BEHAVIOR OF CLAYS ASSOCIATED WITH LOW-RANK COALS IN COAL-CLEANING PROCESSES

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About 65 percent of the 400 plus million tons of coal produced in the United States annually is mechanically cleaned to remove the inorganic impurities before being sent to market. The removed impurities, principally shale and clay with some pyrite, average about 20 percent of the raw coal treated. Nearly 95 percent of the tonnage treated is dealt with by wet processes in which water, suspensions of solids in water, or occasionally calcium chloride solutions are employed. Difference in density between coal and impurity is the basis of these processes.

Of major importance in the separation is the competency of the impurities, that is, the resistance of the impurities to size disintegration in water. In general, the impurities are more resistant in geologically older coals or those in effect made older by metamorphism. If the impurities suffer reduction in particle size when immersed in water, the separation of organic from inorganic material becomes more difficult. Recently the Scientific Department of the National Coal Board (Great Britain) undertook a fundamental investigation of the interaction of shale and water and also developed an empirical method of assessing shale breakdown or disintegration (1).

Comparatively little is known about the behavior of the clay and shale associated with subbituminous coal and lignite because experience in upgrading them by the more efficient wet-beneficiation methods is limited. These lower-rank coals occur in the western states where energy requirements in the past have been relatively small, and supplies of alternate fuels have been abundant. Now however, these coals, which comprise the bulk of the Country's reserves of mineral fuel, are becoming of interest as sources of fuel for power generation and as potential sources of metallurgical carbon and carbonization byproducts. Thus, their behavior in preparation processes may soon become important.

The more common tendency of geologically younger shale associated with low-rank coal to disintegrate and form slimes or suspensions in the wet-cleaning operation has been examined in our coal-preparation laboratory during the treatment of a subbituminous coal and a lignite from Washington and a subbituminous coal from Oregon. Not only was it found that particle-size disintegration through softening and dispersion of colloidal matter was of importance, but also that the lattice structure of the particular clay minerals which rendered it susceptible to swelling and consequent reduction in apparent density was of great significance.

Thermal Analysis

Differential thermal analyses (DTA) of the principal interbedded impurities in the three coals are shown in figure 1. These data characterize all of the clays as bentonitic, with sodium and calcium montmorillonite minerals predominating. One characteristic property of montmorillonites is their extremely small particle size and hence the ability to form fairly stable suspensions in water.

Interpretation of the DTA curves in the figure is considered to characterize sample 1, from the Big Dirty Bed, Lewis County, Wash., as principally sodium montmorillonite; sample 2 from the Southport bed, Coos County, Oreg., contains mainly calcium montmorillonite with some illite; and sample 3, the lignite from near

