PERFORMANCE CHARACTERISTICS OF COAL-WASHING EQUIPMENT

Dense-Medium Coarse-Coal Vessels

By J. Hudy, Jr.

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ABSTRACT

The performance of six dense-medium washers was evaluated in five preparation plants. Three of the plants were making a two-product separation that produced a clean coal and a refuse; one plant employed dense-medium vessels in series to effect a primary and a secondary separation; and one plant was equipped with a two-compartment washer effecting two separations in one vessel. The separate secondary drum-type washer produced a low-ash metallurgical coal and an intermediate-ash product suitable for plant fuel or steam generation. The two-compartment washer produced a premium anthracite product and a middlings product. The sharpness-of-separation values ranged from good to excellent for the five primary separations and for the secondary separation.

INTRODUCTION

The profitable operation of a coal preparation plant under today's stringent product standards and ever-rising labor and equipment costs requires that the preparation engineer continually strive for maximum recovery of salable coal. Good performance data are a prerequisite to the design of a new plant or to the expansion of existing facilities, and they serve as a yardstick with which the engineer may measure the performance of his plant. Having such data and a washability analysis of the raw coal enables the preparation engineer to make a rational choice of washing equipment.

This report is the third Bureau of Mines study, in a series that will provide performance data on the principal types of coal-washing equipment. The first report was a study of concentrating tables[2] and the second a study of sand cones.[3]

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[1]Mining engineer, Pittsburgh Coal Research Center, Bureau of Mines, Pittsburgh, Pa.

[2]Deurbrouck, A. W., and E. R. Palowitch. Performance Characteristics of Coal-Washing Equipment: Concentrating Tables. BuMines Rept. of Inv. 6239, 1963, 26 pp.

[3]Deurbrouck, A. W., and J. Hudy, Jr. Performance Characteristics of Coal-Washing Equipment: Sand Cones. BuMines Rept. of Inv. 6606, 1965, 26 pp.

To meet the current product quality requirements, dense-medium vessels are cleaning an ever-increasing percentage of the total prepared coal. Today approximately 30 percent of the mechanically cleaned coal is washed in dense-medium equipment.

The first commercial dense-medium cleaning plant using magnetite in the United States went "on line" in 1946. This was the Champion No. 1 plant, built by the Link-Belt Co. under a licensing agreement with the American Cyanamide Co. Today, approximately 160 dense-medium units using magnetite medium are washing coarse coal (plus ¼ inch) at capacities ranging from 75 to 900 tons per hour.

Dense-medium processes are especially advantageous when cleaning raw, coarse coals at specific gravities that are lower than the practical range of jigs, or coals that are difficult to clean efficiently because of high percentages of near-separating gravity material. Also, dense-medium systems are capable of producing a wide range of products to meet varying demands with only minor changes or adjustments.

ACKNOWLEDGMENTS

The author appreciates the cooperation of the coal mine operators who granted permission to sample their preparation plants and to publish the test results. The continuing encouragement, support, and cooperation of the members of the Preparation Subcommittee of the American Mining Congress is gratefully acknowledged.

MAGNETITE DENSE-MEDIUM PROCESS

In general commercial usage, magnetite dense-medium coal washing is the separation of coal from the bone, shale, and other impurities in a suspension of finely divided magnetite in water, in which the coal floats and the impurities sink. The stability of the suspension of magnetite in water is maintained by the fine magnetite grind, the amount of coal and shale slimes, and the gentle agitation of the refuse-removal mechanism causing recirculation of the magnetite medium.

Apparatus

The basic apparatus of a magnetite dense-medium coal-washing process is illustrated in figure 1. The system consists of the following: (1) the separating vessel which is filled with a suspension of magnetite and water; (2) an overflow weir or some means of mechanically assisting the coal across the surface of the bath and out of the separator; (3) when a third product is desired, a middlings removal system; (4) a refuse removal system; (5) drain and rinse screens for removing magnetite medium from the clean coal, middlings, and refuse products; (6) a dense-medium sump and pump which collects the drained medium from all products and returns the medium to the separating vessel; (7) a dilute dense-medium sump and pump which collects the rinsings from the rinse screens of all products and sends the rinsings to the medium recovery apparatus; (8) a medium recovery and cleaning system which densifies and

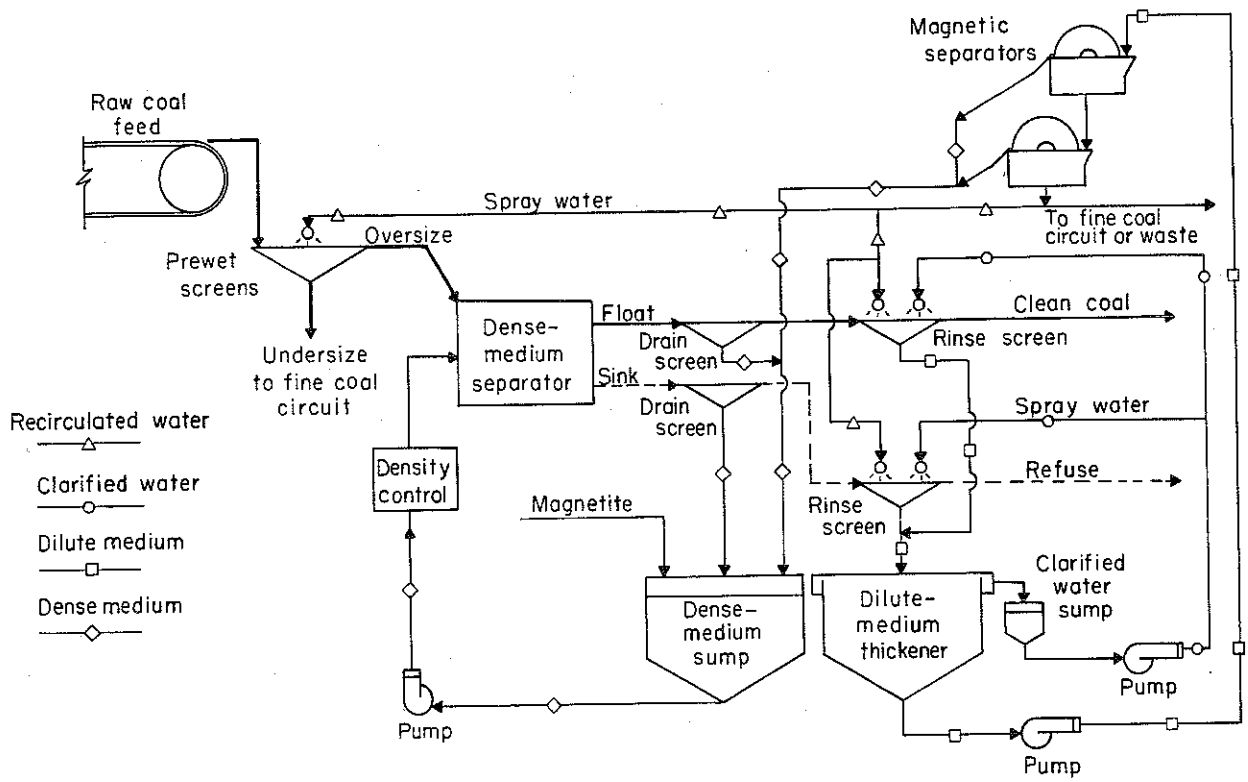

FIGURE 1. - Simplified Typical Dense-Medium Coarse-Coal Washer Flowsheet.

cleans the magnetite from the associated coal and clay slimes; (9) a fresh water supply for the rinsing sprays; (10) a magnetite feeding system which adds fresh magnetite; and (11) a density control system which maintains the desired specific gravity of the bath.

Operation

Sized feed for the vessel is prewet in a stream of circulating water and introduced at or below the bath surface. The coal floats just below the bath surface and flows, or is mechanically assisted, out of the separator with some magnetite medium. The bone, shale, and other impurities sink in the magnetite suspension and are removed from the bottom of the bath. The coal is drained, rinsed, and sized, and the refuse is drained and rinsed.

The drained portion from both products goes to the dense-medium sump for direct return to the separator to maintain the medium level and stability in the bath. The diluted medium from the rinsing portions of the product screens is piped to the dilute-medium sump where the magnetite is thickened. The thickened magnetite is pumped to a double stage of magnetic separators for further magnetite concentration and medium cleaning. Overflow water from the dilute-medium sump is returned to the circuit as prewet and spray water.

The concentrated clean magnetite from the magnetic separators is returned to the separator bath via the dense-medium sump. A portion of the water and slimes removed from the coal and refuse by the magnetic separator can either

be used as prewet water on the incoming feed, or be sent directly to a water clarifier-thickener where the solids go to a fine-coal-recovery circuit and clarified water returns to the spray system.

The size range of the raw feed that can be treated by a dense-medium vessel is from 1/8 inch to 8 inches or more. The general practice in the United States is to feed 6- or 4-inch top-size material, with a bottom size of 3/8 or 1/4 inch, to the separator. The benefits of washing finer than 1/4-inch material usually are offset by increased magnetite losses and reduced capacity.

The capacity of the separator is a function of the size consist of the feed, the quantity of near-separating gravity material in the feed, and the proportion of refuse in the feed. The width of the bath controls the capacity, which ranges from 10 to 15 tons of coal per hour per foot of bath width in the 1- to 1/2-inch size range, and from 15 to 25 tons per hour in the 3- to 2-inch size range.

The use of magnetite (5.0 specific gravity) permits practical suspension densities ranging up to 2.0 specific gravity. The lower limit for semistable suspensions is about 1.30 specific gravity.

SAMPLING AND TEST PROCEDURE

Samples of the washer products were collected after draining and rinsing. All of the vessels that were sampled received feed sized at 1/4- or 3/8-inch bottom size (9/16-inch bottom size for anthracite); the top size was approximately 5 inches except in one case where it was 8 inches. All plants appeared to be well operated and had adequate screening facilities to remove the undersize material prior to washing. The clean coal and refuse products were collected before sizing to eliminate the problem of reconstituting the products from sized fractions.

The gross samples of each product weighed at least 2,000 pounds and were comprised of 40 increments of 50 pounds or more, taken over 4 to 6 hours of normal plant operation. The samples were placed in 55-gallon drums and shipped to the Bureau of Mines laboratory for analysis.

In the laboratory the samples were air-dried, weighed, and sized on 4-, 2-, 1-, 1/2-, and 1/4-inch round-hole screens. The anthracite samples were sized on 3-1/4-, 2-7/16-, 1-5/8-, 13/16-, and 9/16-inch round-hole screens. The minus 1/4- or 9/16-inch material, which is either a degradation product or tramp material, and the feed size fractions were not further screened but analyzed for ash and sulfur only. The fractions of clean coal and refuse coarser than 1/4 or 9/16 inch were float-and-sink tested in aqueous solutions of zinc chloride, at eight specific gravity values ranging from 1.30 through 1.90. All specific gravity fractions were analyzed for ash and sulfur. The raw laboratory data were then processed through a computer, which was programed to yield distribution data from which the distribution curves were plotted and performance criteria derived.

