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Washability tests and heat-content predictions for New Mexico coals

by Robert Shantz

New Mexico Bureau of Mines & Mineral Resources

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The purpose of this series is the immediate release of significant new information which otherwise would have to await release at a much later date as part of a comprehensive and formal document. These data are preliminary in scope and, therefore, subject to revision and correction.

SOCORRO 1978

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PREFACE

This report was prepared for the New Mexico Energy Resources Board under a contract titled "Assessment of the potential for coal preparation in New Mexico." The purpose of the project was to determine the applicability of coal-washing techniques to the high-ash, low-sulfur coals of the San Juan Basin and to assess the economic advantage of using washed coal for generating power. Additional washability data were developed and the suitability of froth flotation for cleaning the coal fines was investigated. An equation for predicting Btu content from percent of dry ash was developed.

Companies mining the high-ash and thin-bedded coals of the San Juan Basin will be interested in the results presented here. Included are data on the heat content and Btu recoveries that might be expected from a washery in the San Juan Basin; tables and figures are located at the end of the report. A technique for facilitating estimates of Btu content and percent of ash is also included. This information will be useful to coal exploration programs.

Two other papers have resulted from this Energy Resources Board contract: "Calculating heat content from ash percentages" in the May 1977 issue of *Coal Mining and Processing* and New Mexico Bureau of Mines and Mineral Resources Progress Report 9, *Strategy for coal-washing operations in New Mexico.* The present report (PR-10) includes the information presented in *Coal Mining and Processing.*

David Tabet, New Mexico Bureau of Mines and Mineral Resources, provided many valuable suggestions during the preparation of this paper. His help is sincerely appreciated.

Robert Shantz
Metallurgist
New Mexico Bureau of Mines
and Mineral Resources

Socorro
January 24, 1978

ABSTRACT

Conventional coal-washing methods can significantly reduce the ash content of coals from New Mexico. However, washing causes a loss of 10-20 percent in the heating value of the coal. Because of this loss and the low unit value of steam coal, conventional single-product coal cleaning can be economically justified only for special cases – including exceptionally high-ash coal (greater than 35 percent), thin beds, and extreme shipping distances. Washability data on coal samples from the operating mines and drill cores are reported. Although results varied among the samples, the float-sink tests indicate that low-ash coal can be produced by gravity-cleaning methods. Preliminary froth-flotation tests were made to determine whether a fine coal could be cleaned. Using diesel fuel as a collector, Btu recoveries over 95 percent were made, and about half the ash was rejected. The desire to reduce the number of Btu analyses required for the float-sink tests led to the development of an equation for predicting heat content from ash percentage for coals within each major coal-producing region of the state. Except for weathered coals, prediction within a few percent relative is generally possible. These prediction equations can be used in process control and exploration.

INTRODUCTION

Coal preparation is widely practiced in the United States but has been used by only a few operators in New Mexico. Phelps Dodge Corporation washed the coal from the Dawson mines prior to their closing, and Kaiser Steel Corporation operates a washery at York Canyon near Raton. Both operations have produced primarily metallurgical coal, which has relatively low ash requirements. The stringent air pollution regulations adopted by the Environmental Protection Agency have forced many operators throughout the country to build washeries to control sulfur, which may reach 8 percent in eastern coals. New Mexico steam coals, however, generally contain less than 1 percent total sulfur (often less than 0.6 percent) and hence normally meet Federal standards without cleaning. Thus, few potential mines in New Mexico will need to consider coal preparation for sulfur removal.

Two problems with New Mexico coals make washing necessary in some cases and advantageous in others. First, some operators are face with mining thin beds, often less than 3 ft thick, which have quantities of interbedded clay. Of necessity, these operators will mine enough material from above and below the bed to necessitate washing. A similar problem arises in mining thicker beds when the wedge portion of the cut is mined and causes overburden to slough into the coal. Second, the ash content of thicker beds can reach 20-30 percent in some areas. While power plants can burn coals of this type, the savings in transportation, ash removal facilities, and plant maintenance and availability make a cleaner coal desirable.

Mines in New Mexico might consider the possibility of washing the coal for a multi-unit power plant to allow reduction in emission control equipment on one unit while sending most or all of the rejects to the other units. Such a multi-unit system has been described for the Homer City, Pennsylvania, power plant, where the purpose was reduction of sulfur rather than of ash (*Coal Age,* 1976). Cleaned coal has even greater advantages when used in small industrial boilers rather than in large utility plants, and so separation of a small, high-quality coal from the general power plant feed might benefit mines in a position to sell to such users.

Several problems have limited the use of coal preparation in New Mexico. The low unit value of steam coal in the past ($3-4/ton) left little margin for preparation costs. In addition, about 20 percent of the heating value of the coal is lost in a typical single-product washery, and this value must be replaced by additional mining. In many cases, the expenditure for this additional mining is the largest cost associated with coal washing. Although lower ash content can save transportation costs, the higher moisture content that often results from washing can offset much of this benefit, especially if the fines are cleaned. The availability of water for a preparation plant in New Mexico may be a major problem.

Little information is available on the washability of the coarser-sized coals that would be treated in a preparation plant. This shortage of data reflects the cost of testing representative samples in larger size ranges. In particular, the maximum size for adequate liberation of the coal and ash has not been determined.

Finally, each mining property has coal with different properties. The amount of overburden that will be mined with the coal and the availability of water for preparation plants varies from one operation to another. Likewise, each plant feeds a user whose requirements are unique. Consequently, the benefits of coal preparation must be evaluated case by case.

WASHABILITY TESTS

The washability test results reported by Shomaker and others (1971) provide some data on the washability of San Juan Basin coals. To expand on these results, seven coal samples were collected from operations in the San Juan Basin for float-sink, screen, and froth-flotation tests. All the samples were crushed to -3 mesh and air dried. The float-sink tests were made by screening out the -100 mesh material and separating the appropriate sizes with series of heavy liquids from 1.30 to 1.80 specific gravity by 0.10 specific gravity. The fractions were then analyzed for ash content and, in a few cases, total sulfur content. Flotation tests were made by grinding 350 grams of the material to 95 percent passing 48 mesh and floating in a 3-liter laboratory cell.

