THE EFFECT OF GRINDABILITY

UPON

NOZZLE PULVERIZATION

By

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INTRODUCTION

With the present trend toward gas turbines for prime movers, and particularly the experimentation in coal-burning, gas-turbine locomotives, a compact, simple method of pulverizing the coal is being developed. This development of the nozzle pulverizer, or "coal atomizer" as it is called, has been carried out largely by the Bituminous Coal Research Committee through the experimentation and supervision of Mr. J. I. Yellott, and the investigations of Mr. W. N. McDaniel.

The authors, after discussing the subject of nozzle pulverization with Mr. McDaniel, decided upon the test of one variable, grindability as it affects nozzle pulverization. Mr. McDaniel has worked several years on nozzle pulverization, and he has studied many of the variables such as air pressure, air temperature, coal-air ratio, and nozzle design. His suggestions for our operating conditions of pressure, temperature, and coal-air ratio were followed as closely as possible, using only those changes necessary to adapt the equipment available.

HISTORY

The principle of pulverizing coal by the internal-explosion method, as employed by the nozzle pulverizer, had its origin in a process used for explosive shattering of

minerals as a substitute for crushing, preparatory to ore dressing. The first experimentation recorded on this method was done by the United States Bureau of Mines about 1932.

"The principle of explosive crushing depends upon the fact that an expandable substance contained within the pores of a solid body will disrupt such a body upon expansion. Such expansion may be obtained by the detonation of an explosive, or by the sudden release of pressure of a superheated liquid. That this principle of disruption may be applied to minerals rests on the fact that cracks, cleavage planes, and pores exist in all minerals to an extent hardly conceivable heretofore."[1]

In the preliminary work along these lines, the United States Bureau of Mines impregnated the minerals with silver nitrate, and then subjected them to acetylene; thus silver acetylide was formed within the mineral. This method was usually ineffective to any great degree because of the impossibility of impregnating all the cracks, cleavage planes, and pores. Later, during these preliminary experiments, water was used quite successfully. The material to be exploded was soaked in water for a period of time and then heated until the water turned to steam, thus exploding the mineral. This

1. Explosive Shattering of Minerals - United States Bureau of Mines Report of Investigation Number 3118 by R. S. Dean and John Gross. February 1932. p 1

process was the main one used in subsequent investigations.

As experiments were carried further, the shattering was found to result from several causes:

a. "Purely mechanical impact of particles against the end of the discharge chamber or with each other.

b. Spalling of the material due to the rapid cooling of the surface.

c. Sudden expansion of the water in the superficial pores and cracks of the minerals.

d. Disruption of the minerals along their secondary structure due to the weakening of this structure by heat, or the penetration of water and the disruption of the weakened structure by the expansion of the water and the explosive wave." [2]

As further investigations produced some good pulverization results on minerals, the idea of using the internal explosion process for coal pulverization was conceived by Mr. V. G. Leach, Chief Combustion Engineer of the Peabody Coal Company. This company undertook the investigation at the Armour Research Foundation.

These tests on coal used the same principle as that employed on the minerals, soaking the coal in water and applying

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2. Explosive Shattering of Minerals - United States Bureau of Mines Report of Investigation Number 3201 by R. S. Dean and John Gross. February 1933. p. 1

heat to change the water into steam. The preliminary tests were run in a crude apparatus consisting chiefly of a heavy-walled, steel cylinder closed at one end and provided with a screwed cap ring on the other. A thin, metallic disc was held tightly in place by the cap ring, and was ruptured by the high pressures produced in the steel cylinder by the formation of steam. This rupture of the disc gave a sudden decrease in pressure within the steel cylinder, and also within the coal, causing the coal to be shattered into minute particles. This thin, metallic disc was later replaced with a quick opening hydraulic valve, thus making possible more accurate control over the pressure and the soaking time.

Although some important data were obtained on the reaction of coal to pulverization by internal explosion, the experiments were not comprehensive enough to insure the possibility of the method being commercially or economically feasible. Among the more important conclusions, the following may be listed:

a. Steam is apparantly the most satisfactory gas tested for low-cost expansion of coal. (Air had not been used as yet.)

b. No advantage is gained by using soaking periods longer than three minutes. The economic limit is probably shorter than this value.

c. In re-explosion, the coal behaves much as in the primary

explosion, with an equivalent size reduction.

d. Pyrites, bone, and similar coal impurities are not appreciably shattered by the explosion process, and this may be a method for separating them from the coal.

The most recent investigations have been carried on by the Locomotive Development Committee of the Bituminous Coal Research, Incorporated, under the direction of Mr. J. I. Yellott, and the studies of Mr. W. N. McDaniel. They advanced the idea of using the "coal atomizer", essentially a nozzle to expand an air and coal mixture from some predetermined inlet pressure to a lower outlet pressure. Their work has been directed toward producing an economical, compact method of pulverizing coal.

They have made investigations to determine the most economical pressure drop, and the results of their tests seem to indicate that a pressure drop of from 60 to 100 pounds per square inch is sufficient. Another phase of their studies that warranted attention was the ratio of the pounds of air per pound of coal sent through the nozzle. Results indicated that a ratio of one to one was sufficient to produce good pulverization.

With an efficiently-designed nozzle pulverizer unit, pulverization was obtained to such an extent that sixty per cent of the particles produced passed through a 200 mesh

screen. By the addition of a "cyclonizer", a simple attrition device, the fineness was increased until about 80 per cent passed through a 325 mesh screen. This nozzle unit not only pulverized the coal, but the high velocity at the exit was reconverted into heat by throttling, thus tending to dry the coal.

A main factor that affects the design of the nozzle, other than the desired pressure drop, is the size of the coal particle entering the nozzle. The diameter of the largest coal particle must be less than one third the diameter of the throat to prevent clogging. For a given nozzle, the size of the coal fed is limited.

Bituminous Coal Research, Incorporated, has not published an official result of their investigations, but it is believed that such a "coal atomizer" may be the answer to pulverizing coal economically on a commercial basis for gas-turbine locomotives.

THE INVESTIGATION

Object:-- To determine the effect of the grindability of coal upon nozzle pulverization by running tests, in a small nozzle pulverizer unit, on various grindability coals from different coal seams in Virginia and West Virginia.

The authors want the reader to know that maximum pulverization was not the object of this test. The relative

pulverization of the different coals was the goal to be obtained. In a more efficiently designed nozzle pulverizer unit with a better nozzle, higher pressure drop across the nozzle, and different coal-air ratios, greater coal pulverization can be obtained.

Apparatus and Materials:-- The nozzle pulverizer unit was set up as shown by the schematic drawing, Figure 1, and the pictorial drawing, Figure 2. The major parts were of the following construction:

I.(a) The pressure tank was constructed as in Figure 3b with a built-in screw conveyor. The tank was made of eight-inch steel pipe with one half-inch steel plates welded to the top and bottom. The top plate had a two-inch pipe nipple welded to it, and a gate valve was screwed on the nipple, allowing the coal to be placed in the tank with a funnel. A hole for a one quarter-inch pipe was drilled and tapped for a pressure equalizing line to balance the pressure on both sides of the screw. Before the top was welded on, concrete was poured in the bottom to form sloping sides down to the screw. These sides allowed all the coal charge to be pushed into the air stream by the screw conveyor.

(b) The screw conveyor was a cut down soil auger fitted to a one and a half-inch pipe. The pipe for the screw

conveyor had a bearing, grease cup, and packing. The screw had a ten-inch wooden pulley keyed to the shaft, driven by a two and a half-inch pulley on a direct current motor through a "V" belt. Rheostats controlled the speed of the motor so that the speed of the screw could be varied from 250 to 350 revolutions per minute.

(c) The nozzle was designed by the equations and method described in Chapter XI, Applied Thermodynamics by V. M. Faires. The dimensions of the finished nozzle are shown in Figure 3a. The nozzle was made of stainless steel to prevent wear and corrosion caused by the particles of coal passing through it.

(d) Two pressure gauges were used as shown in Figures 1 and 2. For inlet pressure, a 0-100 psi gauge was used, and for the exit pressure, a 0-30 psi guage was installed.

(e) The two dust collectors were commercial Aerotec separators connected in series.

(f) A thermometer, 0-130°F, was used to measure the air temperature.

(g) Miscellaneous pipe and fittings to complete the unit as shown in Figure 2.

(h) A source of air at 110 psi guage obtained from the Ingersoll Rand Air Compressor in the Mechanical

Engineering laboratory.

(i) A source of direct current obtained from a small direct current generator driven by a gasoline engine.

II. For screening the coal the following apparatus was used:

(a) A vibrating screen for the main separation while working on the 300 pound mine sample. A number four mesh screen was used in the vibrator.

(b) A set of Tyler eight-inch screens for use on the Rotap screening machine. The set included the following screens: 14, 28, 35, 48, 65, 100, and 150 mesh.

(c) One ten-inch, 200 mesh, Tyler screen for use on the gyrating mechanical screening device.

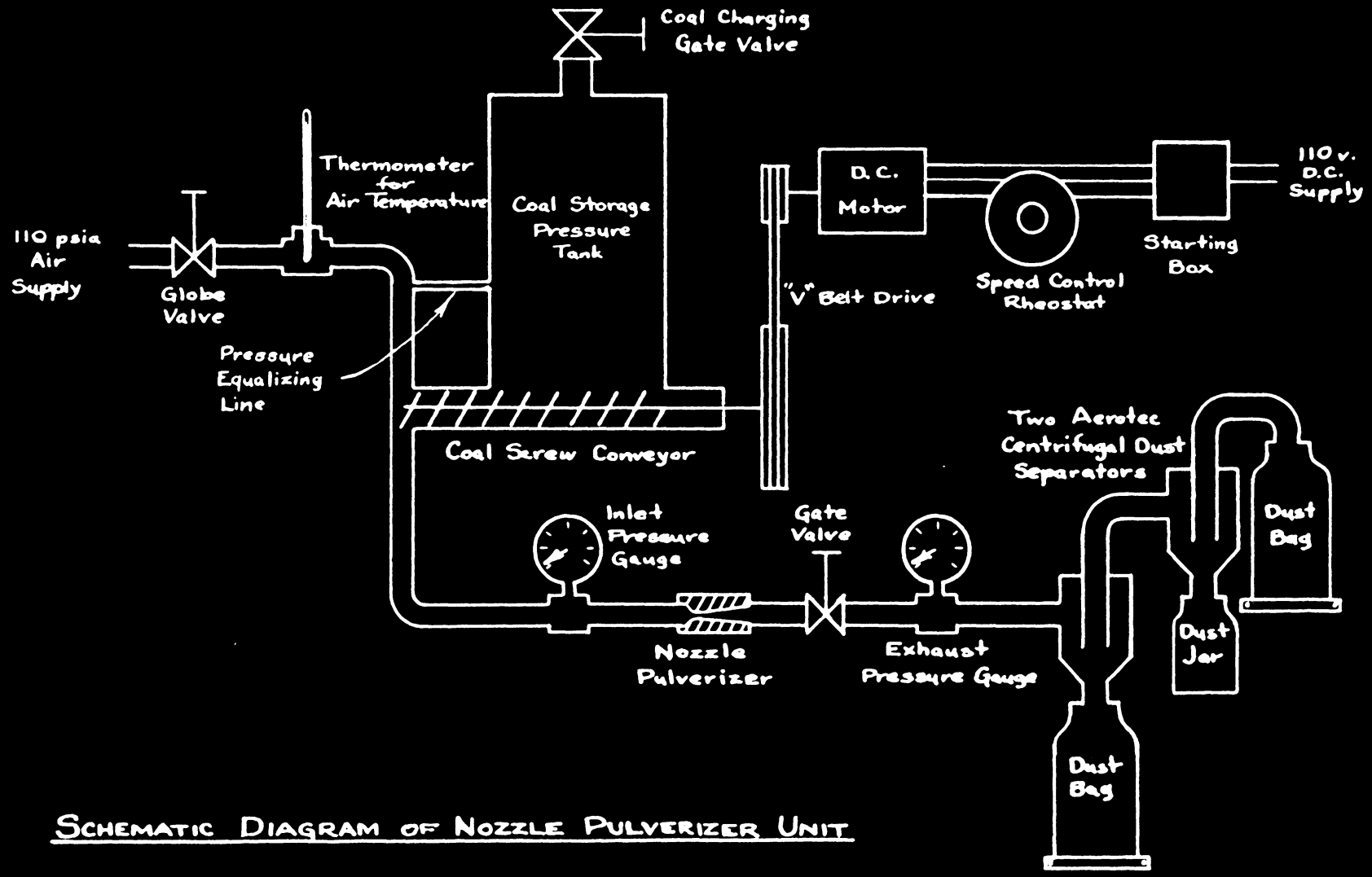
III. All the weight measurements were made on the following:

(a) For the screen analysis weights, a two-range Toledo Scale was used. Ranges were 0-500 grams and 0-10 kilograms.