DESCRIPTION OF PLANTS AND COALS

The dense-medium vessels included in this study were employed in three different types of flowsheets:

1. A conventional single-unit primary separator where a clean coal and a refuse product are produced.

2. A two-vessel installation where the primary separator removes the refuse material and a secondary unit rewashes the initial float product to make two salable products.

3. A two-compartment vessel where the separation effected in the first compartment removes the clean anthracite product and the second bath separates a high-ash middlings product from the heaviest refuse material. The middlings product is crushed and recleaned in the fine-coal washer.

Plant A

Plant A, located in Virginia, receives 175 to 200 tons per hour of Taggart-bed coal; of this, the 5- by ¼-inch material, approximately 130 tons per hour, is washed in a trough-type vessel which has a 5-foot weir. The ¼-inch by 28-mesh material is cleaned in equal proportions by a feldspar jig and concentrating tables. The minus 28-mesh fraction is fed to froth-flotation cells. Magnetite losses are reported to be slightly higher than ½ pound per ton of clean coal produced.

The specific gravity analysis of the feed to the vessel is given in table 1. In the raw form it contains 19.2 percent ash. The portion of coal lighter than 1.30 specific gravity amounts to 74.3 percent, while 18.9 percent of the impurity is heavier than 1.80 specific gravity. There is no appreciable quantity of coal throughout the intermediate specific gravity range; therefore, any separating specific gravity selected in this range should result in a very easy separation.

TABLE 1. - Specific gravity analyses of composite feed, plant A[1]

Size fraction and weight	Specific gravity	Direct percent		Cumulative percent	
		Weight	Ash	Weight	Ash
Plus 4 inches; 4.9 percent.....	Float-1.30	15.3	2.3	15.3	2.3
	1.30-1.35	5.8	4.1	21.1	2.8
	1.35-1.40	.0	-	21.1	2.8
	1.40-1.45	.0	-	21.1	2.8
	1.45-1.50	.0	-	21.1	2.8
	1.50-1.60	.0	-	21.1	2.8
	1.60-1.70	.2	42.8	21.3	3.1
	1.70-1.80	.5	51.2	21.8	4.2
	1.80-sink	78.2	92.2	100.0	73.1

See footnote at end of table.

TABLE 1. - Specific gravity analyses of composite feed, plant A[1]--Continued

Size fraction and weight	Specific gravity	Direct percent		Cumulative percent	
		Weight	Ash	Weight	Ash
4 by 2 inches; 18.3 percent.....	Float-1.30	53.3	2.0	53.3	2.0
	1.30-1.35	4.6	5.8	57.9	2.3
	1.35-1.40	.1	13.8	58.0	2.3
	1.40-1.45	.1	22.2	58.1	2.4
	1.45-1.50	.6	24.9	58.7	2.6
	1.50-1.60	.5	30.3	59.2	2.8
	1.60-1.70	.3	36.7	59.5	3.0
	1.70-1.80	.3	47.2	59.8	3.2
	1.80-sink	40.2	91.5	100.0	38.7
2 by 1 inch; 29.9 percent.....	Float-1.30	73.0	1.7	73.0	1.7
	1.30-1.35	4.8	6.9	77.8	2.0
	1.35-1.40	.8	14.8	78.6	2.1
	1.40-1.45	.4	21.5	79.0	2.2
	1.45-1.50	.3	25.8	79.3	2.3
	1.50-1.60	.5	31.7	79.8	2.5
	1.60-1.70	.3	38.0	80.1	2.7
	1.70-1.80	.3	46.1	80.4	2.8
	1.80-sink	19.6	89.4	100.0	19.8
1 by ½ inch; 31.9 percent.....	Float-1.30	82.1	1.6	82.1	1.6
	1.30-1.35	3.5	7.4	85.6	1.8
	1.35-1.40	1.1	13.7	86.7	2.0
	1.40-1.45	.5	21.5	87.2	2.1
	1.45-1.50	.4	25.3	87.6	2.2
	1.50-1.60	.5	32.1	88.1	2.4
	1.60-1.70	.3	39.6	88.4	2.5
	1.70-1.80	.2	46.4	88.6	2.6
	1.80-sink	11.4	88.6	100.0	12.4
½ by ¼ inch; 15.0 percent.....	Float-1.30	86.7	1.5	86.7	1.5
	1.30-1.35	3.0	6.6	89.7	1.7
	1.35-1.40	.9	12.6	90.6	1.8
	1.40-1.45	.4	19.5	91.0	1.8
	1.45-1.50	.3	25.9	91.3	1.9
	1.50-1.60	.4	32.3	91.7	2.0
	1.60-1.70	.2	40.5	91.9	2.1
	1.70-1.80	.2	47.5	92.1	2.2
	1.80-sink	7.9	88.2	100.0	9.0
Composite plus ¼ inch; 100.0 percent..	Float-1.30	74.3	1.7	74.3	1.7
	1.30-1.35	4.4	6.5	78.7	2.0
	1.35-1.40	.8	13.7	79.5	2.1
	1.40-1.45	.4	21.2	79.9	2.2
	1.45-1.50	.3	25.5	80.2	2.2
	1.50-1.60	.4	31.7	80.6	2.4
	1.60-1.70	.3	38.8	80.9	2.5
	1.70-1.80	.2	47.0	81.1	2.6
	1.80-sink	18.9	90.2	100.0	19.2

[1]Material finer than ¼ inch, amounting to 6.9 percent of sample and analyzing 11.4 percent ash, was not subjected to float-and-sink testing.

Plant B

Plant B, located in southern West Virginia, washes 300 tons per hour of 4-inch by 0 coal from the No. 2 Gas bed. Approximately 180 tons per hour of 4- by ¼-inch material is washed in a 10-foot-diameter, 7-foot-long drum; the ¼-inch by 28-mesh material is cleaned in a feldspar jig and the minus 28-mesh material in froth flotation cells. Magnetite consumption is reported to be 0.6 pound per ton of clean coal produced.

Specific gravity data for each size fraction and the composite feed are given in table 2. Approximately 67 percent of the composite plus ½-inch feed floated at 1.35 specific gravity and contained 3.4-percent ash. The sink 1.80-specific gravity material amounted to 15.6 percent and contained 87.0-percent ash. The material washed in the vessel becomes progressively lower in ash as the top size of the material decreases.

TABLE 2. - Specific gravity analyses of composite feed, plant B[1]

Size fraction and weight	Specific gravity	Direct percent		Cumulative percent	
		Weight	Ash	Weight	Ash
Plus 4 inches; 5.2 percent.....	Float-1.30	47.6	2.4	47.6	2.4
	1.30-1.35	7.3	5.9	54.9	2.9
	1.35-1.40	2.4	10.8	57.3	3.2
	1.40-1.45	.0	-	57.3	3.2
	1.45-1.50	4.1	25.9	61.4	4.7
	1.50-1.60	7.3	32.7	68.7	7.7
	1.60-1.70	2.0	38.0	70.7	8.6
	1.70-1.80	.2	45.9	70.9	8.6
	1.80-sink	29.1	87.3	100.0	31.5
4 by 2 inches; 26.1 percent.....	Float-1.30	45.9	2.3	45.9	2.3
	1.30-1.35	9.9	7.5	55.8	3.2
	1.35-1.40	4.5	12.6	60.3	3.9
	1.40-1.45	3.6	20.1	63.9	4.8
	1.45-1.50	4.5	24.8	68.4	6.2
	1.50-1.60	5.6	31.2	74.0	8.1
	1.60-1.70	2.2	38.7	76.2	8.9
	1.70-1.80	1.3	46.2	77.5	9.6
	1.80-sink	22.5	88.1	100.0	27.2
2 by 1 inch; 32.6 percent.....	Float-1.30	57.4	2.5	57.4	2.5
	1.30-1.35	11.7	8.4	69.1	3.5
	1.35-1.40	6.4	13.2	75.5	4.3
	1.40-1.45	3.6	18.8	79.1	5.0
	1.45-1.50	2.5	24.1	81.6	5.6
	1.50-1.60	2.9	31.0	84.5	6.4
	1.60-1.70	1.3	39.5	85.8	7.0
	1.70-1.80	.8	47.6	86.6	7.3
	1.80-sink	13.4	87.0	100.0	18.0

See footnote at end of table.

TABLE 2. - Specific gravity analyses of composite feed, plant B[1]--Continued

Size fraction and weight	Specific gravity	Direct percent		Cumulative percent	
		Weight	Ash	Weight	Ash
1 by ½ inch; 24.5 percent.....	Float-1.30	57.6	2.8	57.6	2.8
	1.30-1.35	13.6	8.0	71.2	3.8
	1.35-1.40	5.7	13.5	76.9	4.5
	1.40-1.45	2.8	19.1	79.7	5.0
	1.45-1.50	2.3	23.5	82.0	5.5
	1.50-1.60	3.1	30.0	85.1	6.4
	1.60-1.70	1.6	38.0	86.7	7.0
	1.70-1.80	.9	46.8	87.6	7.4
	1.80-sink	12.4	85.7	100.0	17.1
½ by ¼ inch; 11.6 percent.....	Float-1.30	58.5	2.3	58.5	2.3
	1.30-1.35	14.6	7.3	73.1	3.3
	1.35-1.40	5.3	12.4	78.4	3.9
	1.40-1.45	2.7	18.0	81.1	4.4
	1.45-1.50	2.0	22.7	83.1	4.8
	1.50-1.60	2.7	29.0	85.8	5.6
	1.60-1.70	1.5	37.6	87.3	6.1
	1.70-1.80	1.1	40.6	88.4	6.6
	1.80-sink	11.6	84.9	100.0	15.7
Plus ¼ inch; 100.0 percent.....	Float-1.30	54.7	2.5	54.7	2.5
	1.30-1.35	12.0	7.8	66.7	3.4
	1.35-1.40	5.4	13.0	72.1	4.2
	1.40-1.45	3.1	18.9	75.2	4.8
	1.45-1.50	2.9	23.8	78.1	5.5
	1.50-1.60	3.8	30.8	81.9	6.6
	1.60-1.70	1.6	37.8	83.5	7.2
	1.70-1.80	.9	46.0	84.4	7.7
	1.80-sink	15.6	87.0	100.0	20.1

[1]Material finer than ¼ inch, amounting to 4.1 percent of sample and analyzing 16.7 percent ash, was not subjected to float-and-sink testing.

Plant C

Plant C, also located in West Virginia, receives 250 tons per hour of Sewell-bed coal; of this, approximately 130 tons of 8- by 3/8-inch material is washed in a trough-type vessel which has a 4-foot weir. The 3/8-inch by 28-mesh fraction is cleaned in dense-medium cyclones and the minus 28-mesh fines are cleaned in froth flotation units. Magnetite consumption is reported to be 1.3 pounds per ton of raw feed.

The specific gravity analysis of the coal cleaned in this vessel (table 3) shows that this coal analyzed at 30.2 percent ash. It contained 30.1 percent impurity that was heavier than the 1.80 specific gravity limit on usable material. The amount of high-ash impurity in itself constituted a washing problem. In addition, this coal contains more material of intermediate density, with 23.4 percent in the 1.35 to 1.80 specific gravity range.