The raw coal analyses are given in table 1; the float-sink test results are given in tables 2-19, the screen test results in tables 20-22, and representative flotation test results in table 23. Reported Btu contents (moisture free) for each separated fraction were calculated by using the equation described in the discussion of heat-content predictions (a = 14,000; b = 15,740).

The following samples from mining properties were used in the washability tests:

1) Stockpile, property A – a grab sample of crushed, blended coal taken from the bedding plant

2) Wedge fraction, property A – a grab sample taken from the wedge area of the mine, includes a considerable amount of overburden

3) Run-of-mine, property B – a grab sample taken from a raw coal stockpile being built ahead of the crushing plant

4) Bulk sample, property C – a grab sample taken from a test pit

5) Cut sample, property C – a cut was made across the exposed face of the coal in a test pit

6) Drill core A, property C – split of core having a significant amount of interbedded shale

7) Drill core B, property C – split of core having a significant amount of interbedded shale.

Tests on these samples indicate that a coal containing about 10% ash can be produced by washing at a specific gravity of roughly 1.50; however, about 20% of the heat value would be lost. Up to 50 percent of the ash can be rejected by cleaning near 1.70 specific gravity, and 90-95 percent of the heating value can be retained. Because of the distribution of near-gravity material, separations in the 1.30-1.50 specific gravity range would be somewhat difficult; on the other hand, separations in the 1.70-1.80 specific gravity range should be relatively simple. Thus, heavy-media devices will probably be required for separations at lighter densities, but water-only devices should be acceptable at a higher density.

Froth-flotation tests indicate that the fines can be cleaned by flotation, but high levels of collector addition appear to be necessary. Fig. 1 shows the effect of collector level on Btu recovery. The reagent costs, together with the high costs of centrifuging or filtering the fine material, probably preclude the use of flotation on steam coal.

Washability tests developed during this study and obtained from other sources indicate that washing can produce a product with as little as 5 percent ash. However, the Btu recovery drops rapidly when the coal is cleaned to below 10-15 percent ash. Because of the low unit value of the product and the washing costs of \$0.50-2.00/ton (depending upon the method used), washing may not be an alternative except in cases where coal of over 30-percent ash is being produced. Such cases would include thin beds or wedge fractions.

Discussions with power-plant personnel lead to the conclusion that the reduction in maintenance associated with lower ash in the feed does not justify a washery. In a few cases, however, large savings may result because of increased power-plant availability. Personnel from each plant would have to make a detailed study to determine if cleaner coal would provide sufficiently higher availability to justify washing costs and coal losses.

Multi-product washing strategies provide opportunities both to produce a high-grade coal for special uses and to achieve high overall heating-value recoveries. One such strategy is described by Shantz (1977a). This proposed process would float 25 percent of the +5/16-inch coal at a specific gravity of about 1.35, resulting in a coal having 6 percent ash and 13,000 Btu/lb (moisture free). The sink coal would then be recleaned at 1.80 specific gravity to reject a high-ash fraction (70 percent). The middlings, which would contain most of the heating value, would feed a mine-mouth power plant. An overall heat recovery of about 95 percent would result.

The use of coal-washing techniques for New Mexico coal should be investigated further, especially in terms of market studies to determine the price that would be paid for coal with a low ash content. The smaller mines throughout the state might find that coal cleaning would allow them to meet product specifications for industrial users in Texas or southern California.

HEAT-CONTENT PREDICTIONS

Float-sink analyses of seven coal samples allowed prediction of separations attainable by gravity washing. Because each float-sink test requires eight Btu-content analyses, which are relatively expensive, the possibility of predicting Btu content from the ash fraction was investigated by plotting coal analyses from Shomaker and others (1971). The plots revealed a high degree of linear correlation between Btu and ash contents. Consequently, a simple linear-regression study was made on coal analyses from the major coal districts in New Mexico having available data. In addition, some production data were examined to see if the Btu-prediction equation was suitable for use on routine analyses. Some of these results have been published (Shantz, 1977b).

Development of Btu-ash content regression parameters

The equation used for the Btu-ash content least-squares regression analyses was

$$\frac{\text{Btu/lb}}{1 - M} = a - b\frac{X}{1 - M}$$

where a and b are the regression parameters, X the ash fraction, and M the moisture fraction. The heat content in Btu/lb is moisture free here. Thus the regression parameters presented in the following sections give Btu/lb (dry) directly from the moisture-free ash analysis:

$$\text{Btu/lb} = a - b\ (\text{ash fraction}).$$

A linear least-squares analysis was made on the available data from each area listed in table 24. Those points in the initial regression analysis that differed by over two standard deviations from the predicted value (usually about 2-5 percent of the available data) were rejected and the regression parameters recalculated.

Data on Btu analyses and ash fractions were obtained from a number of sources, principally U.S. Bureau of Mines Technical Paper 569 and company records. The results of the regression analyses by various groupings are given in table 24. The regression parameters calculated for various areas in the San Juan Basin are remarkably consistent although they encompass an area of over 26,000 sq mi. The consistency of a is particularly significant because it corresponds to the moisture- and ash-free analysis. The slightly higher parameters for Rio Arriba County in the northeastern part of the basin are from the Monero field near Lumberton. The higher value of a from this field could be expected because the area has undergone more structural deformation and intrusive activity than most of the basin has. Likewise, regression parameters for La Plata County, Colorado, are somewhat high. The extreme variations and large confidence intervals for b in the delivered coal for the Rio Arriba County and Black Mesa, Arizona, regressions are primarily the result of the limited range of ash fractions and Btu contents in the data for these areas. The deviation of the Chaco Canyon regression parameters from the other areas of the basin could be the result of having only limited data available.

The standard deviation of the differences for the basin as a whole (409 Btu/lb) indicates a relative error of 4 percent compared to the average moisture-free Btu content of about 10,000 Btu/lb. This accuracy is sufficient for guiding exploration efforts provided that care is taken to avoid oxidized coal. (See table 28 for examples of the large differences that can be encountered.) Calculated Btu contents can not completely replace the actual analyses but can reduce the number required. Also, such predictions allow faster estimation of the Btu values because the moisture and ash analyses can be made easily in the field.