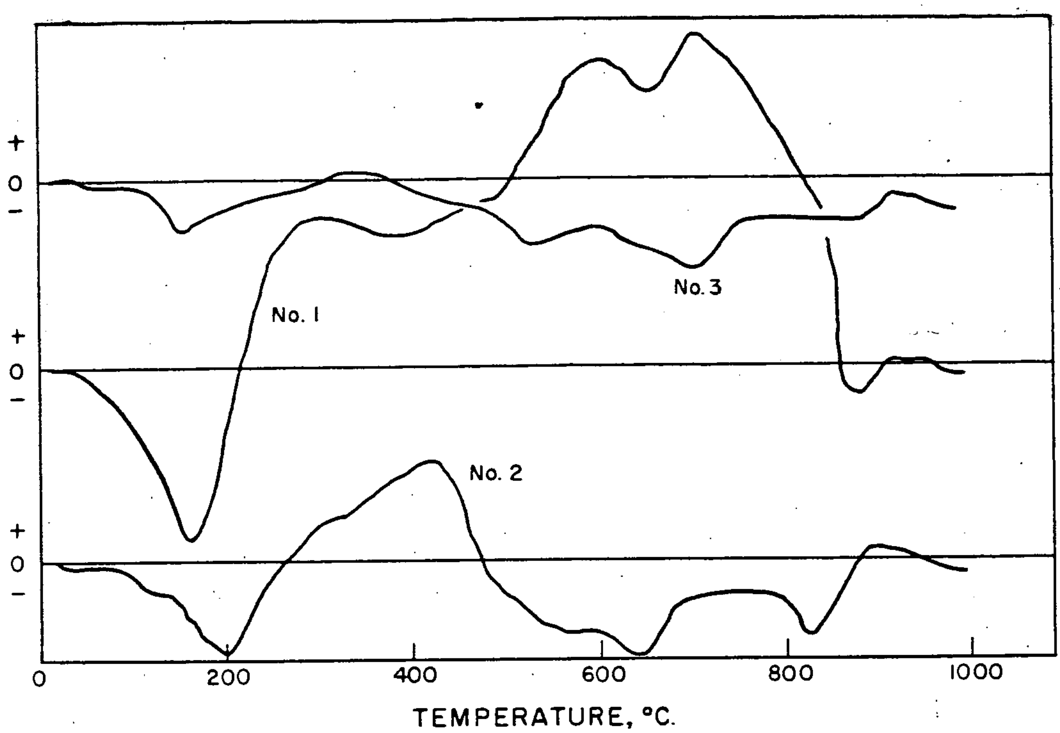

Figure 1. Differential-thermal-analysis curves.

Figure 2. (Left to right). Swollen clay in 1.50 to 1.60, 1.60 to 1.70, and 1.70 to 1.80 density fractions of subbituminous coal from Lewis County, Wash., size 3/4 to 1 1/2 inches.

Swelling is due to water penetration between the lattice layers. The following tabulation shows the extent of relative swelling of the principal impurities of the three coals, as determined by a commonly used swelling test (2).

Sample No. and source	Volume increase, percent 6 hours	24 hours
1. - Big Dirty bed, Wash.	100	114
2. - Southport bed, Oreg.	75	75
3. - Toledo lignite, Wash.	25	25

The clay from the Big Dirty bed was hand picked from a 1.5 to 1.6 specific gravity fraction. Its swelling illustrated the magnitude of the density change that might be encountered in cleaning young coals, and also explains why clay was present in the 1.5 to 1.6 fraction.

Washington Subbituminous Coal

The first coal examined was from the Big Dirty bed in Lewis County, Wash., a deposit with sufficient reserves of relatively low-cost coal to be of interest for onsite power generation, despite its low grade. It is subbituminous B in rank, and in the raw condition has the following analysis:

	As received	Moisture-free
Moisture, percent	20.0	----
Volatile matter, percent	28.6	35.8
Fixed carbon, percent	27.9	34.8
Ash, percent	23.5	29.4
Sulfur, percent	0.6	0.8
B.t.u., per pound	7240	9050
Ash-softening temperature, °F.	----	2250

The fresh coal is strong, resists degradation, and has a Hardgrove grindability index of 35 to 40, depending on its degree of freedom from impurity. If allowed to dry, however, the coal rapidly develops shrinkage cracks and becomes quite friable.

Washability Examination. A 28-ton sample of coal was obtained for examination, about 3 tons for specific-gravity analyses, and the rest for cleaning trials. Special precautions were observed in preparing the samples for float-and-sink tests to insure against drying, which would have altered the particle size of both the coal and the clay. All sizes of coal coarser than 20 mesh were tested in aqueous solutions of zinc chloride, using each 0.1 interval in specific gravity from 1.30 to 1.80. Material finer than 20 mesh was air-dried and was tested in organic liquids of the same densities.

Of special interest in these analyses, shown in table I, was the abnormally high ash contents of the specific-gravity fractions between 1.40 and 1.80, particularly in the coarser sizes, occasioned by the swelling nature of the clay. For example, in the 4- to 2-inch size, the 1.70 to 1.80 fraction analyzed 75.4 percent ash, whereas about 50 percent ash would be normal; similarly, in the next lighter fraction, the ash content was 65.9 percent, instead of the usual 40 to 45 percent. These high ash contents confirmed the visually observed anomaly that free pieces of clay, derived from partings within the coal bed, were present in all specific-gravity fractions heavier than 1.40. Figure 2 is a photograph of several of the density fractions of the 3/4- to 1 1/2-inch size, showing the presence of clay.