TABLE 3. - Specific gravity analyses of composite feed, plant C[1]

Size fraction and weight	Specific gravity	Direct percent		Cumulative percent	
		Weight	Ash	Weight	Ash
Plus 4 inches; 7.6 percent.....	Float-1.30	9.1	2.0	9.1	2.0
	1.30-1.35	1.0	5.4	10.1	2.3
	1.35-1.40	.0	-	10.1	2.3
	1.40-1.45	.0	-	10.1	2.3
	1.45-1.50	1.4	26.7	11.5	5.3
	1.50-1.60	3.7	29.9	15.2	11.3
	1.60-1.70	6.5	42.1	21.7	20.5
	1.70-1.80	4.0	48.1	25.7	24.8
	1.80-sink	74.3	81.7	100.0	67.1
4 by 2 inches; 13.7 percent.....	Float-1.30	14.6	1.9	14.6	1.9
	1.30-1.35	1.7	4.8	16.3	2.2
	1.35-1.40	1.3	13.4	17.6	3.0
	1.40-1.45	1.4	18.7	19.0	4.2
	1.45-1.50	3.6	24.6	22.6	7.4
	1.50-1.60	10.3	31.7	32.9	15.0
	1.60-1.70	11.8	39.9	44.7	21.6
	1.70-1.80	7.5	47.1	52.2	25.3
	1.80-sink	47.8	73.3	100.0	48.2
2 by 1 inch; 26.3 percent.....	Float-1.30	34.2	2.0	34.2	2.0
	1.30-1.35	4.4	5.5	38.6	2.4
	1.35-1.40	2.4	13.6	41.0	3.1
	1.40-1.45	2.8	19.0	43.8	4.1
	1.45-1.50	3.8	24.0	47.6	5.7
	1.50-1.60	7.8	31.2	55.4	9.2
	1.60-1.70	7.0	39.5	62.4	12.6
	1.70-1.80	4.8	44.2	67.2	14.9
	1.80-sink	32.8	69.2	100.0	32.7
1 by ½ inch; 37.2 percent.....	Float-1.30	53.7	2.1	53.7	2.1
	1.30-1.35	7.8	5.1	61.5	2.5
	1.35-1.40	2.6	13.0	64.1	2.9
	1.40-1.45	2.2	18.9	66.3	3.4
	1.45-1.50	2.5	23.9	68.8	4.2
	1.50-1.60	4.5	31.1	73.3	5.8
	1.60-1.70	4.1	39.6	77.4	7.6
	1.70-1.80	3.3	47.5	80.7	9.2
	1.80-sink	19.3	67.0	100.0	20.4
½ by ¼ inch; 15.2 percent.....	Float-1.30	61.2	2.0	61.2	2.0
	1.30-1.35	10.2	5.0	71.4	2.4
	1.35-1.40	2.7	11.7	74.1	2.8
	1.40-1.45	1.9	18.3	76.0	3.2
	1.45-1.50	1.8	23.5	77.8	3.6
	1.50-1.60	3.1	30.6	80.9	4.7
	1.60-1.70	2.8	39.4	83.7	5.8
	1.70-1.80	2.5	46.5	86.2	7.0
	1.80-sink	13.8	66.9	100.0	15.3

See footnote at end of table.

TABLE 3. - Specific gravity analyses of composite feed, plant C[1]--Continued

Size fraction and weight	Specific gravity	Direct percent		Cumulative percent	
		Weight	Ash	Weight	Ash
Plus ¼ inch; 100.0 percent.....	Float-1.30	40.7	2.1	40.7	2.1
	1.30-1.35	5.8	5.1	46.5	2.4
	1.35-1.40	2.2	12.9	48.7	2.9
	1.40-1.45	2.1	18.8	50.8	3.6
	1.45-1.50	2.9	24.0	53.7	4.7
	1.50-1.60	6.0	31.2	59.7	7.4
	1.60-1.70	5.9	39.8	65.6	10.3
	1.70-1.80	4.3	46.4	69.9	12.5
	1.80-sink	30.1	71.4	100.0	30.2

[1]Material finer than ¼ inch, amounting to 2.1 percent of the sample and analyzing 12.4 percent ash, was not subjected to float-and-sink testing.

In the individual size fractions, the float-1.35 specific gravity material increases as the feed-particle top size decreases; 93.6 percent of this material is of 2-inch top size or less. Also, the ash content becomes progressively lower as the top size decreases.

Plant D

Plant D, located in western Pennsylvania, washes approximately 250 tons per hour of Pittsburgh-bed coal in each circuit. The total feed is screened at ¼ inch; the undersize is cleaned by tabling and froth flotation, and the oversize (200 tph) is processed in a primary 10-foot-diameter by 6-foot-long drum where the heaviest impurity is rejected. The float coal is rinsed, drained, and then conveyed to the secondary drum, also 10 feet in diameter by 6 feet long, where a separation is made at a lower specific gravity to produce a float product of metallurgical quality and a sink product for steam generation. The total magnetite consumption averages 0.9 pound per ton of clean coal produced.

A specific gravity analysis of the feed for the primary vessel is shown in table 4 and for the secondary vessel in table 5. The primary dense-medium vessel was operated at 1.56 specific gravity; therefore, material in the feed to the secondary vessel, having a specific gravity greater than 1.56, is either misplaced from the primary separation or is the result of degradation in the process.

TABLE 4. - Specific gravity analyses of composite feed, plant D primary[1]

Size fraction and weight	Specific gravity	Direct percent		Cumulative percent	
		Weight	Ash	Weight	Ash
Plus 2 inches; 20.4 percent.....	Float-1.30	48.0	4.5	48.0	4.5
	1.30-1.35	15.3	7.8	63.3	5.3
	1.35-1.40	6.2	14.8	69.5	6.1
	1.40-1.45	2.3	20.7	71.8	6.6
	1.45-1.50	1.4	25.8	73.2	7.0
	1.50-1.60	1.2	31.5	74.4	7.4
	1.60-1.70	1.0	40.0	75.4	7.8
	1.70-1.80	1.4	49.0	76.8	8.5
	1.80-sink	23.2	86.9	100.0	26.7
2 by 1 inch; 31.3 percent.....	Float-1.30	39.5	4.3	39.5	4.3
	1.30-1.35	13.0	8.0	52.5	5.2
	1.35-1.40	5.9	14.5	58.4	6.1
	1.40-1.45	3.1	20.0	61.5	6.8
	1.45-1.50	1.7	23.4	63.2	7.3
	1.50-1.60	2.2	30.2	65.4	8.1
	1.60-1.70	1.5	38.7	66.9	8.7
	1.70-1.80	1.2	43.8	68.1	9.4
	1.80-sink	31.9	84.1	100.0	33.2
1 by ½ inch; 32.9 percent.....	Float-1.30	47.7	4.4	47.7	4.4
	1.30-1.35	16.4	8.1	64.1	5.3
	1.35-1.40	6.1	14.3	70.2	6.1
	1.40-1.45	3.0	19.2	73.2	6.6
	1.45-1.50	1.7	23.5	74.9	7.0
	1.50-1.60	1.9	29.2	76.8	7.6
	1.60-1.70	1.1	36.4	77.9	8.0
	1.70-1.80	.8	42.9	78.7	8.4
	1.80-sink	21.3	85.2	100.0	24.7
½ by ¼ inch; 15.4 percent.....	Float-1.30	50.4	3.9	50.4	3.9
	1.30-1.35	19.1	7.7	69.5	4.9
	1.35-1.40	5.6	13.8	75.1	5.6
	1.40-1.45	2.4	18.6	77.5	6.0
	1.45-1.50	1.4	22.9	78.9	6.3
	1.50-1.60	1.5	28.2	80.4	6.7
	1.60-1.70	.9	35.8	81.3	7.0
	1.70-1.80	.7	39.5	82.0	7.3
	1.80-sink	18.0	83.8	100.0	21.1
Plus ¼ inch; 100.0 percent.....	Float-1.30	45.8	4.3	45.8	4.3
	1.30-1.35	15.5	7.9	61.3	5.2
	1.35-1.40	6.0	14.4	67.3	6.0
	1.40-1.45	2.9	19.6	70.2	6.6
	1.45-1.50	1.6	23.7	71.8	7.0
	1.50-1.60	1.7	29.6	73.5	7.5
	1.60-1.70	1.2	37.9	74.7	8.0
	1.70-1.80	1.0	44.7	75.7	8.5
	1.80-sink	24.3	85.1	100.0	27.1

[1]The minus ¼-inch material, amounting to 1.2 percent of sample and analyzing 19.0 percent ash, was not subjected to float-and-sink testing.

TABLE 5. - Specific gravity analyses of composite feed, plant D secondary[1]

Size fraction and weight	Specific gravity	Direct percent		Cumulative percent	
		Weight	Ash	Weight	Ash
Plus 2 inches; 18.3 percent.....	Float-1.30	65.5	4.6	65.5	4.6
	1.30-1.35	20.5	7.7	86.0	5.3
	1.35-1.40	7.1	15.1	93.1	6.1
	1.40-1.45	3.6	19.8	96.7	6.6
	1.45-1.50	1.6	24.7	98.3	6.9
	1.50-1.60	1.5	29.7	99.8	7.2
	1.60-1.70	.1	38.5	99.9	7.2
	1.70-1.80	.1	45.5	100.0	7.3
	1.80-sink	.0	-	.0	-
2 by 1 inch; 30.2 percent.....	Float-1.30	63.4	4.4	63.4	4.4
	1.30-1.35	19.5	8.0	82.9	5.3
	1.35-1.40	7.8	14.9	90.7	6.1
	1.40-1.45	4.4	19.9	95.1	6.7
	1.45-1.50	2.6	25.0	97.7	7.2
	1.50-1.60	1.9	30.0	99.6	7.6
	1.60-1.70	.2	36.8	99.8	7.7
	1.70-1.80	.1	43.6	99.9	7.7
	1.80-sink	.1	58.5	100.0	7.8
1 by ½ inch; 33.4 percent.....	Float-1.30	62.6	4.3	62.6	4.3
	1.30-1.35	21.8	8.1	84.4	5.3
	1.35-1.40	7.2	14.2	91.6	6.0
	1.40-1.45	3.7	18.8	95.3	6.5
	1.45-1.50	2.2	23.1	97.5	6.9
	1.50-1.60	1.8	27.8	99.3	7.2
	1.60-1.70	.3	34.4	99.6	7.3
	1.70-1.80	.2	40.0	99.8	7.4
	1.80-sink	.2	62.3	100.0	7.5
½ by ¼ inch; 18.1 percent.....	Float-1.30	64.4	4.0	64.4	4.0
	1.30-1.35	23.7	7.8	88.1	5.0
	1.35-1.40	6.1	13.8	94.2	5.6
	1.40-1.45	2.5	18.4	96.7	5.9
	1.45-1.50	1.3	22.4	98.0	6.1
	1.50-1.60	1.2	27.1	99.2	6.4
	1.60-1.70	.4	32.8	99.6	6.5
	1.70-1.80	.1	36.5	99.7	6.5
	1.80-sink	.3	58.8	100.0	6.7
Plus ¼ inch; 100.0 percent.....	Float-1.30	63.6	4.3	63.6	4.3
	1.30-1.35	21.3	7.9	84.9	5.2
	1.35-1.40	7.1	14.5	92.0	5.9
	1.40-1.45	3.7	19.3	95.7	6.4
	1.45-1.50	2.0	23.9	97.7	6.8
	1.50-1.60	1.7	28.6	99.4	7.2
	1.60-1.70	.3	34.8	99.7	7.3
	1.70-1.80	.1	40.2	99.8	7.3
	1.80-sink	.2	60.6	100.0	7.4

[1]The minus ¼-inch material, amounting to 1.2 percent of sample and analyzing 8.0 percent ash, was not subjected to float-and-sink testing.