A generalized relationship giving weight of ash per million Btu as a function of ash fraction can be readily developed. Fig. 2 shows such a graph using the overall San Juan Basin regression parameters. The general expression is as follows:

$$\text{lb ash/MMBTU} = \frac{X \cdot 10^6}{a - bX}$$

where X is the ash fraction on a moisture-free basis and a and b the appropriate regression parameters.

Application to float-sink tests

The original purpose for developing a means of predicting Btu content was to reduce the number of Btu analyses required for float-sink tests during washability studies. A high degree of correlation between measured and predicted Btu contents within the fractions from each float-sink test would indicate that only two or three Btu analyses would be required to determine the necessary regression parameters, and then the other Btu contents could be calculated. Table 25 shows the results of regression analyses on three float-sink tests from Shomaker and others (1971). Regression analyses were made for each of the float-sink tests; and representative tests were taken for table 3. The very high correlation coefficients, 0.9871-1.0000 (usually about 0.999), indicate the acceptability of the approach.

Calculation of the cumulative Btu recovery (as a percentage) for each specific gravity is the major requirement for Btu analyses on the individual fractions in float-sink testing. Table 26 gives a comparison of Btu recoveries calculated from the measured Btu contents in Shomaker and others (1971) and those predicted by a linear equation using the basin-wide regression parameter (a = 14,006; b = 15,743). The agreement is excellent: the largest difference noted in the 25 tests was 4 percent (actual) with the average under 1 percent. Consequently, these regression parameters were used to calculate the Btu contents in the experimental work on washability tests.

Application to quality control of delivered coal

Sixty-four analyses, each representing approximately 1,000 tons of coal from mine production, were provided by one operator. A comparison of the measured Btu content (as received) and the values calculated using the results of the basin-wide regression (a = 14,006; b = 15,743) is presented in table 27, which gives 40 randomly selected values. The average difference was

3.5 Btu/lb with a standard deviation of 169 Btu/lb. The largest difference was 891 Btu/lb or about 10 percent relative.

Thus an operator should be able to calculate his own regression parameters to predict the average delivered Btu content and significantly reduce the number of Btu analyses required. Since many operators use the bomb washing from the calorimeter for sulfur analyses, the labor saved in bypassing the Btu analysis is difficult to assess.

Application to coal exploration sampling

After the overall San Juan Basin regression analysis had been made, some additional coal analyses were received from an exploration project in the Basin. The basin-wide regression parameters were used to predict the Btu contents, and a comparison was made between the calculated and measured values. Some representative points are given in table 28, and a plot of representative points versus the basin-wide regression line is given in fig. 3. The overall mean difference was 0 Btu/lb with a standard deviation of 527 Btu/lb, largely as a result of a few 1,000-2,000 Btu/lb differences. In all cases, these large differences occurred in samples taken from the top interval of the hole, and the measured values were lower than the predicted values; all holes did not show significant differences in the top interval.

Conclusions

The following conclusions about heat-content predictions were reached from a study of the available coal analyses: 1) correlation coefficients between measured and predicted Btu contents on the order of 0.88 and 0.99 can be obtained in each of the major coal-producing areas and 2) the linear model is essentially as satisfactory as the quadratic model.

Depending upon the particular operation, considerable savings in labor and time could result from predicting rather than from measuring the Btu contents. However, in all cases, some Btu analyses should be made to insure that an atypical coal has not been encountered. In addition, any coal suspected of being weathered should be analyzed for Btu content.

REFERENCES

Coal Age, 1976, Multi-stream coal cleaning system promises help with sulfur problem: Coal Age, v. 81, no. 1, p. 86-88

Peirce, H. W., Keith, S. E., and Wilt, S. C., 1970, Coal, oil, natural gas, helium, and uranium in Arizona: Arizona Bureau of Mines, Bull. 182, 612 p.

Pillmore, C. L., and Hatch, J. R., 1976, Geochemical data on selected coal beds, Raton coal field, Colfax County, New Mexico: U. S. Geological Survey, Open-file Rept. 76-542, 26 p., 11 tables, 2 figs.

Shantz, R., 1977a, Strategy for coal-washing operations in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Progress Rept. 9, 7 p.

_____, 1977b, Calculating heat content from ash percentages: Coal Mining and Processing, v. 14, no. 5, p. 112-114

Shomaker, J. W., Beaumont, E. C., and Kottlowski, F. E., 1971, Strippable low-sulfur coal resources of the San Juan Basin in New Mexico and Colorado: New Mexico Bureau of Mines and Mineral Resources, Mem. 25, 189 p.

U. S. Bureau of Mines, 1936, Analyses of New Mexico coals: U. S. Bureau of Mines, Tech. Paper 569, 112 p.

U. S. Bureau of Mines, 1937, Analyses of Colorado coals: U. S. Bureau of Mines, Tech. Paper 574, 327 p.

U. S. Bureau of Mines, 1947, Analyses of Arizona, California, Idaho, Nevada, and Oregon coals: U. S. Bureau of Mines, Tech. Paper 696, 83 p.