(b) The Hardgrove Test weights were made on a Fisher Scientific triple beam balance. Range was 0-111 grams.

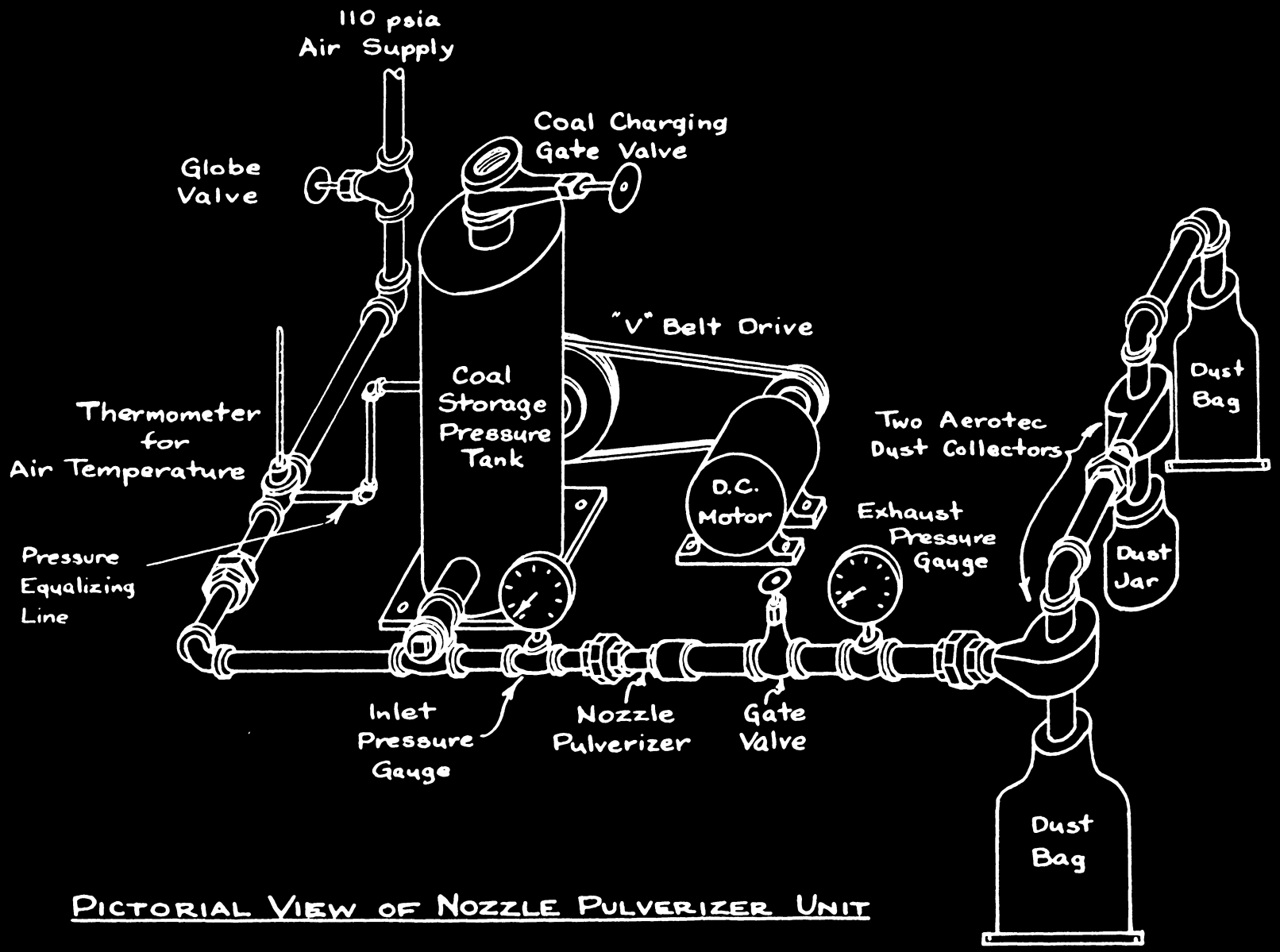
IV. The Hardgrove Tests were run on a standard Hardgrove Testing Machine. The machine had an automatic stopping device as well as a revolution counter.

Method of Procedure:-- The 300 pound sample of coal, as received from each of the various mines, was crushed in a jaw crusher until it passed through a number four mesh screen.



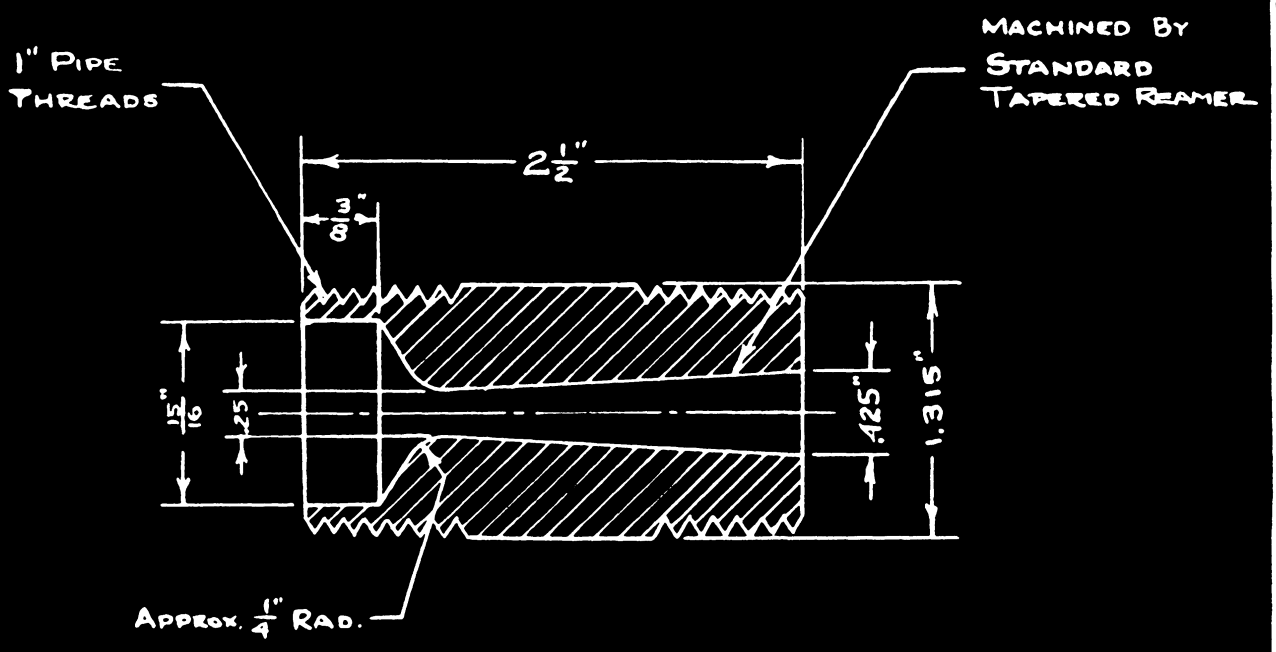
SCHEMATIC DIAGRAM OF NOZZLE PULVERIZER UNIT

FIGURE 1



PICTORIAL VIEW OF NOZZLE PULVERIZER UNIT

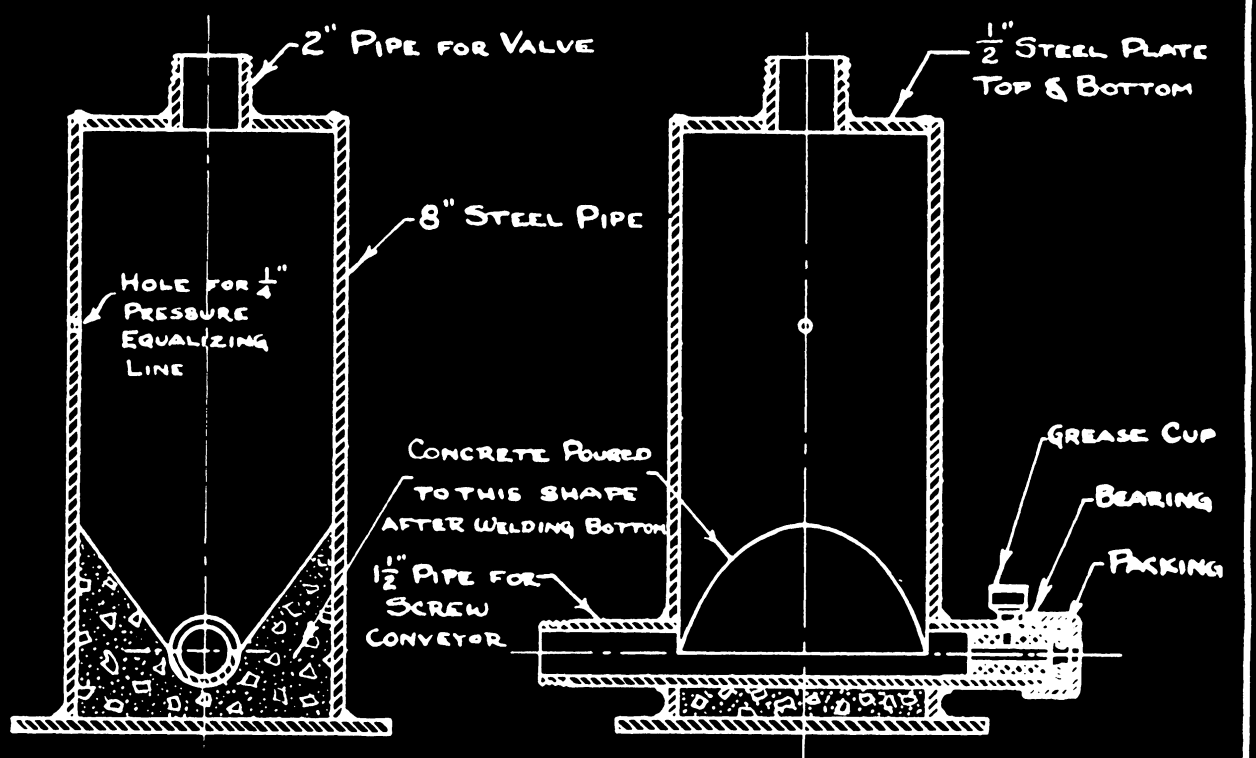
FIGURE 2



SECTION THROUGH NOZZLE

NOZZLE MATERIAL- STAINLESS STEEL

FIGURE 3a



PRESSURE TANK

WELDED ALL OVER

FIGURE 3b

Each mine sample was kept clean and free from contamination by other coals at all times. After all the coal passed through the number four mesh screen, it was sampled according to ASTM Standard Procedure of alternate shovels and opposite quarters of the coal pile.[3] Two ten-pound samples were taken of each coal, and they were set aside for the Hardgrove grindability tests.

