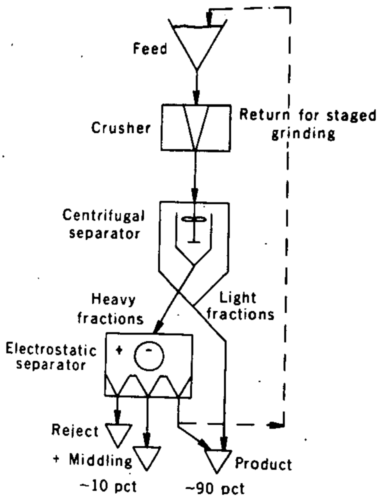

FIGURE 1. - Dry Process for Removal of Pyrite from Coal

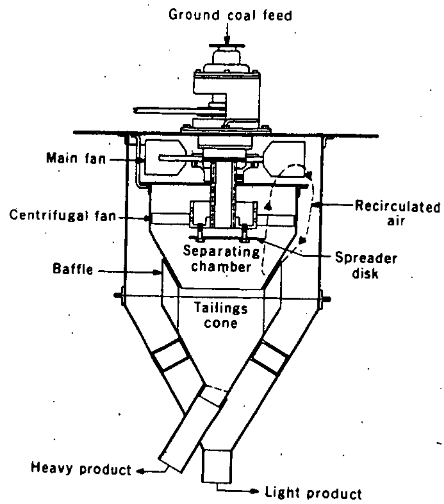

FIGURE 2. - Cross Section of Centrifugal Separator

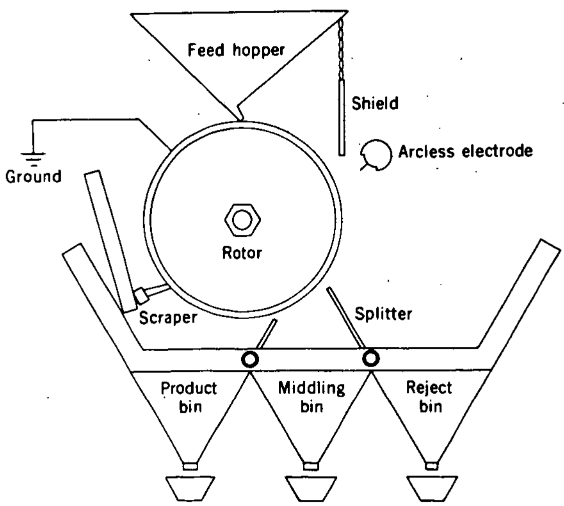

FIGURE 3. - Sketch of Electrostatic Separator

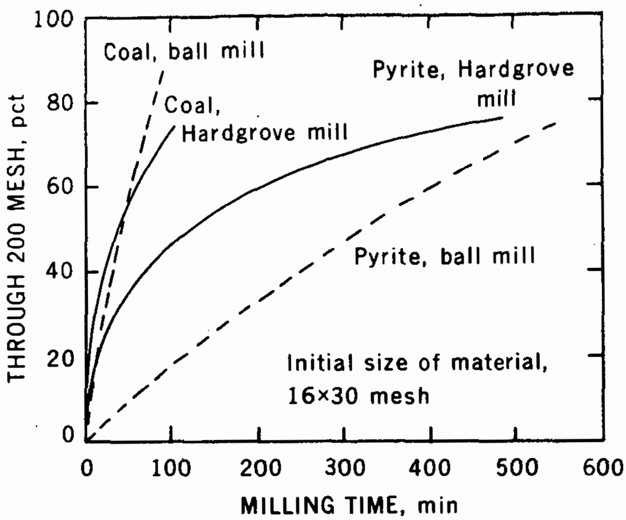

FIGURE 4. - Grindability of Pittsburgh-Seam Coal and Pyritic Material by Ball and Hardgrove Mills

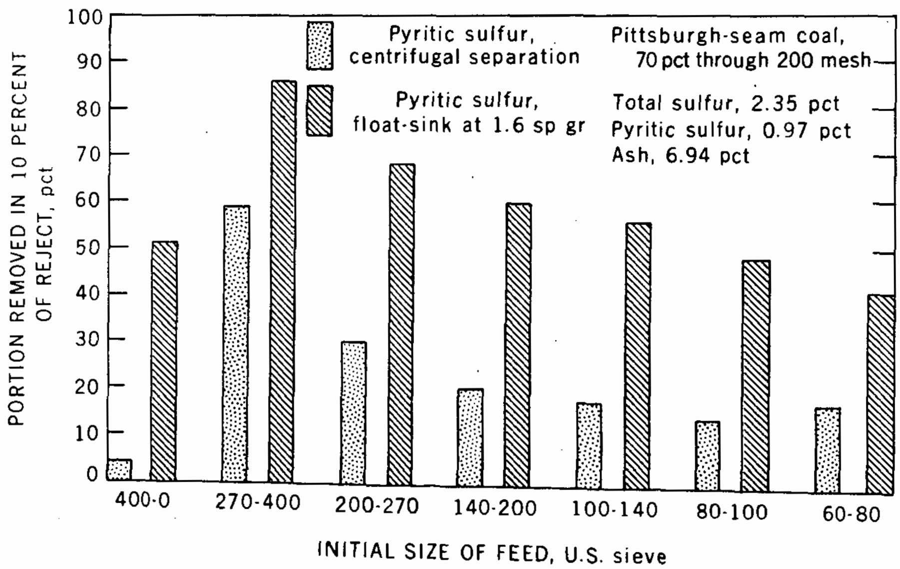

FIGURE 5. - Removal of Pyrite from Closely Sized Fractions of Finely Ground Coal by Centrifugal Separation