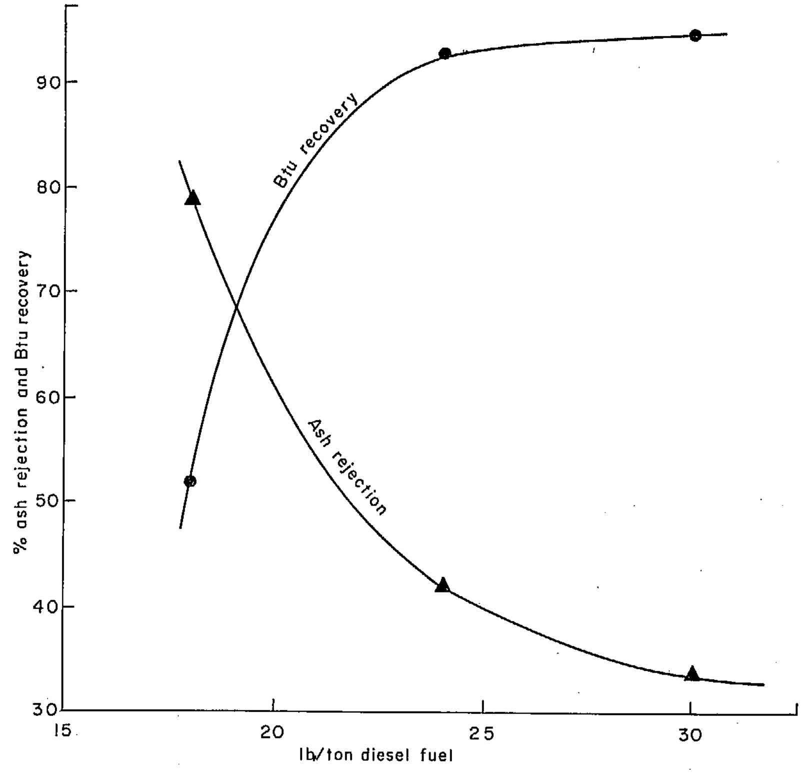

FIGURE 1—Effect of collector level on flotation (bulk sample, Property A).

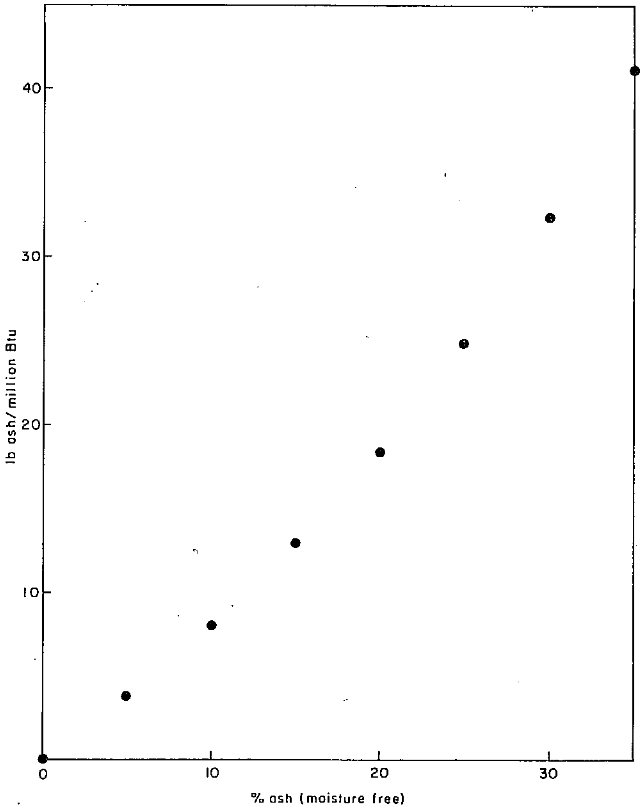

FIGURE 2—Predicted lbs of ash per million Btu; lb ash/million Btu = ash • 10^6/14006 − 15473 (ash).

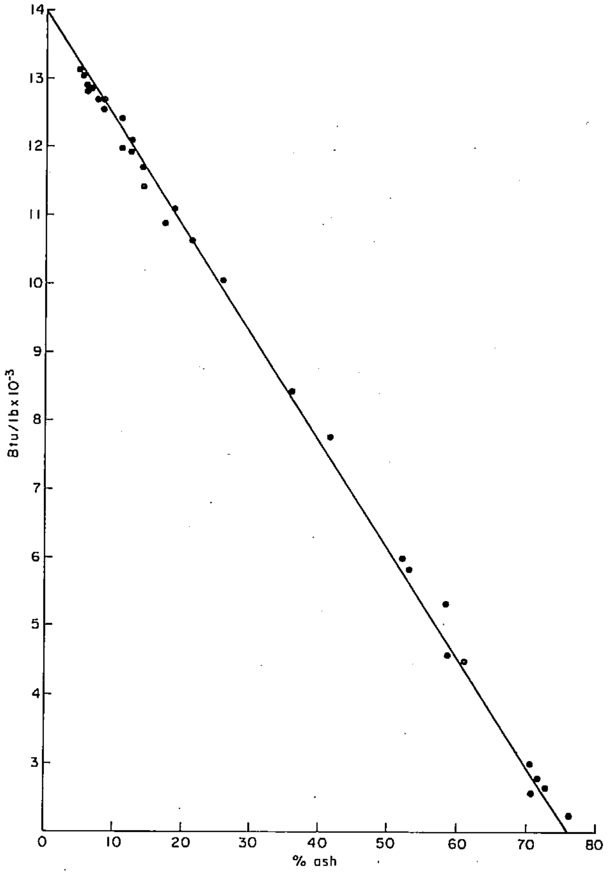

FIGURE 3—Heat content vs. ash for representative core analyses (moisture-free basis).

TABLE 1—Raw coal analyses (MF = moisture free).

Sample	Moisture %	Ash % (MF)	Total sulfur % (MF)
Stockpile, Property A	12.4	25.4	0.57
Wedge, Property A	13.2	56.5	0.35
Run-of-Mine, Property B	9.7	35.5	0.55
Bulk Sample, Property C	9.1	29.6	-
Cut Sample, Property C	10.4	36.2	-
Drill Core A, Property C	8.8	53.6	-
Drill Core B, Property C	8.3	41.1	-

TABLE 2—Washability test, stockpile, Property A, -3, +10 mesh.

Sp. gr. fraction	Direct				Cumulative			
	wt%	ash%	total sulfur%	Btu/lb	wt%	ash%	total sulfur%	Btu/lb
Float-1.30	7.2	4.0	0.5	13,400	7.2	4.0	0.5	13,400
1.30-1.40	48.0	9.5	0.5	12,500	55.2	8.8	0.5	12,600
1.40-1.50	13.4	23.1	0.5	10,400	68.6	11.6	0.5	12,200
1.50-1.60	6.2	35.4	0.6	8,400	74.8	13.5	0.5	11,900
1.60-1.70	3.8	45.4	0.5	6,900	78.7	15.1	0.5	11,600
1.70-1.80	4.0	53.1	0.5	5,600	82.7	17.0	0.5	11,300
1.80-Sink	17.3	72.5	0.9	2,600	100.0	26.5	0.6	9,800

TABLE 3—Washability test, stockpile, Property A, - 10, +28 mesh.