TABLE I. - Specific-gravity analyses of raw coal from Big Dirty bed

Size, inches	Specific gravity	Weight-percent	Ash[1/] percent	Cumulative[1/] Weight-percent	Cumulative[1/] Ash, percent
4 to 2	Under 1.30	10.4	6.7	10.4	6.7
Weight, 22.2 percent	1.30 to 1.40	59.5	13.5	69.9	12.5
	1.40 to 1.50	12.1	32.5	82.0	15.4
	1.50 to 1.60	6.0	54.7	88.0	18.1
	1.60 to 1.70	3.8	65.9	91.8	20.1
	1.70 to 1.80	1.8	75.4	93.6	21.2
	Over 1.80	6.4	80.9	100.0	25.0
2 to 1/4	Under 1.30	8.3	6.4	8.3	6.4
Weight, 58.2 percent	1.30 to 1.40	56.1	11.8	64.4	11.1
	1.40 to 1.50	13.3	28.7	77.7	14.1
	1.50 to 1.60	5.4	43.9	83.1	16.1
	1.60 to 1.70	2.6	57.8	85.7	17.3
	1.70 to 1.80	2.0	70.6	87.7	18.5
	Over 1.80	12.3	84.3	100.0	26.6
1/4 to 0	Under 1.30	1.7	6.3	1.7	6.3
Weight, 19.6 percent	1.30 to 1.40	45.2	8.4	46.9	8.3
	1.40 to 1.50	12.6	19.6	59.5	10.7
	1.50 to 1.60	6.9	29.5	66.4	12.7
	1.60 to 1.70	3.9	39.3	70.3	14.1
	1.70 to 1.80	2.4	47.7	72.7	15.2
	Over 1.80	27.3	81.9	100.0	33.4

1/ Moisture-free basis

from the 4- to 2-inch size fraction and were tested individually in solutions of zinc chloride, with the results shown in the following tabulation.

Specific gravity	Weight-percent	Moisture-free ash, percent
1.40 to 1.50	18.8	52.9
1.50 to 1.60	22.9	72.6
1.60 to 1.70	16.3	85.8
1.70 to 1.80	10.9	88.3
Over 1.80	31.1	89.1

The ash content of 52.9 percent for the lightest particles showed that imbedded coal was present, but the high ash contents of the other density fractions indicated that they were essentially pure clay.

Cleaning Trials With Jig. The jig employed in the cleaning trials was a scale model of a full-size Baum-type jig in every respect except that it had separate elevators for the draw and hutch refuse. The draw product was removed from the upper surface of the screen, and the hutch passed through perforations in the screen. The jig was a 3-cell, single-compartment unit having a nominal capacity of 5 to 6 tons per hour.

The jig was adjusted to remove only the impurity of over 1.65 specific gravity. Operation was entirely on fresh water, all of which was metered. Except for the negligible proportion entrained in the refuse products, all this water left the system as the overflow of a 6- by 20-foot drag-settling tank in which the washed coal was dewatered; this overflow was sampled continuously to determine the amount and nature of the suspended solids.

The amount of coarse clay observed entering the jig in the feed compared with that leaving in the draw refuse made it evident that much of the clay was being disintegrated in the bed and either was reporting to the hutch or leaving as finely divided solids suspended in the water. Occasional particles of clay, ranging up to 1/2-inch size, were observed in the washed coal.

The following tabulation shows the material balance for the trial and the quality of the products:

Product	Weight-percent	Moisture-free ash, percent
Washed coal	76.4	16.9
Draw refuse	7.5	72.4
Hutch refuse	5.0	68.4
Slimes	11.1	73.7
Total	100.0	29.9

The slimes, that is, the solids suspended in the water, amounted to 11.1 percent of the jig feed, nearly equaling the combined amount of the draw and hutch refuse. The high ash content of these solids indicated they were predominantly clay.

The effectiveness of the jig in removing impurity is shown in the following tabulation:

Size, inches and mesh	Sink 1.70 in washed coal, percent
2 to 1/4	0.5
1/4 to 20	2.4
20 to 0	31.1

Although the removal of impurity from the size coarser than 1/4 inch was excellent, and elimination in the 1/4-inch to 20-mesh fraction was fair, the washed coal finer than 20 mesh was badly contaminated with clay. Many clay particles that did not disintegrate fine enough to become suspended in the water, and were not coarse enough to be drawn down into the refuse bed, adhered to coal particles or were mechanically entrapped in the coal.