The remainder of the coal was screened between the limits of 14 mesh and 28 mesh Tyler screens; these screen limits were set by the authors to give a constant coal size fed into the unit. All the undersize material was thrown away, and the oversize crushed in a double-roll crusher until the coal was between 14 and 28 mesh or undersize. The recovery of coal was about 25 per cent between the limits set, and this method of crushing and screening gave 75 pounds for the nozzle pulverization tests.

After the coal was crushed to size, ten pounds of each sample was used to determine the calibration curve of the screw conveyor. The screw was rotated at various speeds, and the coal was caught and weighed after a minute's run. A calibration curve for each coal was plotted, showing the pounds of coal conveyed in a second for any value of screw revolu-

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3. ASTM Standards on Coal and Coke - American Society of Testing Materials - Section D 21-40 pp. 3-4

tions per minute. From these curves[4], the test speed corresponding to nine pounds of coal per minute was selected for each coal. The nozzle in the pulverizer unit was designed for one tenth of a pound of air per second; and a coal to air ratio of 1.5 to 1 was arbitrarily chosen. This meant that nine pounds of coal per minute must be fed into the air stream to satisfy these conditions. The different coals varied quite a bit in density, and each had a different speed of rotation of the screw to give the desired coal flow.

Five pounds of the screened coal was then placed in the tank without the nozzle pulverizer in use. The screw was rotated at the test speed, and the coal was caught and screened on a series of screens (28, 35, 48, 65, 100, 150, and 200 Tyler mesh). The per cent retained on each screen was recorded, and a cumulative plot was made. This procedure was followed twice for each different coal sample, and was done to determine the crushing of the coal caused by handling, pouring, and the crushing effect of the screw conveyor. The cumulative plot of the screen analysis was representative of the coal actually entering the nozzle.

Before any tests were run on the nozzle pulverizer unit, the Hardgrove grindabilities of the different coals

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4. See Appendix for Calibration Curve of Screw Conveyor.

were determined. The grindability tests were run twice on each coal according to ASTM Specifications on a standard Hardgrove grindability machine.[5]

After all the calibration was completed, the actual nozzle pulverization tests were ready to be run. The Ingersoll Rand air compressor in the mechanical engineering laboratory, which supplied the air under pressure, and the engine-driven, direct-current generator were started. While the pressure was building up, the speed of the screw conveyor was selected from the calibration curve of the coal to be tested, and the rheostats were adjusted until this speed was obtained. The screw was then stopped, and a five-pound sample of the coal to be tested was placed in the pressure tank through the gate valve in the top. This valve and the valve in the exhaust line were then closed, and the inlet valve opened until the pressure in the tank was 110 pounds per square inch absolute (96 pounds per square inch gauge for the atmospheric pressure on the test day). The coal was allowed to soak in this air pressure for two minutes. Then the exhaust valve was opened and the inlet valve adjusted for 105 pounds per square inch absolute (91 pounds per square inch gauge). This inlet pressure was equal to one tenth of a pound of air per

5. ASTM Standards on Coal and Coke - American Society of Testing Materials - Section D 409-37T pp. 46-49

second through the nozzle. The coal was allowed to soak one more minute during this adjustment, until a total of three minutes soaking time had elapsed. At the end of this time, the screw conveyor was started, feeding the coal into the air stream. During the run, the inlet pressure, exhaust pressure, and air temperature were recorded.

After running the screw for one minute to make sure all of the coal was out of the tank, the screw was stopped and the inlet valve closed. The coal dust was then removed from the dust collectors, and placed in a paper bag for later screen analysis. The pulverizer test was repeated two more times on the same coal under the same conditions, and each coal dust product was kept separate from all of the others.

The coal dust was sifted on a series of eight-inch screens (28, 35, 48, 65, 100, and 150 Tyler mesh) by the use of a Rotap machine. The coal dust smaller than 150 mesh was placed on a 200 mesh ten-inch screen, and sifted by the use of a gyrating mechanical screener. The weights retained on each were recorded, and the per cent retained on each was calculated for the screen analysis plots.

The above procedure was repeated three times for each separate coal, making a total of fifteen tests run under the same conditions, with only the hardness of the coal the variable.

Results:-- The Hardgrove grindability test data and results are given in Table 1. The Hardgrove Grindability Index for both tests on the same coal came within the two per cent specified by the American Society of Testing Materials. The average of these two values was taken as the grindability of the coal.

A typical run, and the calculation of the Hardgrove Grindability Index are as follows:

50 g = Weight of original sample

43.9 g = Weight of material retained on a 200 mesh screen after the coal had been crushed in the Hardgrove machine.

W = Weight of material passing through a 200 mesh screen = Weight of original sample - Weight retained on the 200 mesh screen.

$$\text{Hardgrove Grindability Index} = 13 + 6.93\,W$$
$$= 13 + 6.93(50 - 43.9)$$
$$= 13 + 6.93(6.1)$$
$$= 13 + 42.3 = 55.3$$

The screen analyses of the coal pulverized by handling, pouring, and the crushing effect of the screw conveyor are listed in Tables 2 through 6, and are shown on cumulative plotting paper in Figures 4 through 8.

The screen analyses of the coal pulverized by passing

through the unit (nozzle, handling, pouring, and the screw conveyor) are listed in Tables 7 through 11, and are shown on cumulative plotting paper in Figures 4 through 8.

The pulverization caused by the nozzle alone was obtained by subtracting the handling, pouring, and screw pulverization analyses from the pulverization analyses of the unit. This was done for the per cent retained on each screen. The resulting data are listed in Table 12, and the cumulative screen analyses plots of all the coal seams are shown in Figure 9. These curves show the increase in pulverization with a decrease in hardness.

The effect of the grindability upon nozzle pulverization is plotted in Figure 10 from the data in Table 12. This family of curves shows the amount of each coal that will pass through the various screens for the different hardnesses from 55 to 100.

Table 1

HARDGROVE TESTS

Coal	Weight on 200 Mesh(g)		Hardgrove Grindability		
	Test 1	Test 2	Test 1	Test 2	Avg
Seam "A"	43.9	43.8	55.3	55.9	55.6
Seam "B"	43.4	43.5	58.7	58.1	58.4
Seam "C"	43.0	42.9	61.6	62.2	61.9
Seam "D"	40.4	40.3	79.5	80.3	79.9
Seam "E"	37.7	37.8	98.2	97.6	97.9

Table 2

COAL SEAM "A"

Handling, Pouring, and Screw Pulverization

Screen Analyses

Screw conveyor revolutions per minute for tests = 300

1.414 Screen Ratio					Test 1			Test 2		
	Opening in.	Opening mm	Tyler Mesh	U.S. No.	wt (g)	per cent	% Cum. wt	wt (g)	per cent	% Cum. wt
On	.0232	.589	28	30	975	95.3	95.3	992	95.1	95.1
On	.0164	.417	35	40	30	2.9	98.2	32	3.1	98.2
On	.0116	.295	48	50	7	.7	98.9	7	.7	98.9
On	.0082	.208	65	70	4	.4	99.3	4	.4	99.3
On	.0058	.147	100	100	2	.2	99.5	2	.2	99.5
On	.0041	.104	150	140	1	.1	99.6	1	.1	99.6
On	.0029	.074	200	200	1	.1	99.7	1	.1	99.7
Thru	.0029	.074	200	200	3	.3	100.0	3	.3	100.0
Total					1023	100.0		1042	100.0	

Table 3

COAL SEAM "B"

Handling, Pouring, and Screw Pulverization

Screen Analyses

Screw conveyor revolutions per minute for tests = 306

1.414 Screen Ratio					Test 1			Test 2		
	Opening in.	Opening mm	Tyler Mesh	U.S. No.	wt (g)	per cent	% Cum. wt	wt (g)	per cent	% Cum. wt
On	.0232	.589	28	30	1028	93.6	93.6	982	93.7	93.7
On	.0164	.417	35	40	52	4.7	98.3	48	4.6	98.3
On	.0116	.295	48	50	8	.7	99.0	7	.7	99.0
On	.0082	.208	65	70	4	.4	99.4	4	.4	99.4
On	.0058	.147	100	100	2	.2	99.6	2	.2	99.6
On	.0041	.104	150	140	2	.2	99.8	2	.2	99.8
On	.0029	.074	200	200	1	.1	99.9	1	.1	99.9
Thru	.0029	.074	200	200	1	.1	100.0	1	.1	100.0
Total					1098	100.0		1047	100.0	

Table 4

COAL SEAM "C"

Handling, Pouring, and Screw Pulverization

Screen Analyses

Screw conveyor revolutions per minute for tests = 296

1.414 Screen Ratio					Test 1			Test 2		
	Opening in.	Opening mm	Tyler Mesh	U.S. No.	wt (g)	per cent	% Cum. wt	wt (g)	per cent	% Cum. wt
On	.0232	.589	28	30	1075	96.1	96.1	1078	96.1	96.1
On	.0164	.417	35	40	31	2.8	98.9	31	2.8	98.9
On	.0116	.295	48	50	5	.4	99.3	5	.4	99.3
On	.0082	.208	65	70	3	.3	99.6	3	.3	99.6
On	.0058	.147	100	100	1	.1	99.7	1	.1	99.7
On	.0041	.104	150	140	1	.1	99.8	1	.1	99.8
On	.0029	.074	200	200	1	.1	99.9	1	.1	99.9
Thru	.0029	.074	200	200	1	.1	100.0	1	.1	100.0
Total					1118	100.0		1121	100.0	

Table 5

COAL SEAM "D"

Handling, Pouring, and Screw Pulverization

Screen Analyses

Screw conveyor revolutions per minute for tests = 294

1.414 Screen Ratio					Test 1			Test 2		
	Opening in.	Opening mm	Tyler Mesh	U.S. No.	wt (g)	per cent	% Cum. wt	wt (g)	per cent	% Cum. wt
On	.0232	.589	28	30	1070	94.2	94.2	1038	93.9	93.9
On	.0164	.417	35	40	46	4.0	98.2	47	4.3	98.2
On	.0116	.295	48	50	8	.7	98.9	7	.6	98.8
On	.0082	.208	65	70	4	.3	99.2	4	.4	99.2
On	.0058	.147	100	100	2	.2	99.4	2	.2	99.4
On	.0041	.104	150	140	2	.2	99.6	2	.2	99.6
On	.0029	.074	200	200	2	.2	99.8	2	.2	99.8
Thru	.0029	.074	200	200	2	.2	100.0	2	.2	100.0
Total					1136	100.0		1104	100.0	