Sp. gr. fraction	Direct			Cumulative		
	wt%	ash%	Btu/lb	wt%	ash%	Btu/lb
Float-1.30	22.4	8.8	12,600	22.4	8.8	12,600
1.30-1.40	40.7	10.9	12,300	63.1	10.2	12,400
1.40-1.50	12.1	24.3	10,200	75.2	12.4	12,000
1.50-1.60	5.8	36.4	8,300	81.0	14.1	11,800
1.60-1.70	3.0	43.7	7,100	84.1	15.2	11,600
1.70-1.80	2.0	48.4	6,400	86.1	16.0	11,500
1.80-Sink	13.9	67.5	3,400	100.0	23.2	10,400

TABLE 4—Washability test, wedge fraction, Property A, - 28, +100 mesh.

Sp. gr. fraction	Direct			Cumulative		
	wt%	ash%	Btu/lb	wt%	ash%	Btu/lb
Float-1.30	12.3	3.6	13,400	12.3	3.6	13,400
1.30-1.40	40.8	7.3	12,900	53.1	6.4	13,000
1.40-1.50	16.9	17.9	11,200	70.0	9.2	12,600
1.50-1.60	7.0	29.4	9,400	77.0	11.0	12,300
1.60-1.70	4.5	39.1	7,800	81.5	12.6	12,000
1.70-1.80	3.2	48.0	6,400	84.7	13.9	11,800
1.80-Sink	15.2	69.0	3,100	100.0	22.3	10,500

TABLE 5—Washability test, wedge fraction, Property A, - 3, +10 mesh.

Sp. gr. fraction	Direct				Cumulative			
	wt%	ash%	total sulfur%	Btu/lb	wt%	ash%	total sulfur%	Btu/lb
Float-1.30	0.6	4.1	0.5	13,400	0.6	4.1	0.5	13,400
1.30-1.40	23.1	6.8	0.4	12,900	23.7	6.7	0.4	12,900
1.40-1.50	20.7	14.9	0.4	11,700	44.4	10.5	0.4	12,300
1.50-1.60	5.3	28.1	0.4	9,600	49.6	12.4	0.4	12,100
1.60-1.70	1.9	37.6	0.4	8,100	51.5	13.6	0.4	11,900
1.70-1.80	1.0	47.5	0.3	6,500	52.5	14.0	0.4	11,800
1.80-Sink	47.4	90.8	0.2	0	100.0	50.4	0.3	6,100

TABLE 6—Washability test, wedge fraction, Property A, - 10, +28 mesh.

Sp. gr. fraction	Direct			Cumulative		
	wt%	ash%	Btu/lb	wt%	ash%	Btu/lb
Float-1.30	1.6	3.8	13,400	1.6	3.8	13,400
1.30-1.40	31.0	7.1	12,900	32.6	6.9	12,900
1.40-1.50	17.5	15.1	11,600	50.1	9.8	12,500
1.50-1.60	6.4	25.2	10,000	56.5	11.5	12,200
1.60-1.70	2.5	34.6	8,600	58.9	12.5	12,000
1.70-1.80	1.5	43.9	7,100	60.4	13.3	11,900
1.80-Sink	39.6	89.3	0	100.0	43.3	7,200

TABLE 7—Washability test, wedge fraction, Property A, -28, +100 mesh.

Sp. gr. fraction	Direct wt%	Direct ash%	Direct Btu/lb	Cumulative wt%	Cumulative ash%	Cumulative Btu/lb
Float-1.30	0.4	3.5	13,500	0.4	3.5	13,500
1.30-1.40	9.0	5.3	13,200	9.4	5.2	13,200
1.40-1.50	16.7	11.5	12,200	26.1	9.2	12,600
1.50-1.60	5.0	21.9	10,600	31.1	11.3	12,200
1.60-1.70	2.6	29.5	9,400	33.7	12.7	12,000
1.70-1.80	1.4	39.5	7,800	35.1	13.8	11,800
1.80-Sink	64.9	93.5	0	100.0	65.5	3,700

TABLE 8—Washability test, run-of-mine, Property B, -3, +10 mesh.

Sp. gr. fraction	Direct wt%	Direct ash%	Direct total sulfur%	Direct Btu/lb	Cumulative wt%	Cumulative ash%	Cumulative total sulfur%	Cumulative Btu/lb
Float-1.30	28.8	4.4	0.6	13,300	28.8	4.4	0.6	13,300
1.30-1.40	32.8	10.4	0.5	12,400	61.6	7.6	0.5	12,800
1.40-1.50	5.7	24.8	0.6	10,100	67.3	9.0	0.5	12,600
1.50-1.60	2.5	34.8	0.5	8,500	69.8	10.0	0.5	12,400
1.60-1.70	1.9	41.1	0.8	7,500	71.7	10.8	0.6	12,300
1.70-1.80	1.7	50.1	0.7	6,100	73.4	11.7	0.6	12,200
1.80-Sink	26.6	81.3	0.6	1,200	100.0	30.2	0.6	9,300

TABLE 9—Washability test, run-of-mine, Property B, -10, +28 mesh.

Sp. gr. fraction	Direct wt%	Direct ash%	Direct Btu/lb	Cumulative wt%	Cumulative ash%	Cumulative Btu/lb
Float-1.30	27.9	3.4	13,500	27.9	3.4	13,500
1.30-1.40	34.8	9.9	12,400	62.7	7.0	12,900
1.40-1.50	6.7	22.3	10,500	69.4	8.5	12,700
1.50-1.60	2.7	32.6	8,900	72.1	9.4	12,500
1.60-1.70	2.1	39.9	7,700	74.2	10.3	12,400
1.70-1.80	1.5	47.4	6,500	75.7	11.0	12,300
1.80-Sink	24.2	80.9	1,300	100.0	27.9	9,600

TABLE 10—Washability test, run-of-mine, Property B, -28, +100 mesh.