Plant E

Plant E, located in eastern Pennsylvania, washes approximately 500 tons per hour of Mammoth-seam anthracite. The feed is screened at 9/16 inch; the undersize is cleaned in a dense-medium cone and Hydrotator[4] separators, and the oversize (300 tons per hour) is washed in a 12-foot-diameter by 20-foot-long, two-compartment, dense-medium drum where the clean anthracite product is floated in the first compartment. The sink material from the first compartment is fed to the second compartment. A bath of higher specific gravity separates a middlings product (float) from the final refuse (sink). The middlings product is crushed to minus 1/2 inch and recleaned in the dense-medium cone and Hydrotators. The total magnetite consumption is approximately 1 pound per ton of clean coal.

The specific gravity analyses of size fractions of the feed for the two-compartment washer is given in table 6. The clean anthracite coal bulks largely in the range from 1.55 to 1.70 specific gravity. The feed analyzed 44.1 percent ash and contained 42.3 percent impurity heavier than 1.90 specific gravity.

TABLE 6. - Specific gravity analyses of composite feed, plant E[1]

Size fraction and weight	Specific gravity	Direct percent		Cumulative percent	
		Weight	Ash	Weight	Ash
3-1/4 inches; 29.0 percent.....	Float-1.55	1.3	5.8	1.3	5.8
	1.55-1.60	16.2	5.1	17.5	5.2
	1.60-1.65	19.8	8.1	37.3	6.7
	1.65-1.70	7.7	13.5	45.0	7.9
	1.70-1.75	3.3	21.1	48.3	8.8
	1.75-1.80	1.3	26.4	49.6	9.2
	1.80-1.85	1.9	31.9	51.5	10.1
	1.85-1.90	1.0	37.4	52.5	10.6
	1.90-sink	47.5	92.5	100.0	49.5
3-1/4 by 2-7/16 inches; 16.5 percent..	Float-1.55	1.4	5.7	1.4	5.7
	1.55-1.60	21.1	4.9	22.5	4.9
	1.60-1.65	14.7	9.2	37.2	6.6
	1.65-1.70	5.8	15.7	43.0	7.8
	1.70-1.75	3.9	19.6	46.9	8.8
	1.75-1.80	2.1	27.1	49.0	9.6
	1.80-1.85	1.8	32.0	50.8	10.4
	1.85-1.90	1.0	37.2	51.8	10.9
	1.90-sink	48.2	89.9	100.0	49.0

See footnote at end of table.

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

TABLE 6. - Specific gravity analyses of composite feed, plant E[1]--Continued

Size fraction and weight	Specific gravity	Direct percent		Cumulative percent	
		Weight	Ash	Weight	Ash
2-7/16 by 1-5/8 inches; 23.6 percent..	Float-1.55	1.0	5.4	1.0	5.4
	1.55-1.60	21.2	4.9	22.2	4.9
	1.60-1.65	19.3	8.6	41.5	6.6
	1.65-1.70	7.6	13.5	49.1	7.7
	1.70-1.75	4.0	18.9	53.1	8.5
	1.75-1.80	3.1	25.2	56.2	9.4
	1.80-1.85	2.1	32.1	58.3	10.3
	1.85-1.90	1.1	37.3	59.4	10.8
	1.90-sink	40.6	88.4	100.0	42.3
1-5/8 by 13/16 inch; 25.0 percent.....	Float-1.55	1.9	5.8	1.9	5.8
	1.55-1.60	19.6	5.1	21.5	5.2
	1.60-1.65	21.0	8.1	42.5	6.6
	1.65-1.70	8.0	13.8	50.5	7.8
	1.70-1.75	5.3	18.5	55.8	8.8
	1.75-1.80	3.7	24.4	59.5	9.7
	1.80-1.85	3.2	31.5	62.7	10.8
	1.85-1.90	2.1	36.0	64.8	11.7
	1.90-sink	35.2	86.2	100.0	37.9
13/16 by 9/16 inch; 5.9 percent.....	Float-1.55	2.5	6.0	2.5	6.0
	1.55-1.60	17.0	5.1	19.5	5.2
	1.60-1.65	19.4	7.7	38.9	6.4
	1.65-1.70	7.0	13.6	45.9	7.5
	1.70-1.75	4.8	17.6	50.7	8.5
	1.75-1.80	4.6	22.1	55.3	9.6
	1.80-1.85	4.5	29.9	59.8	11.2
	1.85-1.90	3.5	36.2	63.3	12.5
	1.90-sink	36.7	82.0	100.0	38.0
Plus 9/16 inch; 100.0 percent.....	Float-1.55	1.5	5.7	1.5	5.7
	1.55-1.60	19.1	5.0	20.6	5.0
	1.60-1.65	19.1	8.3	39.7	6.6
	1.65-1.70	7.4	13.8	47.1	7.7
	1.70-1.75	4.1	19.3	51.2	8.7
	1.75-1.80	2.7	25.0	53.9	9.5
	1.80-1.85	2.4	31.6	56.3	10.4
	1.85-1.90	1.4	36.7	57.7	11.1
	1.90-sink	42.3	89.2	100.0	44.1

[1]Material finer than 9/16 inch, amounting to 3.2 percent of sample and analyzing 37.9 percent ash, was not subjected to float-and-sink testing.

PERFORMANCE CRITERIA

The performance criteria used in this report are those in common usage; hence, only summary definitions are given. More complete definitions may be

found in a paper by Yancey and Geer.[5] All performance criteria values are generally considered to be constant only for a given size consist, feed rate, and quality of operation.

Dependent Criteria

Performance criteria that depend both on the washing characteristics of the coal being treated and on the sharpness of the separation achieved by the washer are usually called dependent criteria, and include recovery efficiency, misplaced material, and ash error.

Recovery efficiency is defined as the ratio, expressed in percentage, of the yield of washed coal to the yield of float coal of the same ash content, shown to be present in the feed by the specific gravity analysis.[6]

Total misplaced material is that percentage of the feed which reported to the wrong product. For sharp separations, the misplaced material is that material having specific gravity values close to the specific gravity of separation, and it thus correlates with the amount of near-gravity material.[7]

Near-gravity material is the percentage of material in the feed within ±0.10 specific gravity unit from the specific gravity of the separation.

Ash error is closely related to recovery efficiency and is of practical importance because it indicates the difference between the ash content of the clean-coal product and the theoretical ash from the washability data at the same yield.

Independent Criteria

Performance criteria which are characteristic of the washing unit and are substantially unaffected by the specific gravity composition of the raw coal are probable error, error area, and imperfection factor. They are commonly referred to as the sharpness-of-separation criteria.

Probable error is measured directly from the distribution curve. It is the slope of the distribution curve, and it equals one-half the specific gravity difference between the 25- and 75-percent ordinates on the curve.

Error area, the area between the actual distribution curve and the theoretically perfect distribution curve, is a measure of the sharpness of the separation between clean coal and refuse. For a theoretically perfect

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[5]Yancey, H. F., and M. R. Geer. Efficiency and Sharpness of Separation in Evaluating Coal-Washery Performance. Trans. AIME, v. 190, 1951, pp. 507-517.

[6]Yancey, H. F., and M. R. Geer. Performance of a Baum-Type Coal Washing Jig. BuMines Rept. of Inv. 3371, 1938, 18 pp.

[7]Lyons, O. R. Comparative Effectiveness of Coal Cleaning Equipment. Trans. AIME, v. 193, 1952, pp. 895-902.

separation the error area is zero. Error area is measured in square centimeters when drawn to a standard scale.[8]

The sharpness of separation for most cleaning devices diminishes with increasing specific gravity of separation. Recognizing this, Cerchar[9] (Centre d'Études et Recherches des Charbonnages de France) developed the imperfection factor, which, for jigs, tables, and other equipment using water as the separating medium, is equal to the probable error divided by the specific gravity of separation (from the distribution curve), minus the specific gravity of the separating medium. Later studies of the imperfection factor, as related to dense-medium vessels, indicate that a more constant imperfection-factor value may be obtained by dividing the probable error by the specific gravity of separation only. Imperfection factor thus corrects for the increase in probable error and results in a numerical figure that characterizes a particular cleaning device regardless of the separating gravity.

UNIT PERFORMANCE

In this presentation of performance data of the five washers, the various size fractions are not always discussed individually because they are in excellent agreement. The medium densities in the vessels sampled were all manually controlled, based on measuring the pulp density using a manual pulp density scale.

Plant A

The performance characteristics of the dense-medium vessel in plant A are summarized in table 7. A washed product of 2.1 percent ash was obtained from a feed that analyzed 21.9 percent ash. The reject material contained 85.5 percent ash. The actual recovery was 76.2 percent, and the recovery efficiency was 99.8 percent. The high efficiency was anticipated since the raw coal contained only 5.0 percent of near-gravity material at the 1.41 separating density. From the distribution curve (fig. 2) the error area was found to be 16, the probable error 0.028, and the imperfection factor 0.020. The elimination of impurity heavier than 1.60 specific gravity was complete.

Plant B

A summary of the performance of the dense-medium washer in plant B is given by size fractions in table 8. The float product of 4.8 percent ash was recovered from a feed of 20.6 percent ash at a 72.6-percent recovery. The recovery efficiency of this separation was 97.6 percent, which was rather low considering that only 15.0 percent of near-gravity material was present at the 1.44 specific gravity of separation.

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[8]Driessen, M. G. The Use of Centrifugal Force for Cleaning Fine Coal in Heavy Liquids and Suspensions, With Special Reference to the Cyclone Washer. J. Inst. Fuel, v. 19, No. 105, December 1945, pp. 33-45.