Table 6

COAL SEAM "E"

Handling, Pouring, and Screw Pulverization

Screen Analyses

Screw conveyor revolutions per minute for tests = 284

1.414 Screen Ratio					Test 1			Test 2		
	Opening in.	Opening mm	Tyler Mesh	U.S. No.	wt (g)	per cent	% Cum. wt	wt (g)	per cent	% Cum. wt
On	.0232	.589	28	30	923	90.0	90.0	959	90.4	90.4
On	.0164	.417	35	40	59	5.7	95.7	60	5.7	96.1
On	.0116	.295	48	50	11	1.1	96.8	10	.9	97.0
On	.0082	.208	65	70	6	.6	97.4	5	.5	97.5
On	.0058	.147	100	100	4	.4	97.8	4	.4	97.9
On	.0041	.104	150	140	3	.3	98.1	3	.3	98.2
On	.0029	.074	200	200	3	.3	98.4	3	.3	98.5
Thru	.0029	.074	200	200	16	1.6	100.0	15	1.5	100.0
Total					1025	100.0		1059	100.0	

Table 7

COAL SEAM "A"

Nozzle Pulverizer Unit Screen Analyses

Inlet Pressure - 91 psig

Exhaust Pressure - 2-3/4 psig

Air Temperature - 80°F

Coal-Air Ratio - 1.5/1

Soaking Time - 3 minutes

Barometric Pressure - 13.80 psi

1.414 Screen Ratio					Test 1			Test 2			Test 3		
	Opening in.	Opening mm	Tyler Mesh	U.S. No.	wt (g)	per cent	% Cum. wt	wt (g)	per cent	% Cum. wt	wt (g)	per cent	% Cum. wt
On	.0232	.589	28	30	507	21.7	21.7	527	21.0	21.0	425	18.9	18.9
On	.0164	.417	35	40	279	11.9	33.6	303	12.1	33.1	271	12.1	31.0
On	.0116	.295	48	50	204	8.7	42.3	221	8.8	41.9	197	8.8	39.8
On	.0082	.208	65	70	196	8.4	50.7	209	8.3	50.2	188	8.4	48.2
On	.0058	.147	100	100	200	8.6	59.3	221	8.8	59.0	195	8.7	56.9
On	.0041	.104	150	140	358	15.3	74.6	472	18.8	77.8	403	17.9	74.8
On	.0029	.074	200	200	489	21.0	95.6	483	19.3	97.1	520	23.2	98.0
Thru	.0029	.074	200	200	105	4.4	100.0	70	2.8	100.0	44	2.0	100.0
Total					2338	100.0		2506	100.0		2243	100.0	

Table 8

COAL SEAM "B"

Nozzle Pulverizer Unit Screen Analyses

Inlet Pressure - 91 psig

Exhaust Pressure - 2-3/4 psia

Air Temperature - 79°F

Coal-Air Ratio - 1.5/1

Soaking Time - 3 minutes

Barometric Pressure - 13.80 psi

1.414 Screen Ratio					Test 1			Test 2			Test 3		
	Opening in.	Opening mm	Tyler Mesh	U.S. No.	wt (g)	per cent	% Cum. wt	wt (g)	per cent	% Cum. wt	wt (g)	per cent	% Cum. wt
On	.0232	.589	28	30	391	17.7	17.7	418	18.5	18.5	407	18.5	18.5
On	.0164	.417	35	40	268	12.1	29.8	270	12.0	30.5	269	12.2	30.7
On	.0116	.295	48	50	196	8.9	38.7	198	8.8	39.3	198	9.0	39.7
On	.0082	.208	65	70	193	8.7	47.4	206	9.1	48.4	187	8.5	48.2
On	.0058	.147	100	100	224	10.1	57.5	218	9.7	58.1	206	9.4	57.6
On	.0041	.104	150	140	475	21.5	79.0	450	19.9	78.0	568	25.8	83.4
On	.0029	.074	200	200	392	17.7	96.7	426	18.9	96.9	283	12.8	96.2
Thru	.0029	.074	200	200	73	3.3	100.0	69	3.1	100.0	83	3.8	100.0
Total					2212	100.0		2255	100.0		2201	100.0	

Table 9

COAL SEAM "C"

Nozzle Pulverizer Unit Screen Analyses

Inlet Pressure - 91 psig

Exhaust Pressure - 2-3/4 psig

Air Temperature - 80°F

Coal-Air Ratio - 1.5/1

Soaking Time - 3 minutes

Barometric Pressure - 13.80 psi

1.414 Screen Ratio					Test 1			Test 2			Test 3		
	Opening in.	Opening mm	Tyler Mesh	U.S. No.	wt (g)	per cent	% Cum. wt	wt (g)	per cent	% Cum. wt	wt (g)	per cent	% Cum. wt
On	.0232	.589	28	30	407	18.1	18.1	392	17.3	17.3	415	18.8	18.8
On	.0164	.417	35	40	264	11.8	29.9	268	11.9	29.2	268	12.2	31.0
On	.0116	.295	48	50	190	8.5	38.4	196	8.7	37.9	187	8.5	39.5
On	.0082	.208	65	70	187	8.3	46.7	188	8.3	46.2	179	8.1	47.6
On	.0058	.147	100	100	187	8.3	55.0	197	8.7	54.9	189	8.6	56.2
On	.0041	.104	150	140	363	16.2	71.2	476	21.1	76.0	387	17.5	73.7
On	.0029	.074	200	200	581	25.9	97.1	473	20.9	96.9	530	24.0	97.7
Thru	.0029	.074	200	200	66	2.9	100.0	70	3.1	100.0	50	2.3	100.0
Total					2245	100.0		2260	100.0		2205	100.0	

Table 10

COAL SEAM "D"

Nozzle Pulverizer Unit Screen Analyses

Inlet Pressure - 91 psig

Exhaust Pressure - 2-3/4 psig

Air Temperature - 80°F

Coal-Air Ratio - 1.5/1

Soaking Time - 3 minutes

Barometric Pressure - 13.80 psi

1.414 Screen Ratio					Test 1			Test 2			Test 3		
	Opening in.	Opening mm	Tyler Mesh	U.S. No.	wt (g)	per cent	% Cum. wt	wt (g)	per cent	% Cum. wt	wt (g)	per cent	% Cum. wt
On	.0232	.589	28	30	320	14.3	14.3	331	14.2	14.2	304	13.9	13.9
On	.0164	.417	35	40	243	10.9	25.2	255	11.0	25.2	233	10.7	24.6
On	.0116	.295	48	50	185	8.3	33.5	193	8.3	33.5	181	8.3	32.9
On	.0082	.208	65	70	186	8.3	41.8	187	8.0	41.5	175	8.0	40.9
On	.0058	.147	100	100	193	8.7	50.5	193	8.3	49.8	185	8.5	49.4
On	.0041	.104	150	140	490	21.9	72.4	437	18.8	68.6	439	20.2	69.5
On	.0029	.074	200	200	572	25.6	98.0	683	29.3	97.9	612	28.0	97.5
Thru	.0029	.074	200	200	45	2.0	100.0	48	2.1	100.0	53	2.5	100.0
Total					2234	100.0		2327	100.0		2182	100.0	

Table 11

COAL SEAM "E"

Nozzle Pulverizer Unit Screen Analyses

Inlet Pressure - 91 psig

Exhaust Pressure - 2-3/4 psig

Air Temperature - 79°F

Coal-Air Ratio - 1.5/1

Soaking Time - 3 minutes

Barometric Pressure - 13.80 psi

1.414 Screen Ratio					Test 1			Test 2			Test 3		
	Opening in.	Opening mm	Tyler Mesh	U.S. No.	wt (g)	per cent	% Cum. wt	wt (g)	per cent	% Cum. wt	wt (g)	per cent	% Cum. wt
On	.0232	.589	28	30	221	10.0	10.0	230	10.3	10.3	223	10.0	10.0
On	.0164	.417	35	40	217	9.9	19.9	221	10.0	20.3	227	10.2	20.2
On	.0116	.295	48	50	173	7.9	27.8	174	7.8	28.1	178	8.0	28.2
On	.0082	.208	65	70	161	7.3	35.1	172	7.7	35.8	168	7.5	35.7
On	.0058	.147	100	100	191	8.7	43.8	204	9.2	45.0	191	8.6	44.3
On	.0041	.104	150	140	554	25.2	69.0	567	25.5	70.5	605	27.2	71.5
On	.0029	.074	200	200	619	28.2	97.2	540	24.3	94.8	579	26.0	97.5
Thru	.0029	.074	200	200	63	2.8	100.0	114	5.2	100.0	55	2.5	100.0
Total					2199	100.0		2222	100.0		2226	100.0	

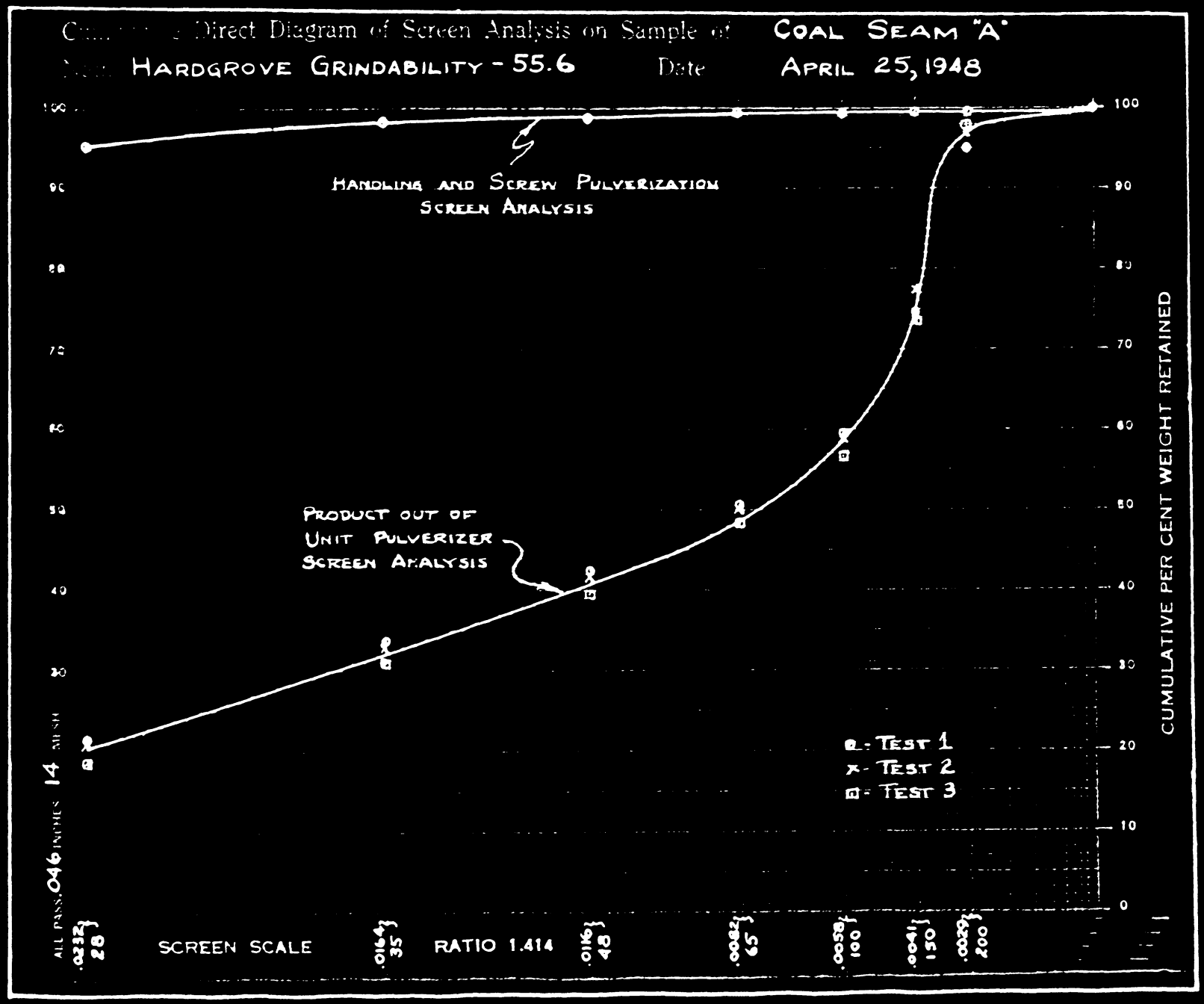
Direct Diagram of Screen Analysis on Sample of COAL SEAM "A"
HARDGROVE GRINDABILITY - 55.6
Date APRIL 25, 1948
HANDLING AND SCREW PULVERIZATION SCREEN ANALYSIS
PRODUCT OUT OF UNIT PULVERIZER SCREEN ANALYSIS
Q - TEST 1
X - TEST 2
□ - TEST 3
CUMULATIVE PER CENT WEIGHT RETAINED
ALL PASS .046 INCHES 14 MESH
SCREEN SCALE
RATIO 1.414
.0232 28
.0164 35
.0116 48
.0082 65
.0058 100
.0041 150
.0029 200