Sp. gr. fraction	Direct wt%	Direct ash%	Direct Btu/lb	Cumulative wt%	Cumulative ash%	Cumulative Btu/lb
Float-1.30	21.6	2.9	13,600	21.6	2.9	13,600
1.30-1.40	36.1	13.8	11,800	57.7	9.7	12,500
1.40-1.50	9.1	21.7	10,600	66.8	11.4	12,200
1.50-1.60	3.1	28.6	9,500	69.9	12.1	12,100
1.60-1.70	2.2	36.6	8,200	72.1	12.9	12,000
1.70-1.80	1.2	42.9	7,300	73.3	13.4	11,900
1.80-Sink	26.7	79.5	1,500	100.0	31.0	9,200

TABLE 11—Washability test, bulk sample, Property C, -3, +100 mesh.

Sp. gr. fraction	Direct wt%	Direct ash%	Direct Btu/lb	Cumulative wt%	Cumulative ash%	Cumulative Btu/lb
Float-1.30	18.3	4.9	13,200	18.3	4.9	13,200
1.30-1.40	18.2	13.4	11,900	36.5	9.1	12,600
1.40-1.50	14.0	23.9	10,200	50.5	13.2	11,900
1.50-1.60	10.1	35.6	8,400	60.6	17.0	11,300
1.60-1.70	7.9	44.0	7,100	68.6	20.1	10,800
1.70-1.80	6.2	56.7	5,100	74.8	23.2	10,400
1.80-Sink	25.2	76.9	1,900	100.0	36.7	8,200

TABLE 12—Washability test, cut sample, Property C, -3, +100 mesh.

Sp. gr. fraction	Direct wt%	Direct ash%	Direct Btu/lb	Cumulative wt%	Cumulative ash%	Cumulative Btu/lb
Float-1.30	39.9	3.9	13,400	39.9	3.9	13,400
1.30-1.40	12.3	13.6	11,900	52.3	6.2	13,000
1.40-1.50	7.1	23.2	10,400	59.3	8.2	12,700
1.50-1.60	5.3	35.5	8,400	64.6	10.4	12,400
1.60-1.70	7.0	44.3	7,000	71.6	13.7	11,800
1.70-1.80	8.9	53.8	5,500	80.6	18.2	11,100
1.80-Sink	19.5	68.1	3,300	100.0	27.9	9,600

TABLE 13–Washability test, core sample A, Property C, -3, +100 mesh.

Sp. gr. fraction	Direct			Cumulative		
	wt%	ash%	Btu/lb	wt%	ash%	Btu/lb
Float-1.30	20.0	4.0	13,400	20.0	4.0	13,400
1.30-1.40	8.3	7.8	12,800	28.3	5.1	13,200
1.40-1.50	3.2	22.2	10,500	31.5	6.9	12,900
1.50-1.60	5.6	30.6	9,200	37.1	10.4	12,400
1.60-1.70	2.8	38.7	7,900	39.9	12.4	12,000
1.70-1.80	3.6	48.9	6,300	43.5	15.4	11,600
1.80-Sink	56.4	84.4	700	100.0	54.3	5,400

TABLE 14–Washability test, core sample B, Property C, -3, +100 mesh.

Sp. gr. fraction	Direct			Cumulative		
	wt%	ash%	Btu/lb	wt%	ash%	Btu/lb
Float-1.30	30.0	5.3	13,200	30.0	5.3	13,200
1.30-1.40	18.6	9.5	12,500	48.6	6.9	12,900
1.40-1.50	13.0	22.6	10,400	61.6	10.2	12,400
1.50-1.60	3.0	29.8	9,300	64.6	11.1	12,300
1.60-1.70	1.1	43.5	7,200	65.7	11.7	12,200
1.70-1.80	1.2	49.6	6,200	66.9	12.4	12,100
1.80-Sink	32.9	90.4	0	100.0	38.0	8,000

TABLE 15–Ash and Btu distributions for stockpile sample, Property A.

Sp. gr. fraction	-3, +10 mesh		-10, +28 mesh		-28, +100 mesh	
	% ash rejection	% Btu recovery	% ash rejection	% Btu recovery	% ash rejection	% Btu recovery
Float-1.30	99	10	92	27	98	16
1.30-1.40	82	71	72	76	85	66
1.40-1.50	70	85	60	88	71	84
1.50-1.60	62	90	50	92	62	90
1.60-1.70	55	93	45	94	54	94
1.70-1.80	47	95	41	96	47	95
1.80-Sink	0	100	0	100	0	100

TABLE 16–Ash and Btu distributions for wedge sample, Property A.

Sp. gr. fraction	-3, +10 mesh		-10, +28 mesh		-28, +100 mesh	
	% ash rejection	% Btu recovery	% ash rejection	% Btu recovery	% ash rejection	% Btu recovery
Float-1.30	100	1	100	3	100	1
1.30-1.40	97	49	95	58	99	30
1.40-1.50	91	88	89	87	96	79
1.50-1.60	88	96	85	96	95	92
1.60-1.70	86	99	83	98	94	97
1.70-1.80	85	100	81	100	93	100
1.80-Sink	0	100	0	100	0	100

TABLE 17–Ash and Btu distributions for run-of-mine sample, Property B.

Sp. gr. fraction	-3, +10 mesh		-10, +28 mesh		-28, +100 mesh	
	% ash rejection	% Btu recovery	% ash rejection	% Btu recovery	% ash rejection	% Btu recovery
Float-1.30	96	42	97	39	98	32
1.30-1.40	84	85	84	84	82	79
1.40-1.50	80	92	79	92	76	90
1.50-1.60	77	94	76	94	73	93
1.60-1.70	74	95	73	96	70	95
1.70-1.80	72	96	70	97	68	96
1.80-Sink	0	100	0	100	0	100

TABLE 18–Ash and Btu distributions for Property C.

Sp. gr. fraction	Bulk sample		Cut sample	
	% ash rejection	% Btu recovery	% ash rejection	% Btu recovery
Minus 100 Mesh	92	6	92	6
Float-1.30	90	34	87	58
1.30-1.40	84	58	81	73
1.40-1.50	75	75	76	80
1.50-1.60	66	85	70	84
1.60-1.70	58	91	59	89
1.70-1.80	49	95	44	94
1.80-Sink	0	100	0	100

TABLE 19—Ash and Btu distributions for drill cores, Property C.