[9]Cheradame, R. J., P. L. R. Saint-Guilhem, and P. Belugou. Evaluating Preparation Results. Coal Age, v. 50, April 1950, pp. 80-83

TABLE 7. - Summary of performance data, plant A

Size.....inches..	Plus 4	4 by 2	2 by 1	1 by ½	½ by ¼	Plus ¼
Screen analysis, percent:						
Feed.....	4.9	18.3	29.9	31.9	15.0	100.0
Clean coal.....	1.9	14.9	30.5	35.9	16.8	100.0
Refuse.....	14.8	28.9	28.1	18.8	9.4	100.0
Ash, percent:						
Feed.....	73.1	38.7	19.8	12.4	9.0	21.9
Clean coal.....	2.8	2.3	2.1	2.0	1.9	2.1
Refuse.....	91.5	88.9	83.7	80.2	81.4	85.5
Actual recovery.....percent..	20.8	58.0	78.4	86.7	91.1	76.2
Theoretical recovery.....do....	21.1	58.0	78.4	86.8	91.4	76.3
Efficiency.....do....	98.6	100.0	100.0	99.9	99.7	99.8
Ash error.....do....	0.1	0.0	0.0	0.0	0.0	0.0
Float in refuse.....percent of product..	0.40	0.16	1.20	2.44	3.66	1.20
Sink in clean coal.....do.....	0.00	0.04	0.10	0.18	0.18	0.14
Total misplaced material.....percent of feed..	0.32	0.09	0.34	0.48	0.49	0.40
Near-gravity ±0.10 material.....do.....	21.0	11.6	6.4	3.6	1.3	5.0
Specific gravity of separation.....	1.35	1.38	1.40	1.42	1.48	1.41
Probable error, specific gravity.....	0.012	0.020	0.020	0.028	0.052	0.028
Imperfection factor.....	0.009	0.014	0.014	0.020	0.035	0.020
Error area.....	8	10	11	15	28	16
Distribution, percent to washed coal:						
Float-1.30.....	100.0	99.9	99.8	99.8	99.8	99.8
1.30-1.35.....	94.5	100.0	99.6	99.6	99.4	99.3
1.35-1.40.....	0.0	58.0	82.8	94.0	97.1	89.6
1.40-1.45.....	0.0	0.0	18.4	48.3	83.6	39.6
1.45-1.50.....	0.0	0.0	0.0	0.0	56.0	6.8
1.50-1.60.....	0.0	0.0	0.0	0.0	23.6	2.7
1.60-1.70.....	0.0	0.0	0.0	0.0	0.0	0.0
1.70-1.80.....	0.0	0.0	0.0	0.0	0.0	0.0
1.80-sink.....	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 8. - Summary of performance data, plant B

Size.....inches..	Plus 4	4 by 2	2 by 1	1 by ½	½ by ¼	Plus ¼
Screen analysis, percent:						
Feed.....	5.3	26.1	32.5	24.5	11.6	100.0
Clean coal.....	2.9	24.1	33.8	26.4	12.8	100.0
Refuse.....	11.8	31.4	29.1	19.3	8.4	100.0
Ash, percent:						
Feed.....	31.5	27.2	18.0	17.1	15.7	20.6
Clean coal.....	3.2	4.4	4.8	5.3	5.1	4.8
Refuse.....	69.5	62.5	60.7	60.6	62.9	62.5
Actual recovery.....percent..	57.3	60.8	76.4	78.6	81.6	72.6
Theoretical recovery.....do....	57.3	62.2	78.3	81.0	84.2	74.4
Efficiency.....do....	100.0	97.6	97.6	97.1	96.9	97.6
Ash error.....do....	0.0	0.4	0.3	0.4	0.6	0.3
Float in refuse.....percent of product..	0.0	5.8	12.5	15.0	17.2	9.4
Sink in clean coal.....do.....	0.0	2.1	1.3	1.5	1.5	1.9
Total misplaced material.....percent of feed..	0.0	3.0	3.9	4.4	4.4	3.9
Near-gravity ±0.10 material.....do.....	13.9	18.8	15.4	10.3	6.8	15.0
Specific gravity of separation.....	1.40	1.42	1.44	1.47	1.52	1.44
Probable error, specific gravity.....	0.012	0.028	0.035	0.052	0.053	0.032
Imperfection factor.....	0.008	0.020	0.024	0.035	0.035	0.022
Error area.....	7	16	20	32	55	25
Distribution, percent to washed coal:						
Float-1.30.....	100.0	98.0	98.4	98.0	97.9	98.4
1.30-1.35.....	100.0	96.8	96.6	96.7	97.0	96.9
1.35-1.40.....	100.0	93.0	92.6	92.8	94.8	93.6
1.40-1.45.....	0.0	47.4	59.4	75.1	88.7	63.7
1.45-1.50.....	0.0	5.4	18.6	47.5	72.3	22.9
1.50-1.60.....	0.0	0.0	2.6	15.1	35.4	6.5
1.60-1.70.....	0.0	0.0	0.0	5.0	10.7	2.3
1.70-1.80.....	0.0	0.0	0.0	0.0	14.8	2.0
1.80-sink.....	0.0	0.0	0.0	0.0	0.7	0.0

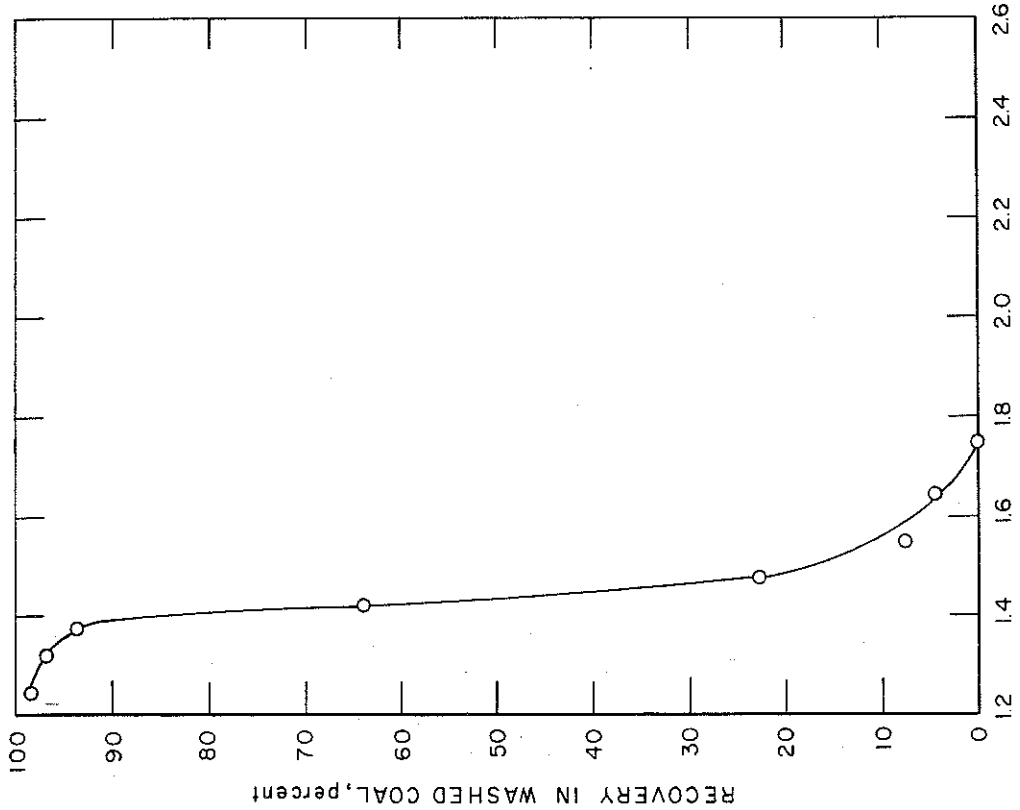

FIGURE 3. - Recovery in Washed Coal Versus Specific Gravity, Plant B.

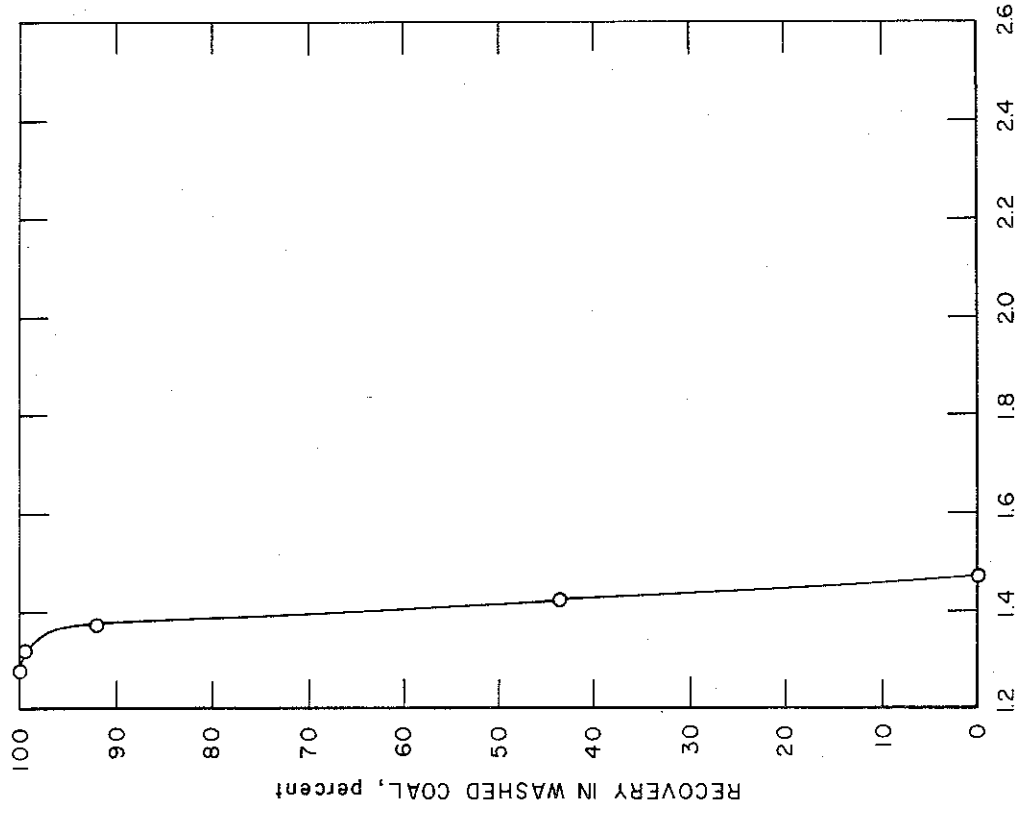

FIGURE 2. - Recovery in Washed Coal Versus Specific Gravity, Plant A.

The distribution curve (fig. 3) indicates that only material heavier than 1.80 specific gravity was completely rejected. The error area was 25, the probable error 0.032, and the imperfection factor 0.022.

Plant C

Performance summary of this vessel is shown in table 9. The composite separation was made at 1.35 specific gravity. The float product of 2.5 percent ash was recovered from a feed of 30.2 percent ash at a 43.1-percent recovery.