FIGURE 4

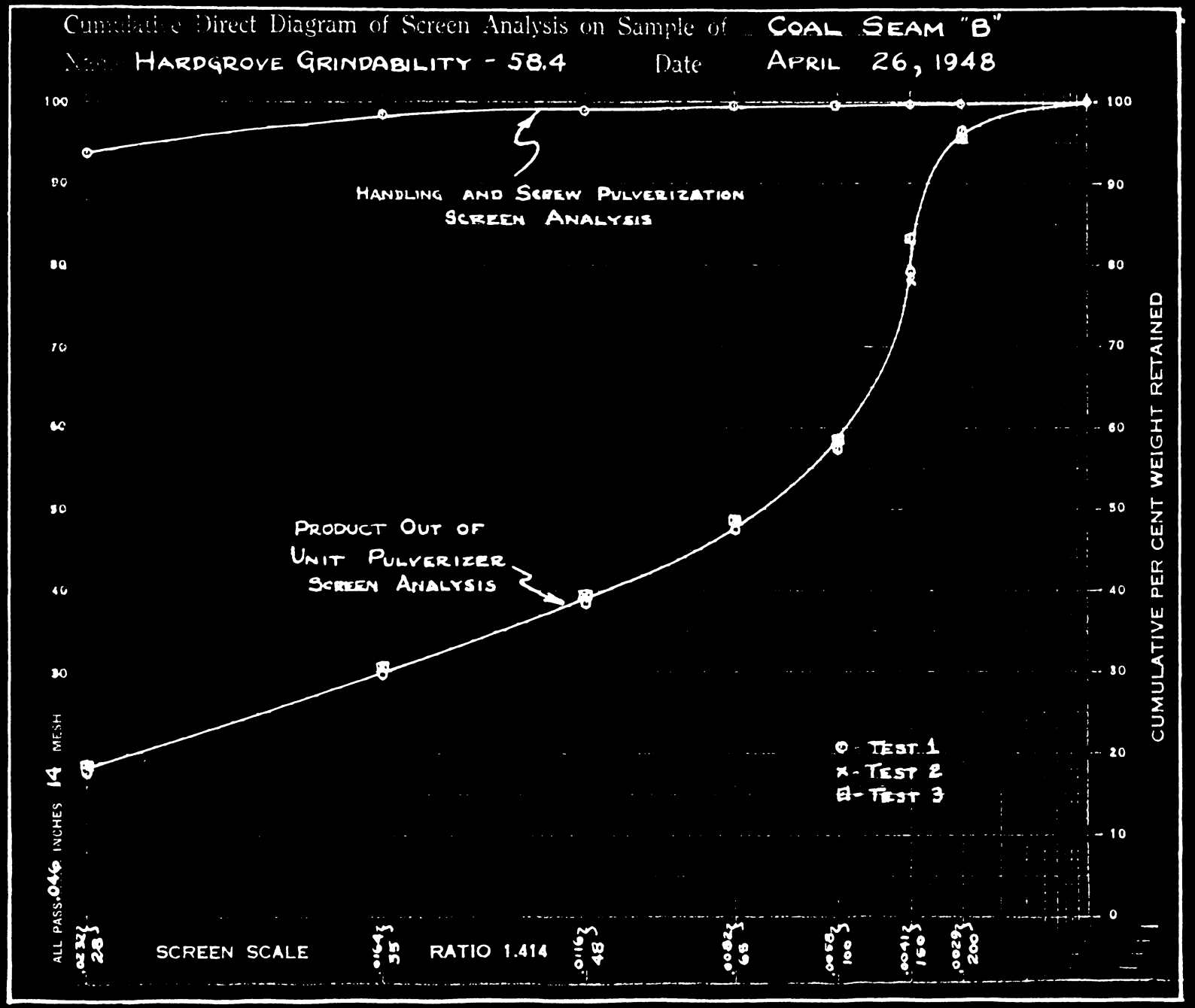
Cumulative Direct Diagram of Screen Analysis on Sample of COAL SEAM "B"
Name HARDGROVE GRINDABILITY - 58.4 Date APRIL 26, 1948
HANDLING AND SCREW PULVERIZATION SCREEN ANALYSIS
PRODUCT OUT OF UNIT PULVERIZER SCREEN ANALYSIS
O - TEST 1
X - TEST 2
⊟ - TEST 3
CUMULATIVE PER CENT WEIGHT RETAINED
ALL PASS .046 INCHES 14 MESH
SCREEN SCALE
RATIO 1.414
28
35
48
65
100
150
200

FIGURE 5

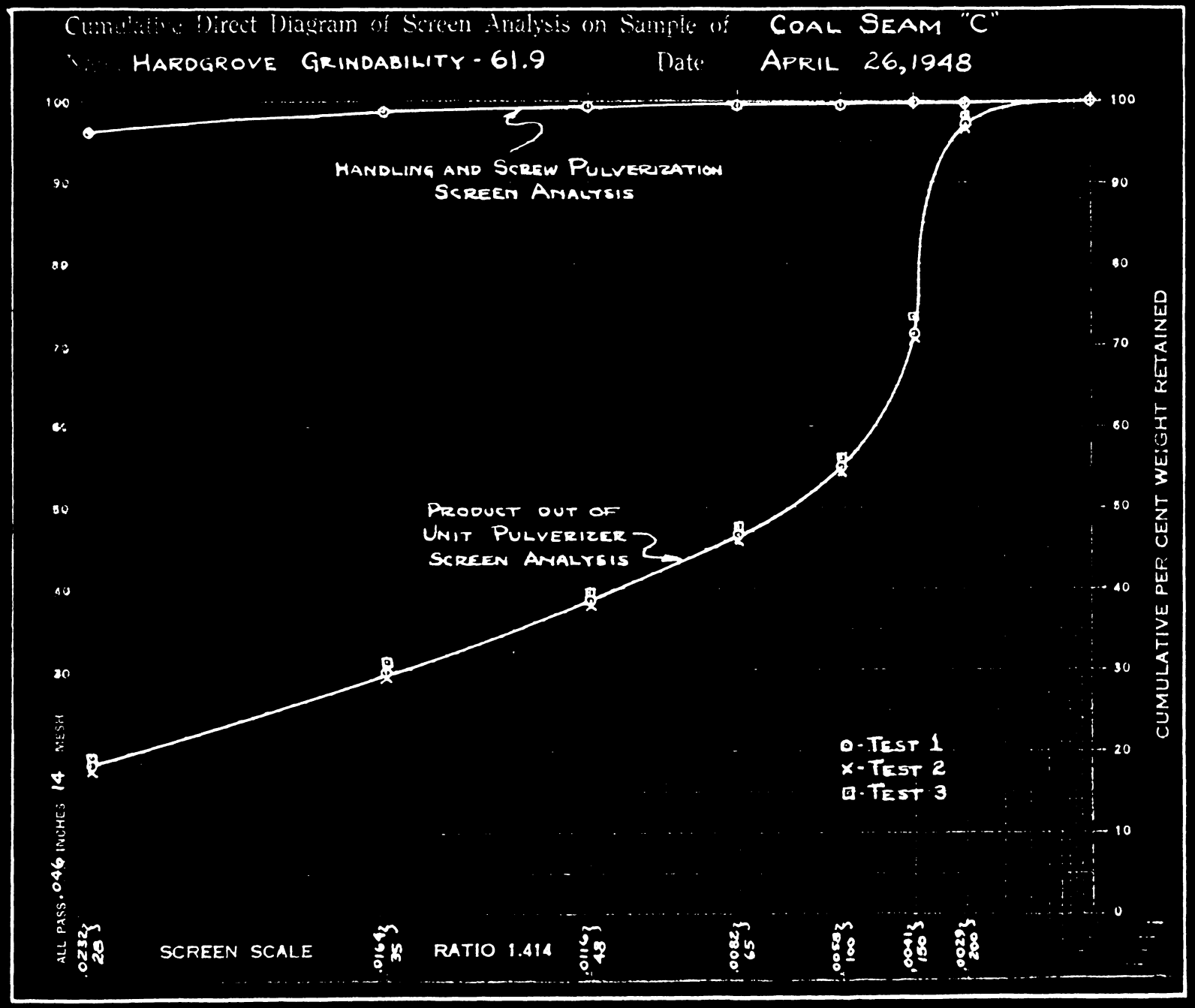
Cumulative Direct Diagram of Screen Analysis on Sample of COAL SEAM "C"
HARDGROVE GRINDABILITY - 61.9
Date APRIL 26, 1948
HANDLING AND SCREW PULVERIZATION SCREEN ANALYSIS
PRODUCT OUT OF UNIT PULVERIZER SCREEN ANALYSIS
O-TEST 1
X-TEST 2
⊡-TEST 3
CUMULATIVE PER CENT WEIGHT RETAINED
ALL PASS .046 INCHES 14 MESH
SCREEN SCALE
RATIO 1.414
.0232 28
.0164 35
.0116 48
.0082 65
.0058 100
.0041 150
.0029 200