Sp. gr. fraction	Drill core A % ash rejection	Drill core A % Btu recovery	Drill core B % ash rejection	Drill core B % Btu recovery
Minus 100 Mesh	86	3	89	3
Float-1.30	85	51	85	51
1.30-1.40	84	70	81	79
1.40-1.50	83	76	74	95
1.50-1.60	80	85	72	98
1.60-1.70	78	89	71	99
1.70-1.80	75	93	69	100
1.80-Sink	0	100	0	100

TABLE 20—Screen analysis, stockpile sample, Property A, 3 mesh x 0.

Tyler mesh fraction	Direct wt%	Direct ash%	Direct Btu/lb	Cumulative wt%	Cumulative ash%	Cumulative Btu/lb
-3, +4	10.9	25.4	10,000	10.9	25.4	10,000
-4, +6	6.0	27.2	9,700	16.9	26.0	9,900
-6, +8	5.6	26.7	9,800	22.5	26.2	9,900
-8, +10	10.8	24.3	10,200	33.3	25.6	10,000
-10, +16	20.9	22.7	10,400	54.2	24.5	10,100
-16, +20	4.8	21.8	10,600	59.0	24.3	10,200
-20, +28	8.7	22.6	10,400	67.7	24.0	10,200
-28, +35	7.9	23.0	10,400	75.6	23.9	10,200
-35, +48	6.2	23.3	10,300	81.8	23.9	10,200
-48, +65	5.6	23.8	10,300	87.4	23.9	10,200
-65, +100	3.7	24.6	10,100	91.1	23.9	10,200
-100, +150	3.0	25.7	10,000	94.1	24.0	10,200
-150, +200	2.0	26.5	9,800	96.1	24.0	10,200
-200	4.1	30.0	9,300	100.0	24.3	10,200

TABLE 21—Screen analysis, wedge fraction, Property A, 3 mesh x 0.

Tyler mesh fraction	Direct wt%	Direct ash%	Direct Btu/lb	Cumulative wt%	Cumulative ash%	Cumulative Btu/lb
-3, +4	7.8	56.8	5,100	7.8	56.8	5,100
-4, +6	7.6	52.7	5,700	15.4	54.8	5,400
-6, +8	9.9	48.7	6,300	25.3	52.4	5,800
-8, +10	11.6	44.1	7,100	36.9	49.8	6,200
-10, +16	14.4	41.8	7,400	51.3	47.5	6,500
-16, +20	3.7	44.6	7,000	55.0	47.3	6,600
-20, +28	6.4	46.5	6,700	61.4	47.3	6,600
-28, +35	5.9	51.2	5,900	67.3	47.6	6,500
-35, +48	5.5	58.5	4,800	72.8	48.4	6,400
-48, +65	7.8	71.3	2,800	80.6	50.6	6,000
-65, +100	7.0	80.4	1,300	87.6	53.0	5,700
-100, +150	4.6	79.0	1,600	92.2	54.3	5,500
-150, +200	2.9	73.3	2,500	95.1	54.9	5,400
200	4.9	69.0	3,100	100.0	55.6	5,300

TABLE 22—Screen analysis, run-of-mine, Property B, 3 mesh x 0.

Tyler mesh fraction	Direct wt%	Direct ash%	Direct Btu/lb	Cumulative wt%	Cumulative ash%	Cumulative Btu/lb
-3, +4	5.6	40.2	7,700	5.6	40.2	7,700
-4, +6	6.3	31.2	9,100	11.9	35.4	8,400
-6, +8	11.1	29.8	9,300	23.0	32.7	8,900
-8, +10	15.2	28.5	9,500	38.2	31.0	9,100
-10, +16	18.5	27.3	9,700	56.7	29.8	9,300
-16, +20	4.9	28.3	9,600	61.6	29.7	9,300
-20, +28	7.9	37.1	8,200	69.5	30.5	9,200
-28, +35	6.8	31.4	9,100	76.3	30.6	9,200
-35, +48	5.6	30.7	9,200	81.9	30.6	9,200
-48, +65	5.4	35.9	8,400	87.3	30.9	9,100
-65, +100	3.6	27.4	9,700	90.9	30.8	9,200
-100, +150	3.0	30.2	9,300	93.9	30.8	9,200
-150, +200	2.1	35.9	8,400	96.0	30.9	9,100
-200	4.1	42.2	7,400	100.0	31.4	9,100

TABLE 23—Results of flotation tests.

Material	Collector		Frother		Concentrate				Tails			
	Type	lb/ ton	Type	lb/ ton	wt,%	ash,%	Btu/ lb	% Btu recovery	wt,%	ash,%	Btu/ lb	% ash rejection
Stockpile, Property A	Diesel	18	DF250	1.5	82.4	16.7	11,400	98	17.6	81.3	1,200	51
Wedge, Property A	Diesel	15	Pine Oil	5	26.8	58.9	4,700	26	73.2	56.9	5,000	73
Bulk, Property C, -35 mesh	-	-	DF250	2.3	8.0	20.5	10,800	11	92.0	41.4	7,500	96
Bulk, Property C, -35 mesh	Diesel	15	DF250	2.3	81.6	28.2	9,600	99	18.4	87.6	200	41
Bulk, Property C, -35 mesh	Kerosene	18	DF250	1.5	80.0	27.7	9,600	100	20.0	87.8	200	44
Bulk, Property C, -35 mesh	Burner Fuel	15	DF250	1.5	80.0	27.7	9,600	99	20.0	85.6	500	44
Drill Core A, Property C	Diesel	15	DF250	1.5	54.0	25.9	9,900	100	46.0	90.4	0	75
Drill Core A, Property C	Kerosene	18	DF250	1.5	50.4	23.6	10,300	98	49.6	87.5	200	78
Drill Core B, Property C	Diesel	18	DF250	1.5	66.1	16.5	11,400	98	33.9	85.9	500	73

TABLE 24—Area correlation parameters.