TABLE 9. - Summary of performance data, plant C

Size.....inches..	Plus 4	4 by 2	2 by 1	1 by ½	½ by ¼	Plus ¼
Screen analysis, percent:						
Feed	7.6	13.7	26.3	37.2	15.2	100.0
Clean coal	3.2	6.5	22.4	44.8	23.1	100.0
Refuse	10.8	19.2	29.4	31.5	9.1	100.0
Ash, percent:						
Feed	67.1	48.2	32.7	20.4	15.3	30.2
Clean coal	2.0	1.8	2.2	2.6	2.9	2.5
Refuse	74.0	56.3	49.0	44.6	42.8	51.2
Actual recovery.....percent..	9.6	14.9	34.8	57.6	69.0	43.1
Theoretical recovery.....do....	9.6	14.9	37.0	62.7	74.9	46.8
Efficiency.....do....	100.0	100.0	94.0	91.9	92.1	92.1
Ash error.....do....	0.0	0.0	0.2	0.3	0.6	0.3
Float in refuse.....percent of product..	0.2	1.0	5.1	11.5	18.5	7.3
Sink in clean coal.....do.....	2.9	3.0	3.5	1.7	2.5	1.6
Total misplaced material.....percent of feed..	0.4	1.3	4.4	5.9	7.7	4.9
Near-gravity ±0.10 material.....do.....	10.1	18.2	36.9	66.3	73.0	50.8
Specific gravity of separation.....	1.32	1.32	1.33	1.35	1.38	1.35
Probable error, specific gravity.....	0.028	0.035	0.024	0.026	0.045	0.025
Imperfection factor.....	0.021	0.026	0.018	0.019	0.033	0.018
Error area.....	14	14	14	20	35	18
Distribution, percent to washed coal:						
Float-1.30.....	100.0	97.1	93.5	94.3	94.4	93.9
1.30-1.35.....	46.3	42.2	58.5	76.7	84.7	71.4
1.35-1.40.....	0.0	0.0	5.7	27.1	52.7	21.4
1.40-1.45.....	0.0	0.0	1.3	7.8	25.7	6.5
1.45-1.50.....	0.0	0.0	0.0	2.3	15.4	2.0
1.50-1.60.....	0.0	0.0	0.0	1.3	6.6	0.8
1.60-1.70.....	0.0	0.0	0.0	0.0	2.5	0.2
1.70-1.80.....	0.0	0.0	0.0	0.0	2.7	0.2
1.80-sink.....	0.0	0.0	0.0	0.0	0.5	0.0

As seen from the distribution curve (fig. 4) the recovery of the lighest fraction was incomplete. However, the material heavier than 1.60 specific gravity was essentially all rejected. All of the sharpness-of-separation criteria were excellent; the error area was 18, the probable error 0.025, and the imperfection factor 0.018. However, owing to the high percentage of near-gravity material present (50.8 percent), the recovery efficiency was only 92.1 percent.

Plant D

The performance of the primary dense-medium drum is summarized in table 10. A float-1.59 specific gravity product of 7.4 percent ash was attained from a feed of 27.2 percent ash at a 73.0-percent recovery. A recovery efficiency of 99.7 percent was achieved in the presence of only 3.8-percent near gravity material. The distribution curve (fig. 5) shows that virtually all of the material lighter than 1.40 specific gravity was recovered and

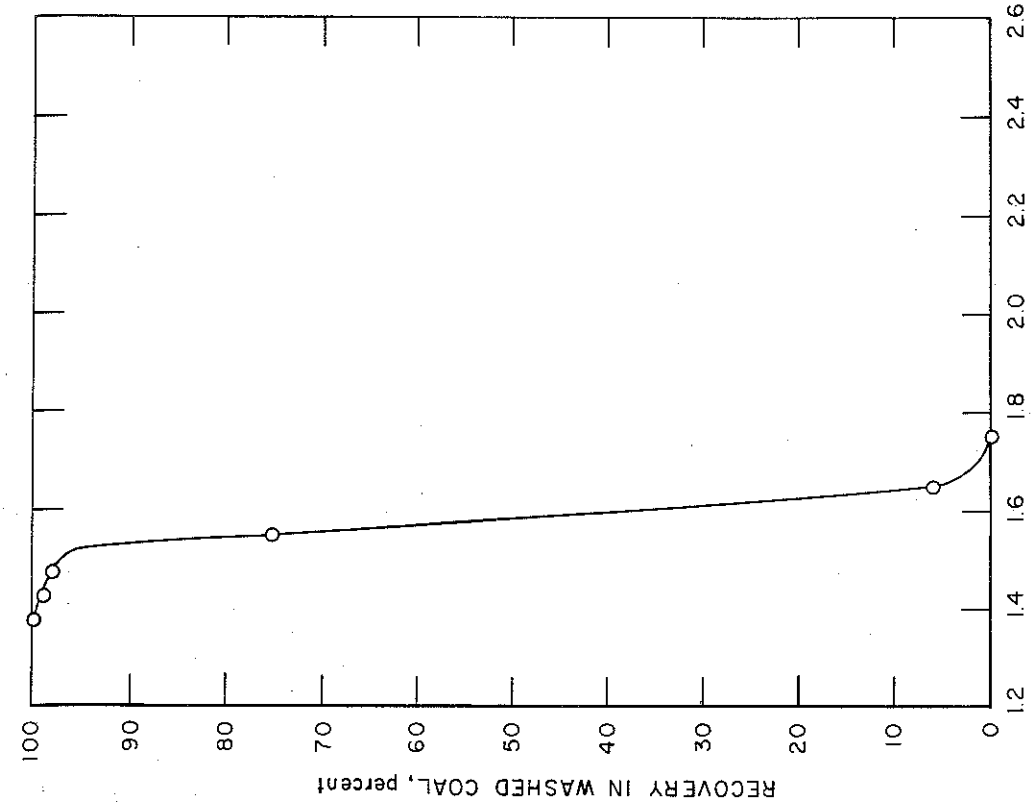

FIGURE 5. - Recovery in Washed Coal Versus Specific Gravity, Plant D Primary.

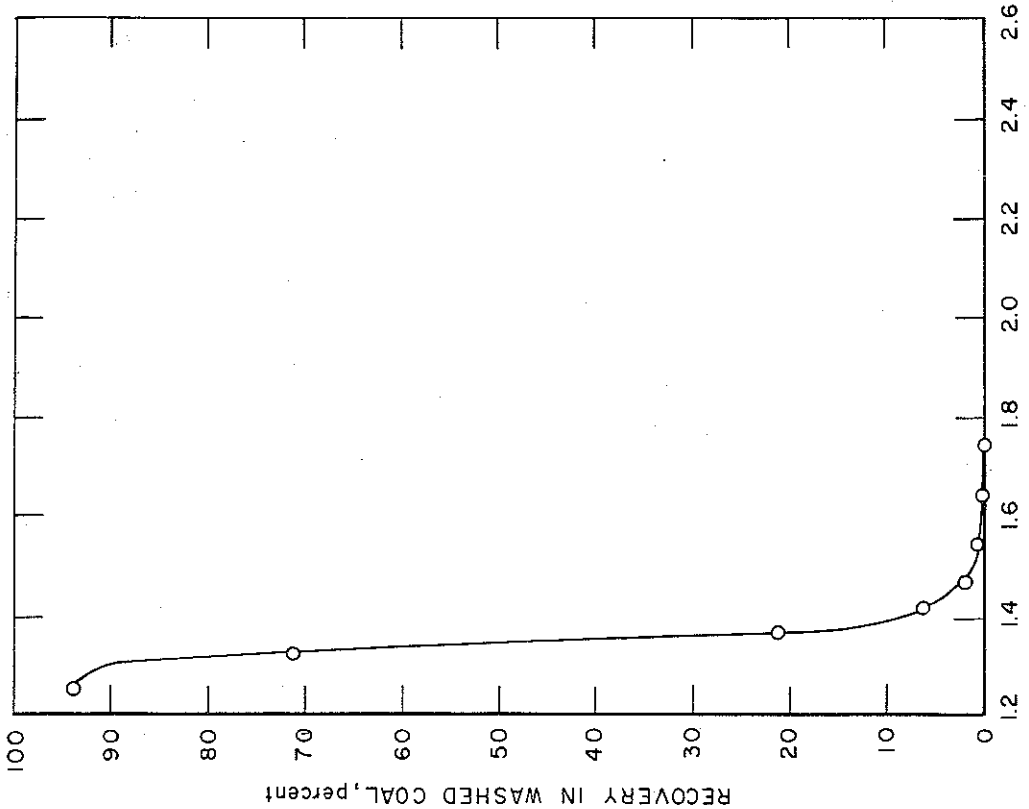

FIGURE 4. - Recovery in Washed Coal Versus Specific Gravity, Plant C.

the elimination of impurity heavier than 1.80 was complete. The error area was 20, the probable error 0.035, and the imperfection factor 0.022.

TABLE 10. - Summary of performance data, plant D primary

Size.....inches..	Plus 2	2 by 1	1 by ½	½ by ¼	Plus ¼
Screen analysis, percent:					
Feed.....	20.4	31.3	32.9	15.4	100.0
Clean coal.....	18.0	31.1	34.0	16.9	100.0
Refuse.....	26.5	31.8	30.1	11.6	100.0
Ash, percent:					
Feed.....	26.7	33.2	24.7	21.1	27.2
Clean coal.....	7.3	7.8	7.5	6.7	7.4
Refuse.....	82.7	79.6	80.3	79.1	80.6
Actual recovery.....percent..	74.3	64.6	76.4	80.2	73.0
Theoretical recovery.....do....	74.4	65.0	76.6	80.4	73.2
Efficiency.....do....	99.9	99.4	99.7	99.8	99.7
Ash error.....do....	0.1	0.2	0.1	0.1	0.1
Float in refuse.....percent of product..	0.4	1.4	1.8	2.0	1.4
Sink in clean coal.....do.....	0.6	1.1	0.8	0.8	0.8
Total misplaced material..percent of feed..	0.5	1.2	1.0	1.0	1.0
Near-gravity ±0.10 material.....do.....	2.7	4.7	3.5	2.9	3.8
Specific gravity of separation.....	1.59	1.57	1.61	1.60	1.59
Probable error, specific gravity.....	0.028	0.042	0.054	0.036	0.035
Imperfection factor.....	0.018	0.027	0.034	0.023	0.022
Error area.....	15	22	35	21	20
Distribution, percent to washed coal:					
Float-1.30.....	100.0	100.0	99.9	99.8	99.9
1.30-1.35.....	100.0	100.0	99.8	99.7	99.9
1.35-1.40.....	100.0	100.0	99.6	99.6	99.8
1.40-1.45.....	100.0	98.9	99.2	98.4	99.2
1.45-1.50.....	100.0	97.9	98.7	97.0	98.6
1.50-1.60.....	85.2	62.5	78.4	85.5	76.0
1.60-1.70.....	0.0	4.5	6.8	17.5	6.2
1.70-1.80.....	0.0	0.0	9.2	0.0	2.3
1.80-sink.....	0.0	0.0	0.0	0.0	0.0

The secondary dense-medium drum in this plant made a float 1.35 specific gravity product containing 5.4 percent ash from a feed containing 7.4 percent ash; the sink material contained 15.7 percent ash, as shown in table 11. This drum had an 80.2 percent yield at a recovery efficiency of 93.9 percent, which is good considering that more than 75 percent of the feed was near-gravity material. The sharpness of separation appears to be excellent; however, only a narrow specific gravity range of material was washed, and the data must be interpreted with this in mind. Figure 6 shows the distribution curve for the separation.