FIGURE 6

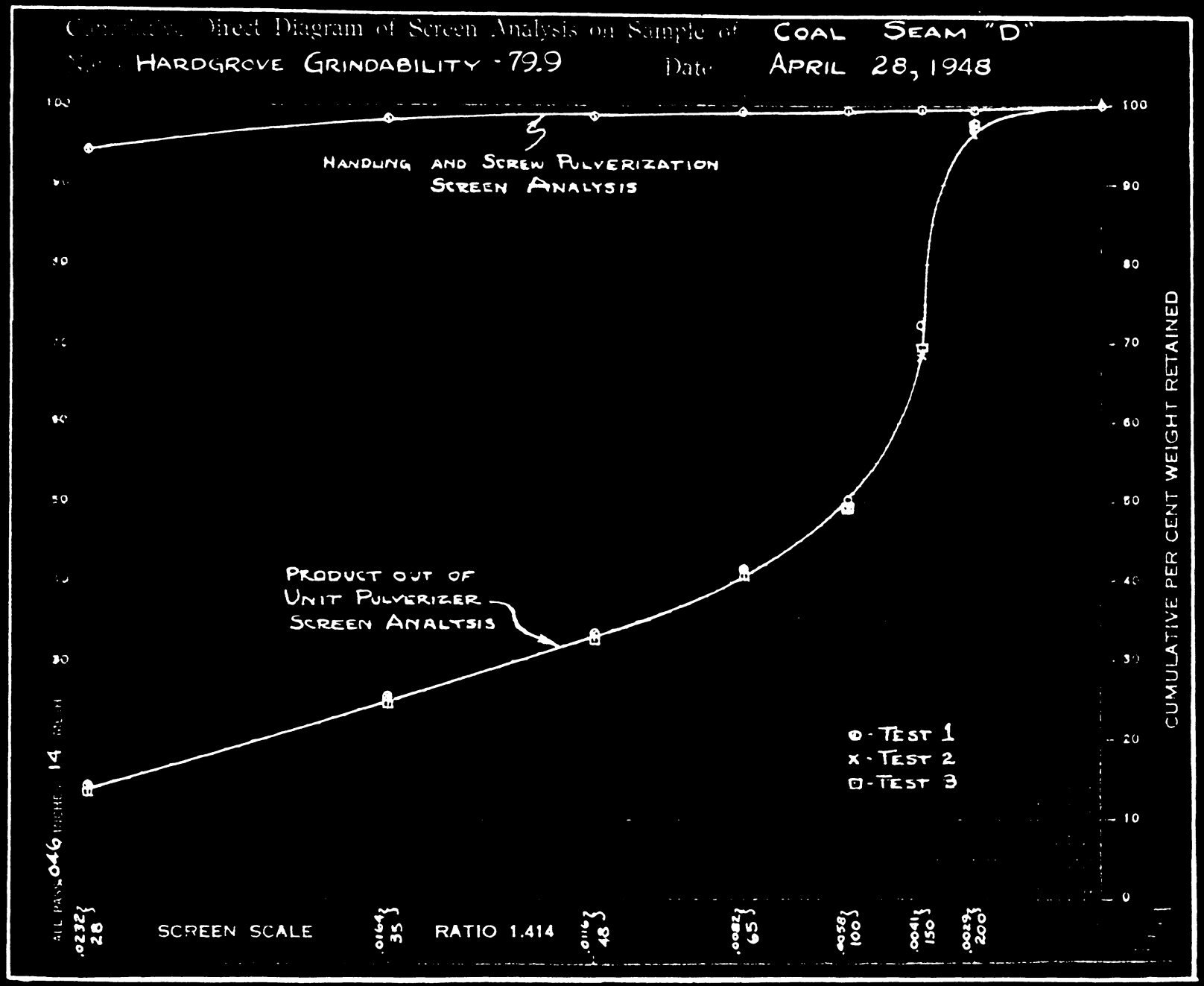
Direct Diagram of Screen Analysis on Sample of COAL SEAM "D"
HARDGROVE GRINDABILITY - 79.9
Date APRIL 28, 1948
HANDLING AND SCREW PULVERIZATION SCREEN ANALYSIS
PRODUCT OUT OF UNIT PULVERIZER SCREEN ANALTSIS
⊕ - TEST 1
x - TEST 2
□ - TEST 3
CUMULATIVE PER CENT WEIGHT RETAINED
100
90
80
70
60
50
40
30
20
10
0
ALL PASS .046 THRU 14 MESH
.0232 28
SCREEN SCALE
.0164 35
RATIO 1.414
.0116 48
.0082 65
.0058 100
.0041 150
.0029 200

FIGURE 7

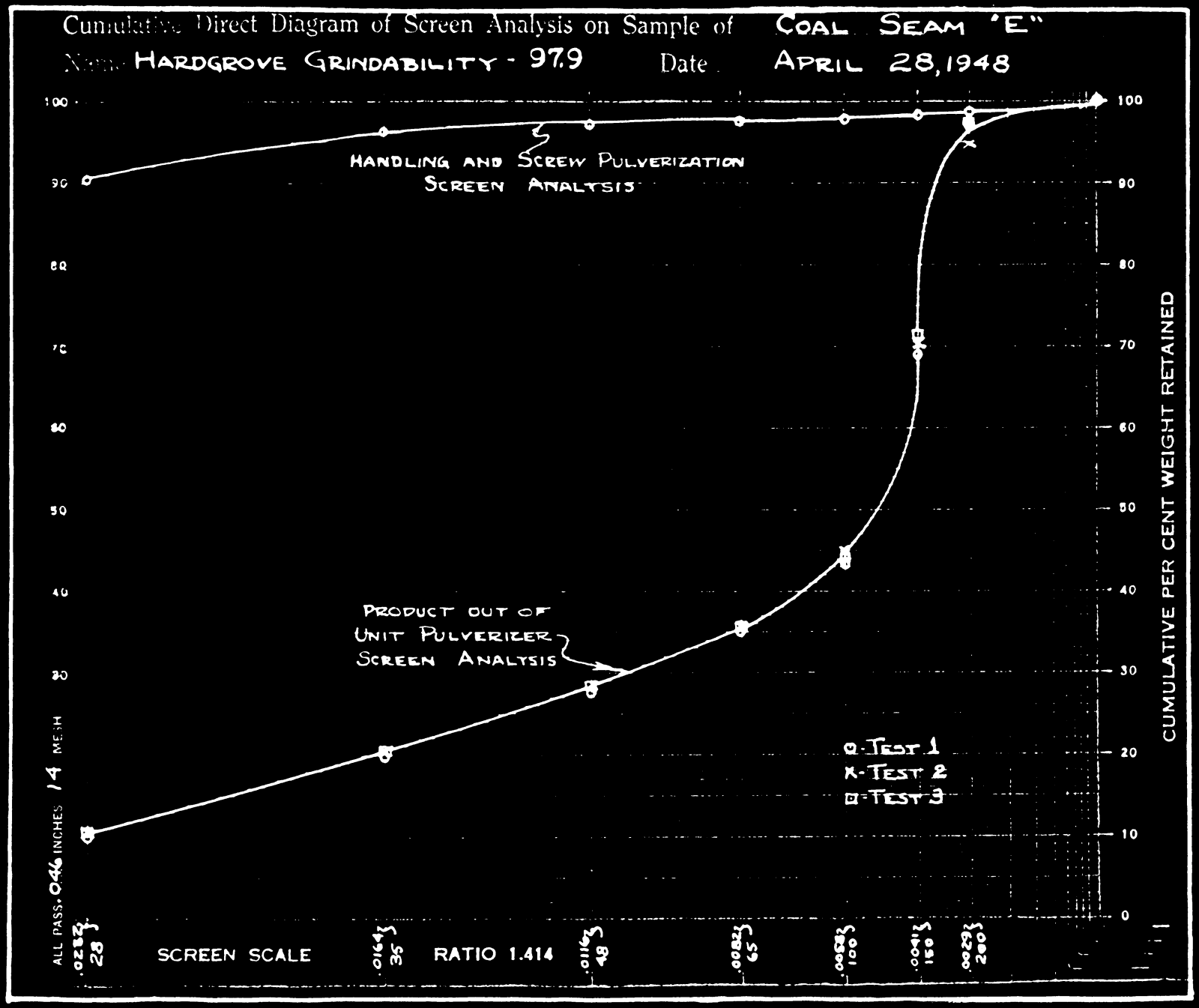
Cumulative Direct Diagram of Screen Analysis on Sample of COAL SEAM "E"
Name HARDGROVE GRINDABILITY - 97.9 Date APRIL 28, 1948
HANDLING AND SCREW PULVERIZATION SCREEN ANALYSIS
PRODUCT OUT OF UNIT PULVERIZER SCREEN ANALYSIS
Q-TEST 1
X-TEST 2
□-TEST 3
CUMULATIVE PER CENT WEIGHT RETAINED
ALL PASS .046 INCHES 14 MESH
SCREEN SCALE
RATIO 1.414
28
35
48
65
100
150
200

FIGURE 8

Table 12

Nozzle Pulverization Screen Analyses

Coal Seam	Tyler Screen	Handling, Pouring, and Screw Crushing cumulative per cent on screen	Unit Pulverization cumulative per cent on screen	Nozzle Pulverization per cent thru screen	Nozzle Pulverization cumulative per cent on screen
	28	95.2	20.6	74.6	25.4
	35	98.2	32.0	66.2	33.8
	48	98.9	40.8	58.1	41.9
"A"	65	99.3	48.8	50.5	49.5
	100	99.5	58.8	40.7	59.3
	150	99.6	75.0	24.6	75.4
	200	99.7	97.0	2.7	97.3
	28	93.6	18.1	75.5	24.5
	35	98.3	29.8	68.5	31.5
	48	99.0	39.0	60.0	40.0
"B"	65	99.4	48.0	51.4	48.6
	100	99.6	58.5	41.1	58.9
	150	99.8	80.0	19.8	80.2
	200	99.9	96.0	3.9	96.1

Table 12 (con't)

Nozzle Pulverization Screen Analyses

Coal Seam	Tyler Screen	Handling, Pouring, and Screw Crushing cumulative per cent on screen	Unit Pulverization cumulative per cent on screen	Nozzle Pulverization per cent thru screen	Nozzle Pulverization cumulative per cent on screen
"C"	28	96.1	18.5	77.6	22.4
	35	98.9	29.5	69.4	30.6
	48	99.3	38.5	60.8	39.2
	65	99.5	46.5	53.0	47.0
	100	99.7	55.0	44.7	55.3
	150	99.8	72.0	27.8	72.2
	200	99.9	97.0	2.9	97.1
"D"	28	94.2	13.9	80.3	19.7
	35	98.1	24.9	73.2	26.8
	48	98.9	33.0	65.9	34.1
	65	99.2	40.5	58.7	41.3
	100	99.4	50.5	48.9	51.1
	150	99.5	70.0	29.5	70.5
	200	99.7	96.5	3.2	96.8

Table 12 (con't)

Nozzle Pulverization Screen Analyses

Coal Seam	Tyler Screen	Handling, Pouring, and Screw Crushing cumulative per cent on screen	Unit Pulverization cumulative per cent on screen	Nozzle Pulverization per cent thru screen	Nozzle Pulverization cumulative per cent on screen
	28	90.5	10.5	80.0	20.0
	35	95.7	20.5	75.2	24.8
	48	96.8	28.5	68.3	31.7
"E"	65	97.4	35.5	61.9	38.1
	100	97.8	44.5	53.3	46.7
	150	98.1	70.0	28.1	71.9
	200	98.4	96.5	1.9	98.1