Area	a*	b*	s**	n	Reference
San Juan Basin field					
Overall, N.M.	14000 ± 40	15740 ± 150	409	724	1, 3, 4
Company data, delivered coal	14880 ± 690	19260 ± 2780	161	64	1
Company data, core analysis	13880 ± 40	15260 ± 120	216	210	1
Company data, core analysis	14070 ± 250	15180 ± 1050	168	54	1
San Juan and McKinley Counties, New Mexico	14050 ± 110	14350 ± 1210	197	149	4
Rio Arriba County, New Mexico	14930 ± 270	15430 ± 2360	154	33	4
Bisti area	13470 ± 172	15140 ± 490	440	80	3
Chaco Canyon area	13600 ± 250	14430 ± 570	136	8	3
Cortez area	15020 ± 110	16740 ± 290	116	16	3
Newcomb area	13630 ± 150	15510 ± 450	185	24	3
Standing Rock area	13710 ± 130	15340 ± 390	257	45	3
Star Lake area	13880 ± 150	15900 ± 410	247	36	3
Black Mesa, Arizona	13880 ± 150	16440 ± 1000	259	49	1, 5, 6
La Plata County, Colorado	14610 ± 250	14930 ± 2630	343	52	7
Raton field					
Colfax County, New Mexico	14950 ± 120	14780 ± 890	151	139	2, 4
Las Animas County, Colorado	15070 ± 130	14660 ± 980	190	204	7
Huerfano County, Colorado	14020 ± 200	12390 ± 1740	236	126	7
Other areas					
Santa Fe County, New Mexico	15110 ± 220	16120 ± 2140	193	68	4
Socorro and Lincoln Counties	14740 ± 490	15210 ± 3090	327	16	4

* 95% confidence interval

** standard deviation of differences between actual and calculated Btu content (in Btu/lb)

References:
1. Company data
2. Pillmore and Hatch (1976)
3. Shomaker and others (1971)
4. USBM TP-569 (1936)
5. USBM TP-696 (1947)
6. Peirce and others (1970)
7. USBM TP-574 (1937)

TABLE 25—Comparisons within individual float-sink tests (moisture-free basis).

		Btu/lb			
Number*	Fraction	Measured	Calculated	Difference	Correlation coefficient
15	Float-1.3	14120	14065	55	0.9993
	1.3-1.4	13420	13330	90	
	1.4-1.5	12000	11960	40	
	1.5-1.6	10530	10474	56	
	1.6-1.8	8270	8253	17	
	Sink-1.8	1810	1757	53	
	Minus-100 mesh	9660	10023	-363	
	Head(48% Ash)	7070	7017	53	
18	Float-1.3	12830	12834	-4	0.9996
	1.3-1.4	11990	12030	-40	
	1.4-1.5	10070	10189	-119	
	1.5-1.6	8280	8256	24	
	1.6-1.8	6870	6755	115	
	Sink-1.8	3380	3460	-80	
	Minus-100 mesh	10320	10205	115	
	Head(15% Ash)	11477	11488	-11	
33	Float-1.30	13040	13029	11	0.9999
	1.30-1.35	12250	12267	-17	
	1.35-1.40	11200	11227	-27	
	1.40-1.50	9890	9953	-63	
	1.50-1.60	8340	8276	64	
	1.60-1.80	6080	6008	-72	
	Sink-1.80	1630	1691	-61	
	Minus-100 mesh	7410	7375	35	
	Head(34% Ash)	8604	8618	-14	

*Table number of float-sink test from Shomaker and others (1971)

TABLE 26—Comparisons of cumulative Btu recoveries for float-sink tests.

		Cumulative Btu recoveries (%)	
Number*	Fraction	From measured Btu/lb	From calculated Btu/lb
15	Minus-100	1.8	1.8
	Float-1.3	4.1	4.2
	1.3-1.4	28.7	29.0
	1.4-1.5	55.1	55.8
	1.5-1.6	75.1	76.0
	1.6-1.8	88.8	89.7
	1.8-Sink	100.	100.
18	Minus-100	2.0	2.0
	Float-1.3	49.6	49.5
	1.3-1.4	86.9	86.9
	1.4-1.5	92.2	92.3
	1.5-1.6	96.5	96.5
	1.6-1.8	99.1	99.0
	1.8-Sink	100.	100.
33	Minus-100	3.4	3.4
	Float-1.30	31.1	31.1
	1.30-1.35	54.6	54.7
	1.35-1.40	67.6	67.7
	1.40-1.50	81.8	82.1
	1.50-1.60	88.7	88.9
	1.60-1.80	95.9	96.0
	1.80-Sink	100.	100.

*Float-sink tests from Shomaker and others (1971)

Calculated Btu/lb from overall San Juan Basin correlations
Btu/lb = 14006-15643 (ash fraction)

TABLE 27—Comparison of calculated and measured production data (as-received basis).

Btu/lb			Btu/lb		
Measured	Calculated	Difference	Measured	Calculated	Difference
8793	8681	112	8774	8731	43
8847	8751	96	8929	8834	95
8739	8700	39	8767	8694	73
8943	8880	63	8913	8849	64
8921	8821	100	8742	8836	-94
8922	8850	72	9159	9020	139
8357	8341	16	8728	8741	-13
8627	8684	-57	9013	8892	121
8651	8661	-10	8858	8918	-60
8425	8585	-160	8752	8731	21
8355	8614	-259	8829	8866	-37
8789	8755	34	8885	8936	-51
8743	8817	-74	8943	8983	-40
8936	8918	18	8921	8830	91
9096	9049	47	9011	8880	131
9122	9061	61	8857	8803	54
9050	9075	-25	8718	8666	52
9002	9008	-6	8871	8799	72
9043	8994	49	8596	8596	0
8691	8628	63	8830	8789	41

TABLE 28—Comparison of Btu content from drill cores (moisture free).

Btu/lb		
Measured	Calculated	Difference
12867	12641	226
6484	6276	208
11743	11327	416
7533	8016	-483
12972	12800	172
10648	10557	91
11349	11152	197
12384	12392	-8
12449	12367	82
11474	11079	395
11255	11116	139
11924	11851	73
11309	11218	91
12674	12484	190
7003	8609	-1606
12276	12377	-101
8157	7577	580
9871	9699	172
10710	12737	-2027
6623	6083	540