TABLE 11. - Summary of performance data, plant D secondary

Size.....inches..	Plus 2	2 by 1	1 by ½	½ by ¼	Plus ¼
Screen analysis, percent:					
Feed.....	18.3	30.2	33.4	18.1	100.0
Clean coal.....	19.6	29.9	32.6	17.9	100.0
Refuse.....	13.1	31.3	37.1	18.5	100.0
Ash, percent:					
Feed.....	7.3	7.8	7.5	6.7	7.4
Clean coal.....	5.4	5.3	5.4	5.4	5.4
Refuse.....	16.7	17.0	15.2	13.8	15.7
Actual recovery.....percent..	83.1	78.7	79.0	84.2	80.2
Theoretical recovery.....do....	87.3	82.7	87.0	92.4	85.4
Efficiency.....do....	95.2	95.2	90.8	91.1	93.9
Ash error.....do....	0.2	0.3	0.4	0.6	0.4
Float in refuse.....percent of product..	22.2	24.4	34.6	58.6	32.2
Sink in clean coal.....do.....	1.0	1.3	2.4	2.0	2.1
Total misplaced material..percent of feed..	4.6	6.2	9.2	10.9	8.0
Near-gravity ±0.10 material.....do.....	+75	+75	+75	+75	+75
Specific gravity of separation.....	1.35	1.35	1.36	1.38	1.35
Probable error, specific gravity.....	0.016	0.018	0.022	0.030	0.020
Imperfection factor.....	0.012	0.013	0.016	0.022	0.015
Error area.....	12	12	16	20	14
Distribution, percent to washed coal:					
Float-1.30.....	97.0	95.0	92.8	92.4	93.8
1.30-1.35.....	91.4	89.6	87.4	88.6	88.4
1.35-1.40.....	9.4	13.1	25.2	54.7	22.5
1.40-1.45.....	4.7	0.0	2.1	13.5	2.2
1.45-1.50.....	0.0	0.0	0.0	0.0	0.0
1.50-1.60.....	0.0	0.0	0.0	0.0	0.0
1.60-1.70.....	0.0	0.0	0.0	0.0	0.0
1.70-1.80.....	0.0	0.0	0.0	0.0	0.0
1.80-sink.....	0.0	0.0	0.0	0.0	0.0

Plant E

Although this was a three-product separator, a two-product separation was considered to evaluate the performance of the drum. Table 12 summarizes the performance data of the separation effected in the first compartment of the drum between the clean coal and the sink products (including the middlings material). From a raw coal containing 44.7 percent ash, a float coal product was obtained which contained 9.4 percent ash at an actual recovery of 52.6 percent. Although the recovery efficiency of 98.0 percent was good, it was expected since only 11.8 percent of near-gravity material was present at the 1.79 separating gravity. The separation between coal and impurity as obtained from the distribution curve (fig. 7) was quite sharp, as characterized by the probable error of 0.032 and the imperfection factor of 0.018. The middlings product contained 29.0 percent ash at a yield of 4.7 percent, and 42.7 percent of the material was reject containing 88.5 percent ash.

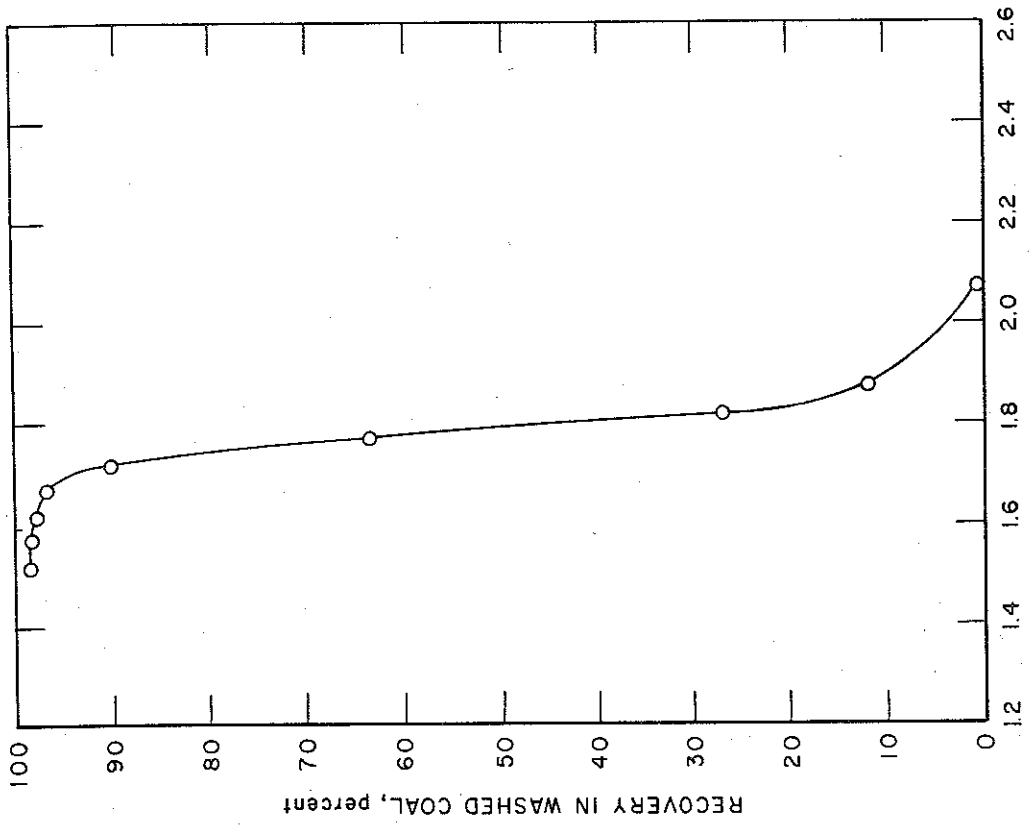

FIGURE 7. - Recovery in Washed Coal Versus Specific Gravity, Plant E.

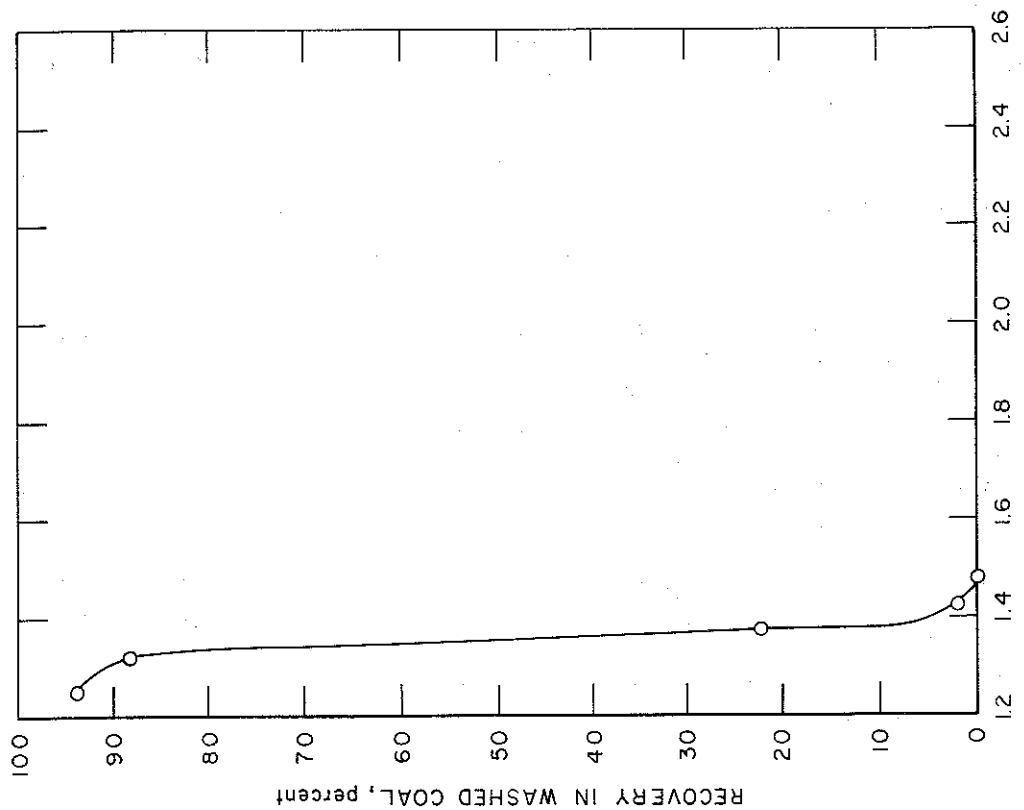

FIGURE 6. - Recovery in Washed Coal Versus Specific Gravity, Plant D Secondary.

TABLE 12. - Summary of performance data, plant E

Size.....inches..	Plus 3-1/4	3-1/4 by 2-7/16	2-7/16 by 1-5/8	1-5/8 by 13/16	13/16 by 9/16	Plus 9/16
Screen analysis, percent:						
Feed.....	29.0	16.5	23.6	25.0	5.9	100.0
Clean coal.....	27.2	15.0	24.8	27.5	5.5	100.0
Refuse.....	30.9	18.2	22.2	22.4	6.3	100.0
Ash, percent:						
Feed.....	47.9	47.8	45.6	39.9	37.0	44.7
Clean coal.....	9.4	9.4	9.4	9.7	9.5	9.4
Refuse.....	88.6	85.3	83.2	76.2	65.5	82.6
Actual recovery.....percent..	49.4	47.8	55.3	57.6	49.0	52.6
Theoretical recovery.....do....	50.1	48.5	56.0	59.5	55.0	53.7
Efficiency.....do....	98.6	98.6	98.8	96.8	89.1	98.0
Ash error.....do....	0.3	0.2	0.2	0.5	1.4	0.4
Specific gravity of separation.....	1.80	1.78	1.80	1.79	1.77	1.79
Probable error, specific gravity.....	0.032	0.028	0.026	0.036	0.070	0.032
Imperfection factor.....	0.018	0.016	0.014	0.020	0.040	0.018
Error area.....	18	32	32	32	48	30
Float in refuse.....percent of product..	1.9	2.3	3.7	6.7	13.2	4.2
Sink in clean coal.....do.....	1.4	1.8	1.4	3.0	6.6	2.3
Total misplaced material....percent of feed..	1.7	2.1	2.4	4.6	10.0	3.2
Near-gravity ±0.10 material.....do.....	7.4	10.7	10.2	15.5	19.6	11.8
Distribution, percent to washed coal:						
Float-1.55.....	100.0	100.0	97.9	98.7	95.8	98.8
1.55-1.60.....	98.6	99.1	99.3	98.3	92.9	98.5
1.60-1.65.....	99.1	98.4	99.0	97.7	91.4	98.2
1.65-1.70.....	98.8	98.1	98.4	96.1	82.8	97.0
1.70-1.75.....	96.6	95.8	93.0	89.4	67.4	91.3
1.75-1.80.....	72.7	58.5	71.2	60.5	47.7	63.6
1.80-1.85.....	36.2	14.4	25.5	26.9	24.2	27.0
1.85-1.90.....	0.0	12.6	20.9	12.5	12.8	11.7
1.90-sink.....	0.0	0.0	0.1	0.4	1.1	0.2