Sample Calculation for Nozzle Pulverization (cumulative per cent on screen):

Nozzle Pulverization (per cent through screen) = (100 - Unit Pulverization cumulative per cent on screen) - (100 - Handling, Pouring, and Screw Crushing cumulative per cent on screen) = (100 - 10.5) - (100 - 90.5) = 89.5 - 9.5 = 80.0%

Nozzle Pulverization (cumulative per cent on screen) = 100 - Nozzle Pulverization (per cent through screen) = 100 - 80.0 = 20.0%

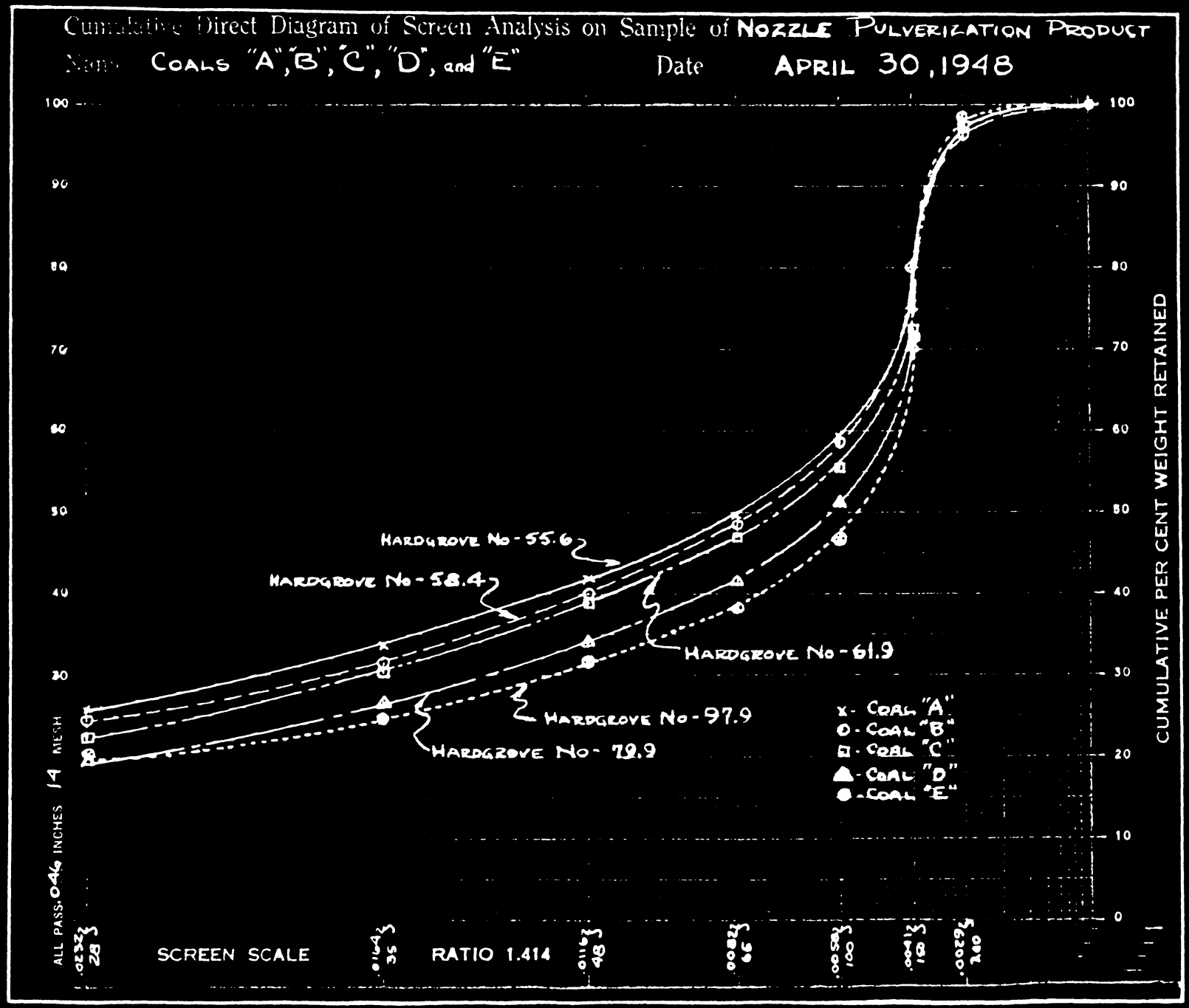
Cumulative Direct Diagram of Screen Analysis on Sample of NOZZLE PULVERIZATION PRODUCT
Name COALS "A", "B", "C", "D", and "E"
Date APRIL 30, 1948
HARDGROVE No - 55.6
HARDGROVE No - 58.4
HARDGROVE No - 61.9
HARDGROVE No - 97.9
HARDGROVE No - 79.9
X - COAL "A"
O - COAL "B"
□ - COAL "C"
▲ - COAL "D"
● - COAL "E"
CUMULATIVE PER CENT WEIGHT RETAINED
ALL PASS .046 INCHES 14 MESH
SCREEN SCALE
RATIO 1.414
28
35
48
65
100
150
200

FIGURE 9

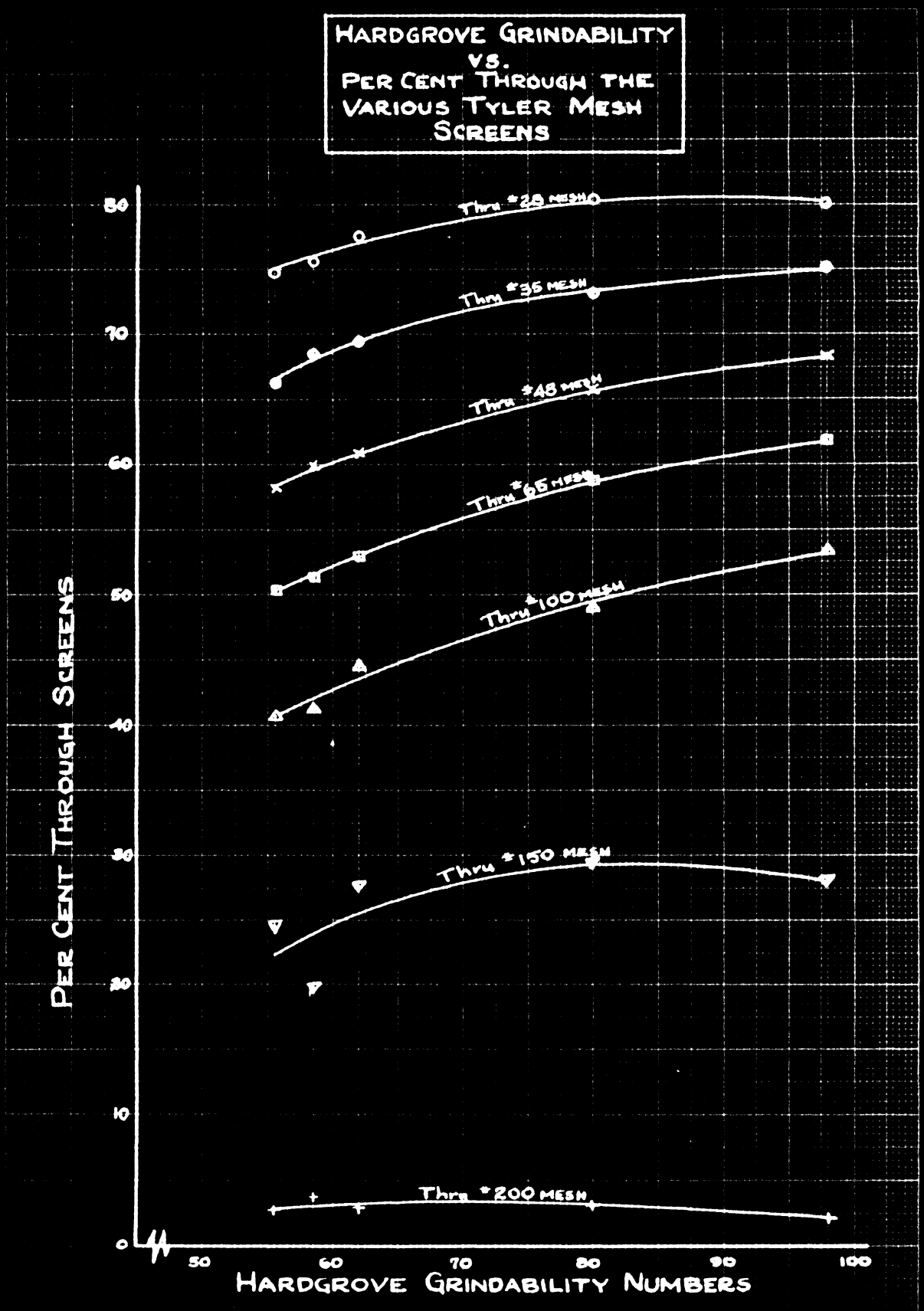
HARDGROVE GRINDABILITY
VS.
PER CENT THROUGH THE
VARIOUS TYLER MESH
SCREENS
Thru *28 MESH
Thru *35 MESH
Thru *48 MESH
Thru *65 MESH
Thru *100 MESH
Thru *150 MESH
Thru *200 MESH
PER CENT THROUGH SCREENS
80
70
60
50
40
30
20
10
0
50
60
70
80
90
100
HARDGROVE GRINDABILITY NUMBERS

FIGURE 10

DISCUSSION

Before discussing the curves and the results, the authors wish to point out several of the difficulties that had to be corrected before running the tests.

The major problem encountered was that of collecting the coal dust after pulverization. Originally, a cloth bag was used on the first Aerotec separator, and a glass jar on the second. After making a preliminary test on the unit, it was found that this arrangement was unsatisfactory because a large amount of the coal leaked out of the small openings in the cloth bag. To correct this trouble, a large glass jar was substituted for the bag. With the new arrangement, 99 per cent of the original coal sample was recovered from the collectors. As this loss was only one per cent, and approximately the same for all the coals, the authors felt that it could be neglected.

The capacity of the recovery jars determined the weight of the coal sample that could be tested. One gallon jars were used on the separators, and each held about five pounds of pulverized coal. It was found that the first separator jar collected about 90 per cent of the sample, the remaining ten per cent being gathered in the second separator jar and exhaust bag. For this reason, the larger the first jar, the greater the weight of coal that can be tested in the unit.

Another difficulty that was overcome was that of

unequal pressure on both sides of the screw conveyor while it was conveying the coal into the air stream. Without the equalizer line installed, the coal, in pushing against the incoming air, clogged the screw conveyor. This choking caused the "V" belt drive to slip, and, as a result, coal ceased to flow into the air stream. As constant coal feed was necessary, a pressure-equalizing line was installed.[6] This device balanced the air pressure on both sides of the screw conveyor, and gave a smooth, uninterrupted coal flow into the air stream.

Approximately one half the time spent on the procedure was used in the preparation of the sized coal. This constant coal size, between limits, is necessary in obtaining the characteristics of a nozzle pulverizer unit. The time spent in crushing and screening to size must be allowed for in future work on nozzle pulverization.