The recovery efficiency of the cleaning trial was 96 percent; that is, the yield of washed coal amounted to 96 percent of the theoretical yield of coal of that ash content shown to be present in the feed by specific-gravity analysis. This efficiency is rather low for a separation at 1.65 specific gravity, and is attributable largely to the poor elimination of clay in the finest sizes.

Cleaning trial With Dense-Medium Pilot Plant. The dense-medium pilot plant, in which a suspension of magnetite in water is used, comprises a 24- by 30-inch drum-type separating vessel, a 12-inch densifier, a 12-inch magnetic separator, and a 26-inch by 9-foot vibrating screen, together with necessary pumps and conveyors for handling materials, all arranged in a conventional flowsheet. The separating vessel is a scale model of a widely-used commercial unit. With a 4-ton-per-hour feed rate and the medium flow employed in the tests, the concentration of coal in the separating bath and the retention time were roughly comparable to those in full-scale equipment.

The feed for this cleaning trial was 2- to 1/4-inch in size. Difficulty was experienced in screening at 1/4 inch, even though strong water sprays were used on the vibrating screen. The sticky nature of the clay precluded effective removal of undersize. The material balance for the trial follows:

Product	Weight-percent	Moisture-free ash, percent
Washed coal	82.9	18.1
Refuse	9.0	79.0
Magnetic-separator tails	8.1	71.8
Composite feed	100.0	27.9

The amount of magnetic-separator tailing was considerably higher than generally encountered because of the poor feed preparation mentioned earlier and the unstable nature of the clay.

At the start of the trial the medium, which had a specific gravity of 1.69, contained 7 percent of nonmagnetic material and had a viscosity of 5.3 centipoises. At the end it contained 25 percent of nonmagnetic material and its viscosity was 7.7 centipoises. In a commercial plant unusually high medium-cleaning capacity would have to be provided to maintain medium of suitable quality.

Numerous pieces of clay were observed in the washed coal. Although most of them were finer than 1/2 inch, and many were smaller than the 1/4-inch bottom size of the feed, some plastic pieces coarser than 1 inch were present. The clay was present in larger amounts and coarser size than in the washed product from the jig. The layer of float material in the dense-medium bath is relatively quiescent and therefore soft pieces of clay that would be disintegrated by the shearing and scrubbing action in a jig bed passed over the dense-medium bath in their original form. A specific-gravity analysis of the clay contaminating the washed coal (removed by hand picking) is shown in the following tabulation.

Specific gravity	Weight-percent
1.30 to 1.40	3.4
1.40 to 1.50	6.7
1.50 to 1.60	13.3
1.60 to 1.70	35.0
1.70 to 1.80	25.9
Over 1.80	15.7

The recovery efficiency for this test was 99.0 percent, indicating that there was little loss of coal in the refuse product. In comparing this efficiency with that of the jig, however, it must be borne in mind that the jig was treating material down to 0 size, whereas the dense-medium equipment only treated material coarser than 1/4 inch.

Washington Lignite

Another deposit investigated because of its potential for onsite power generation, is a lignite occurring near Toledo, in Lewis County (2). The analysis of the raw coal follows:

	As received	Moisture-free
Moisture, percent	34.1	----
Volatile matter, percent	22.6	34.3
Fixed carbon, percent	19.3	29.3
Ash, percent	24.0	36.4
Sulfur, percent	.5	.7
B.t.u., per pound	5,070	7,700

When fresh the lignite is tough and resists degradation, but on drying it disintegrates practically to a powder. The bed contains numerous partings of clay; most are friable compared to the coal. Thus, as shown by the specific-gravity analyses in table II, the impurity tends to concentrate in the finer sizes. Material finer than 20 mesh contained 60 percent of sink 1.70, compared with 17 percent in the plus-20-mesh size.