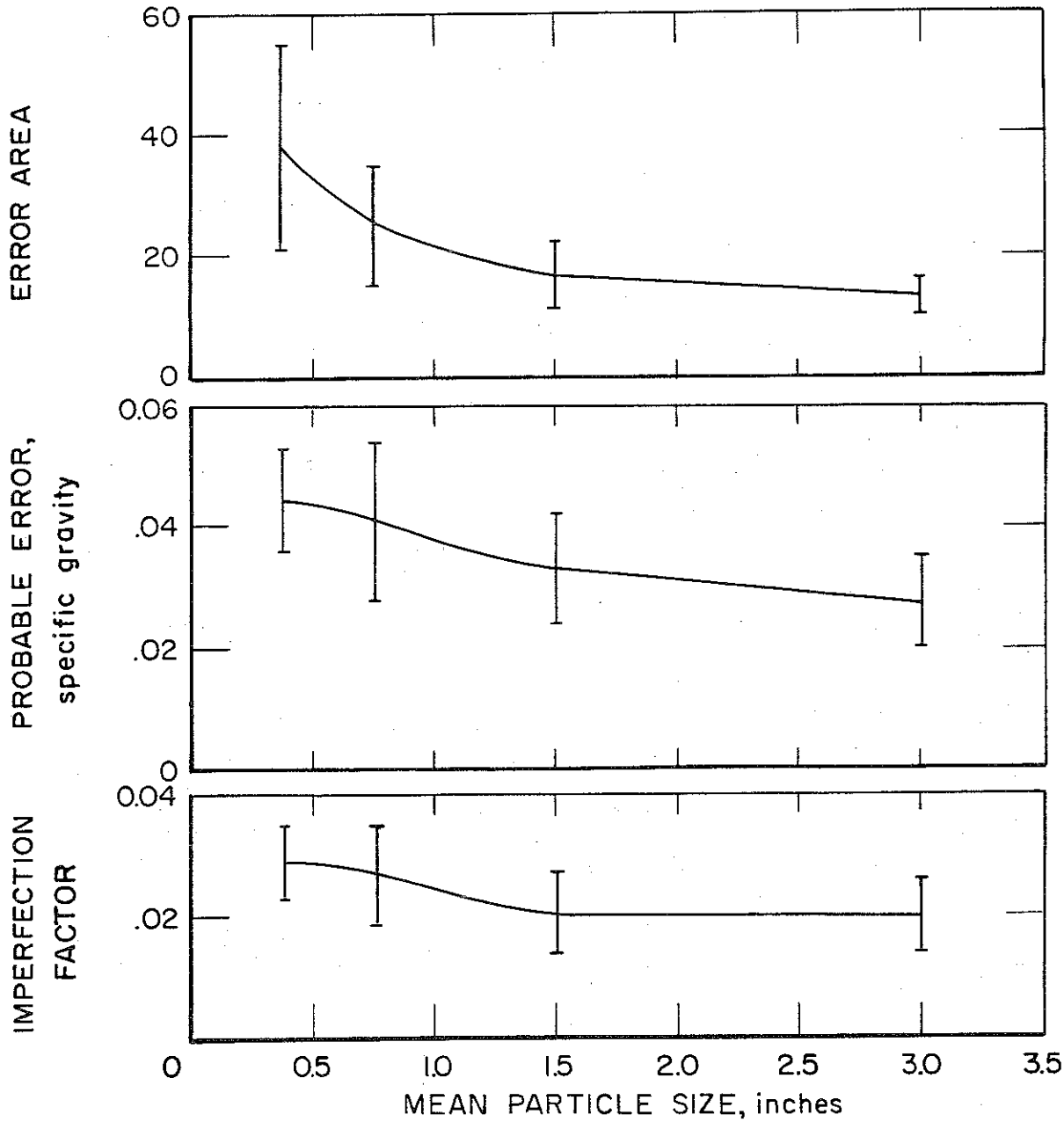

FIGURE 8. - Probable Error, Error Area, and Imperfection Factor by Mean Particle Size.

Performance by Size Fractions

The performance data of the various size fractions for all the plants studied support the following conclusions:

1. The recovery efficiencies generally decreased as the size-fraction values decreased, but with little correlation to the amount of near-gravity material present.

2. The separating gravity values increased as the size-fraction values decreased, a normal characteristic of upward current vessels.

3. The sharpness-of-separation criteria seemed to substantiate the generally accepted theory that sharpness of separation deteriorates when washing finer material. This can be shown by the increase of the probable error, the imperfection factor, and the error area in the finest sizes.

Figure 8 is a graph of the error areas, probable errors, and imperfection factors by mean particle size of the primary separations for the bituminous preparation plants. The anthracite vessel is not included in figure 8 because the specific gravity of separation is in a higher specific gravity range than in the vessels from the bituminous field, and does not permit a direct comparison of the performance data. However, for the intermediate gravity material, the sharpness-of-separation values, given by the probable error, and the imperfection factor values were in excellent agreement, except for the finest size fraction (13/16- by 9/16-inch). The tendency of performance to deteriorate as particle size decreases is clearly indicated.

4. In general, the actual recovery, the ash error, and the total misplaced material increased as the particle size decreased. The increase in total misplaced material was normally caused by an increase in the float coal reporting to refuse.

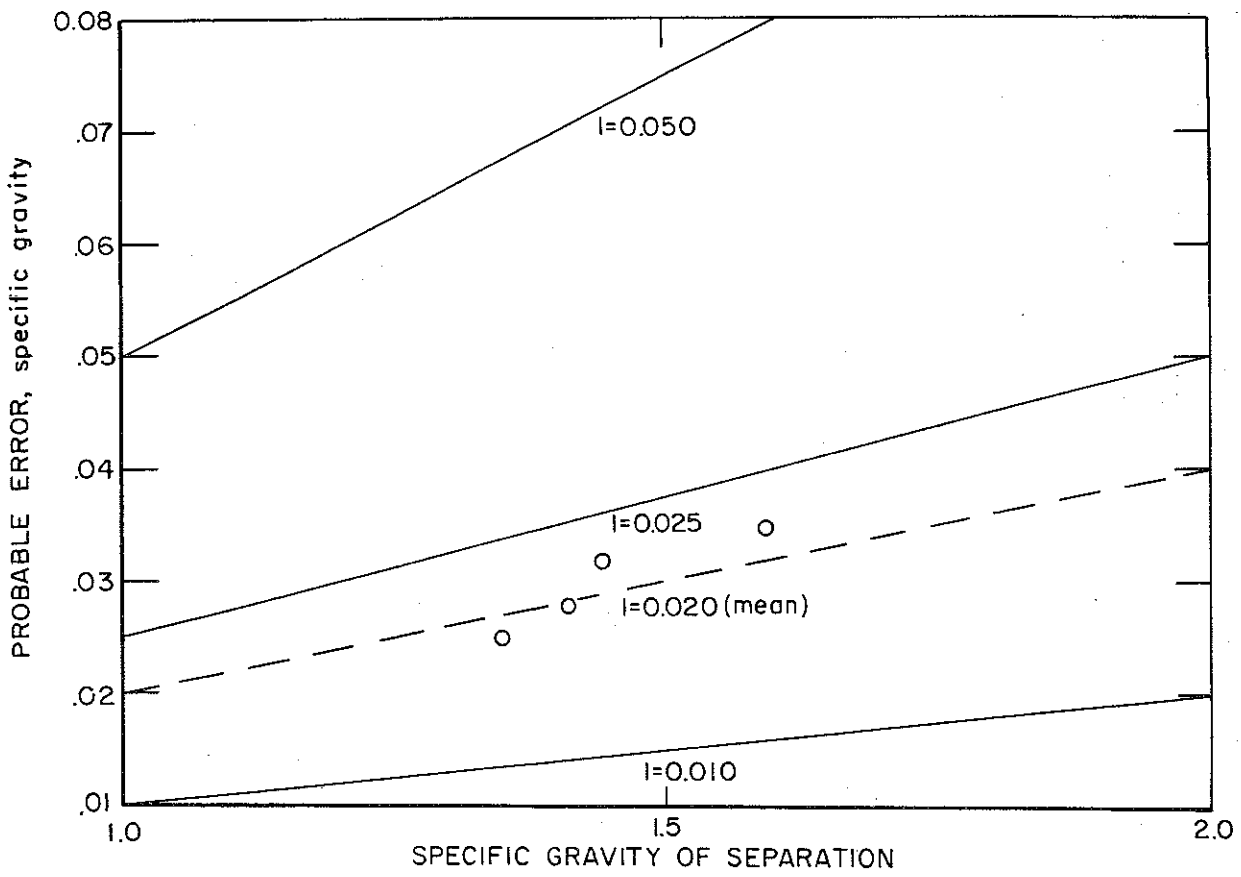

FIGURE 9. - Imperfection as a Function of Probable Error and Specific Gravity of Separation.

Comparison of the Six Separations

The performance of the six dense-medium vessels is compared in table 13. The summary of the overall separations indicates that the recovery efficiencies ranged from 99.8 to 92.1 percent for the composite feed as the percentage of near-gravity material increased from 3.8 to more than 75. With such an increase in the near-gravity material, the decrease in efficiency is expected.

TABLE 13. - Summary of performance data of the six separations, plus 1/4-inch material

	Plants					
	A	B	C	D	D_s	E[1]
Ash, percent:						
Feed	21.9	20.6	30.2	27.2	7.4	44.7
Clean coal	2.1	4.8	2.5	7.4	5.4	9.4
Refuse	85.5	62.5	51.2	80.6	15.7	82.6
Actual recovery, percent	76.2	72.6	43.1	73.0	80.2	52.6
Theoretical recovery, do	76.3	74.4	46.8	73.2	85.4	53.7
Efficiency, do	99.8	97.6	92.1	99.7	93.9	98.0
Ash error, do	0.0	0.3	0.3	0.1	0.4	0.4
Float in refuse, percent of product	1.2	9.4	7.3	1.4	32.2	4.2
Sink in clean coal, do	0.1	1.9	1.6	0.8	2.1	2.3
Total misplaced material, percent of feed	0.4	3.9	4.9	1.0	8.0	3.2
Near-gravity ±0.10 material, do	5.0	15.0	50.8	3.8	+75	11.8
Specific gravity of separation	1.41	1.44	1.35	1.59	1.35	1.79
Probable error, specific gravity	0.028	0.032	0.025	0.035	0.020	0.032
Imperfection factor	0.020	0.022	0.018	0.022	0.015	0.018
Error area	16	25	18	20	14	30
Distribution, percent to washed coal:						
Float-1.30	99.8	98.4	93.9	99.9	93.8	(1)
1.30-1.35	99.3	96.9	71.4	99.9	88.4	(1)
1.35-1.40	89.6	93.6	21.4	99.8	22.5	(1)
1.40-1.45	39.6	63.7	6.5	99.2	2.2	(1)
1.45-1.50	6.8	22.9	2.0	98.6	0.0	(1)
1.50-1.60	2.7	6.5	0.8	76.0	0.0	(1)
1.60-1.70	0.0	2.3	0.2	6.2	0.0	(1)
1.70-1.80	0.0	2.0	0.2	2.3	0.0	(1)
1.80-sink	0.0	0.0	0.0	0.0	0.0	(1)

[1]Bottom size for plant E is 9/16 inch, and the specific gravity range is float-1.55 to 1.90-sink.

The sharpness-of-separation criteria for the secondary vessel of plant D seem to be much better than those of the five primary separations. However, it must be realized that the feed to the secondary vessel is a rewash material of a narrower specific gravity range.

Most of the independent performance criteria indicate sharp separations at substantially constant values. Figure 9 is a graph of the imperfection factor, as a function of probable error and specific gravity of separation, for the four primary bituminous washers. As previously stated, the imperfection factor for the overall separation of plant E would compare very well with those for the four primary bituminous coal washers, even though the size range for plant E is somewhat coarser (plus 9/16-inch) than those for the bituminous coals (plus 1/4-inch). The excellent agreement of these data should make then useful in forecasting coal cleaning results.

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