The coal was ordered from Virginia and West Virginia coal seams according to their approximate grindability. The different seams were selected from a bulletin,[7] so as to cover the range of Hardgrove Grindability Indices from 40 to 100 in steps of 15. After the grindability tests were run,

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6. See Figures 1 and 2.
7. Grindability of Coals Mined in the United States, Canada, and Other Countries - The Babcock and Wilcox Company Bulletin 3-241, May 1938.

it was found that the Hardgrove Indices of several of the coals were nearly the same; however, the grindabilities of the coals were spaced, though not equally, over a wide range.

The screen analyses data from the three tests run on each coal in the nozzle pulverizer unit checked very closely, as can be seen from the cumulative plots made in Figures 4 through 8. The average curve of these three tests was drawn and the nozzle pulverization data calculated, using this average curve for each coal. Figure 9 shows the different grindability coals plotted on screen analysis paper for nozzle pulverization only, and indicates an increase of pulverization with an increase in Hardgrove Indices.

Figure 10 shows the per cent of coal passing through the various screens from nozzle pulverization only versus Hardgrove Grindability, and it gives a better representation of the increase in pulverization. The increase in nozzle pulverization over the grindability range was small. As can be seen from this figure, all the points fell very close to the smooth curves drawn through the average of the points except those on the Thru 150 Mesh curve. The error on this curve seems to be the coal whose Hardgrove Grindability is 58.4. This coal had a different appearance from the others when received, and seemed to have been treated with oil or calcium chloride. As the openings in the 150 mesh screen are very small, blinding might have occurred with a coal that was sticky or wet.

This blinding would give a low per cent through 150 mesh, and would cause the point on the Thru 150 Mesh curve to be low.

From the trend of the family of curves in Figure 10, the Hardgrove Grindability seems to have less effect on the per cent of fines produced than on the larger sized coal particles. This trend may only be characteristic of the unit as designed by the authors. With a differently designed unit, greater pulverization may be obtained; and with more fines produced, an increase or decrease with Hardgrove Grindability may be more easily measured. All the curves in this figure, excluding Thru 200 Mesh, may be used in estimating the per cent increase in pulverization for a definite interval of Hardgrove Grindability Indices.

CONCLUSIONS

1. A small nozzle pulverizer unit can be built on which reproducible results may be obtained.
2. From the results obtained, grindability has an effect upon nozzle pulverization, but it is small over the range of Hardgrove Grindabilities studied.
3. The Hardgrove Grindability seemed to have less effect upon the per cent of fines produced than on the larger sized coal particles.

RECOMMENDATIONS

During the investigation, many ideas for future work on the nozzle pulverizer unit were thought of by the authors. Some of them have been done by others interested in the development of the nozzle pulverizer, while a few have never been studied before. For those who may be interested in carrying on further investigations with the unit, the following suggestions are listed:

1. Design various nozzles as to throat area, length of diverging section, or angle of divergence to find how each might affect the degree of pulverization with a given coal.

2. Install a flow nozzle so that the air flow may be measured continuously, and vary the coal-air ratios, noting the changes in pulverization for different coal-air ratios.

3. Insert a small metal plate, centered in the pipe, on the discharge side of the nozzle for use as an impact plate to further shatter the coal. The position and size of this "target" may be varied and its effect upon the degree of pulverization noted.

4. Design a quartz nozzle, such that the particles of coal, when exposed to a stroboscope of proper frequency, may be seen as they pass through the nozzle.

5. Pass the pulverized coal through the nozzle again and note the increase in pulverization.

APPENDICES

A. Bibliography

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Appendix B

Calibration Curves For Screw Conveyor

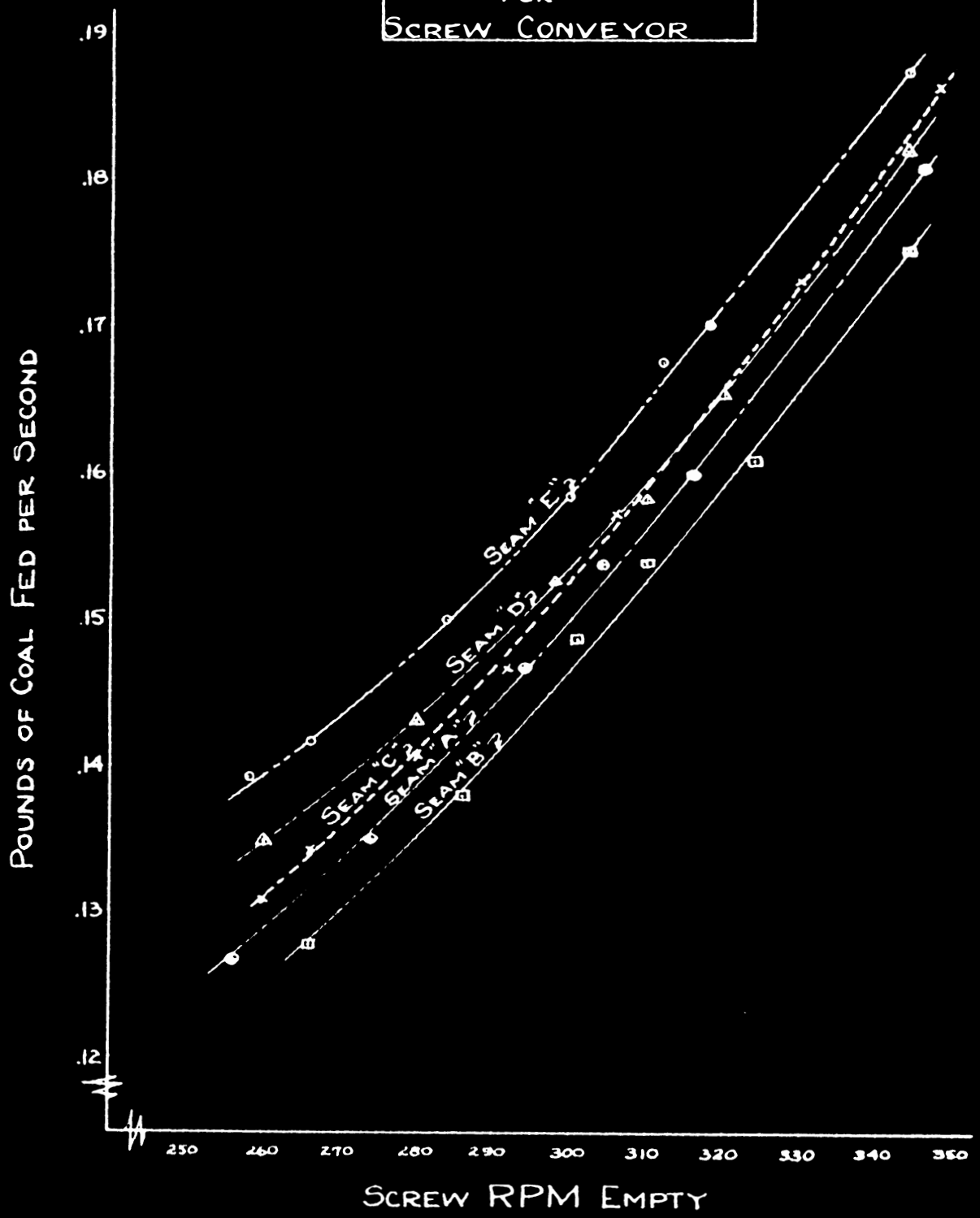
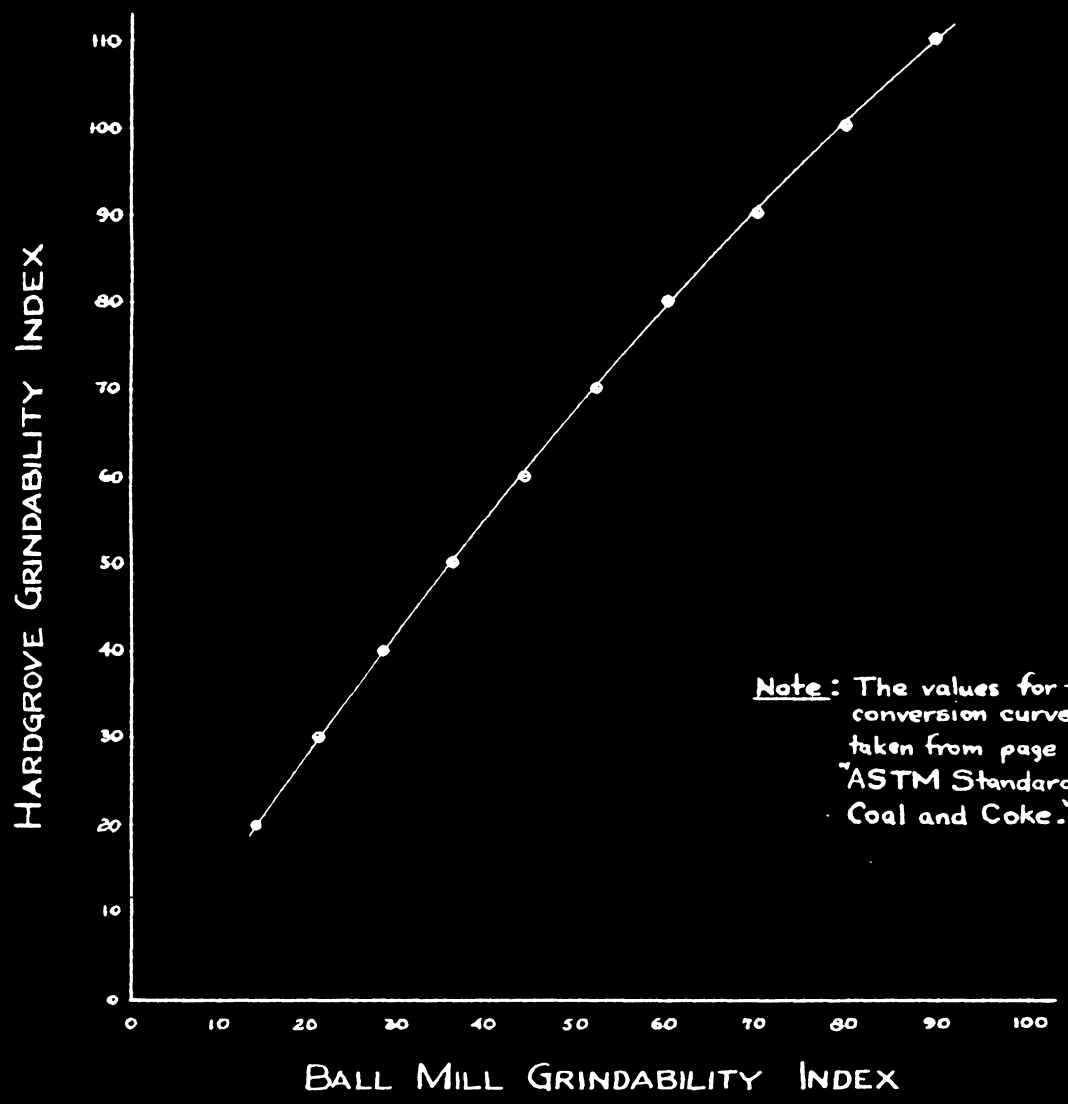


Figure 11

Appendix C

Conversion Curve for Hardgrove and Ball Mill Grindability Indices



Note: The values for this conversion curve were taken from page 49 "ASTM Standards on Coal and Coke."

Figure 12