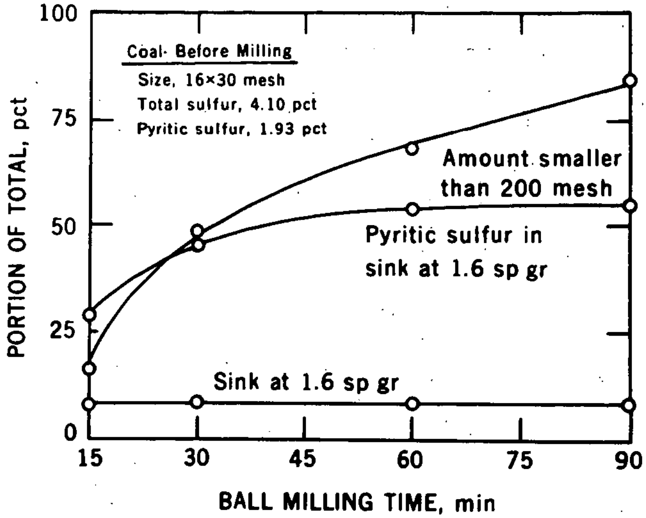

FIGURE 6. - Float-Sink Behavior of Pittsburgh-Seam Roof Coal Following Pulverization by Ball Milling

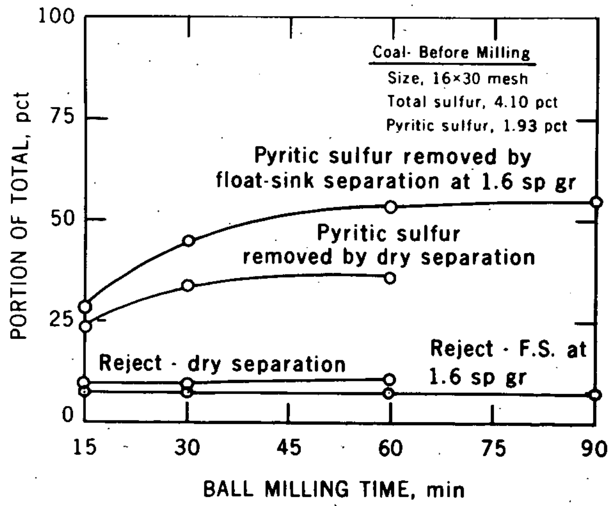

FIGURE 7. - Combined Centrifugal-Electrostatic Removal of Pyrite from a Pittsburgh-Seam Roof Coal

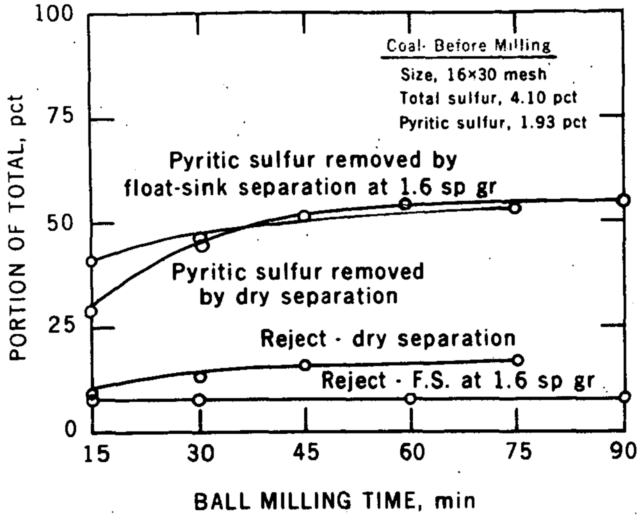

FIGURE 8. - Combined Centrifugal-Electrostatic Separation of Pyrite from a Pittsburgh-Seam Roof Coal Using Stage Grinding

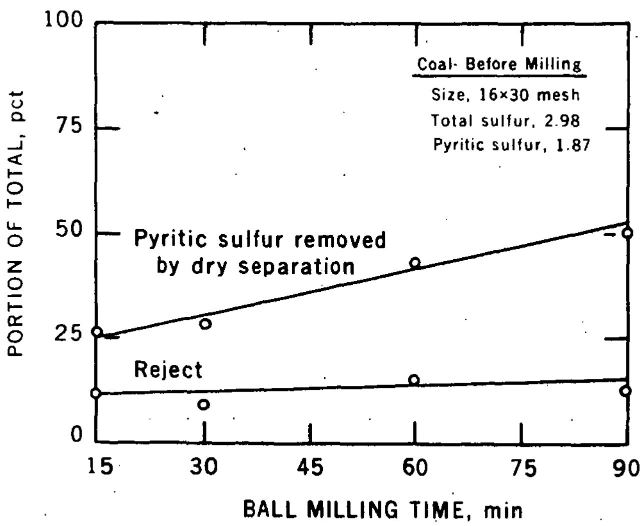

FIGURE 9. - Combined Centrifugal-Electrostatic Removal of Pyrite from a Pittsburgh-Seam Strip Coal