TABLE II. - Specific-gravity analyses of raw Toledo lignite

				Cumulative	
Sizes, inches and mesh	Specific gravity	Weight-percent	Ash[1/] percent	Weight-percent	Ash[1/] percent
1-1/2 to 20	Under 1.40	49.3	17.3	49.3	17.3
Weight, 95.6 percent	1.40 to 1.50	17.0	32.2	66.3	21.1
	1.50 to 1.70	16.4	43.8	82.7	25.6
	Over 1.70	17.3	75.9	100.0	34.3
Under 20	Under 1.40	2.4	9.4	2.4	9.4
Weight, 4.4 percent	1.40 to 1.50	13.6	18.8	16.0	17.4
	1.50 to 1.70	23.6	32.4	39.6	26.3
	Over 1.70	60.4	76.4	100.0	56.6
Composite, 1-1/2 to 0	Under 1.40	45.9	17.3	45.9	17.3
Weight, 100.0 percent	1.40 to 1.50	16.4	31.7	62.3	21.1
	1.50 to 1.70	16.3	43.1	78.6	25.7
	Over 1.70	21.4	76.0	100.0	36.4

1/ Moisture-free basis

A cleaning trial on this material in the Baum-type jig provided the results summarized in the following tabulation.

Product	Weight-percent	Ash, percent
Washed coal	75.1	25.1
Refuse	14.2	70.5
Slimes	10.7	70.5
Total	100.0	36.4

This clay did not swell enough to cause a troublesome decrease in density, but it disintegrated readily in the jig bed and became suspended in the water. Thus, 10.7 percent of the jig feed, nearly equaling the combined amount of draw and hutch refuse, left the system with the overflow of the washed-coal drag-settling tank.

Oregon Subbituminous Coal

The third coal investigated was from the Southport bed, Coos Bay field, Oregon. It is subbituminous B in rank and does not weather or slack as readily as the two discussed previously. An analysis of the raw coal is shown in the following tabulation.

	As received	Moisture-free
Moisture, percent	16.2	----
Volatile matter, percent	29.2	34.8
Fixed carbon, percent	36.4	43.5
Ash, percent	18.2	21.7
Sulfur, percent	.8	.9
B.t.u., per pound	8,673	10,350

The coalbed contains a 7- to 8-inch parting of clay which swells readily, is rather friable, and therefore contaminates predominately the finer sizes of coal. As shown by the specific-gravity analyses in table III, the fraction finer than 20

TABLE III. - Specific-gravity analyses of raw Coos Bay coal

Size, inches and mesh	Specific gravity	Weight-percent	Ash,1/ percent	Cumulative Weight-percent	Cumulative Ash1/ percent
2 to 20	Under 1.40	73.2	9.1	73.2	9.1
Weight, 92.1 percent	1.40 to 1.50	10.4	20.6	83.6	10.5
	1.50 to 1.70	3.5	37.1	87.1	11.6
	Over 1.70	12.9	81.2	100.0	20.6
Under 20	Under 1.40	49.0	8.0	49.0	8.0
Weight, 7.9 percent	1.40 to 1.50	11.0	18.4	60.0	9.9
	1.50 to 1.70	7.1	32.9	67.1	12.3
	Over 1.70	32.9	80.3	100.0	34.6
Composite, 2 to 0	Under 1.40	71.3	9.0	71.3	9.0
Weight, 100.0 percent	1.40 to 1.50	10.4	20.4	81.7	10.5
	1.50 to 1.70	3.8	36.5	85.5	11.6
	Over 1.70	14.5	81.0	100.0	21.7

1/ Moisture-free basis

mesh contained 32.9 percent of heavy impurity, whereas the coarser size contained only 12.9 percent.

The behavior of this clay in the laboratory Baum-type jig differed from that of the other two described previously. When exposed to water, much of it disintegrated, but not to the fine particles that become suspended in the water. The disintegrated particles were of the size that reported predominately to the hutch product. As shown in the following tabulation, 5.8 percent of the feed, representing a substantial portion of the total clay, was removed as hutch refuse.

Product	Weight-percent	Moisture-free ash, percent
Washed coal	83.2	11.9
Draw refuse	7.6	68.7
Hutch refuse	5.8	56.9
Slimes	3.4	93.3

Another 3.4 percent of the feed was virtually pure clay suspended in the overflow of the washed-coal drag-settling tank.

This clay differed from the others in another respect also. More of it formed plastic masses into which particles of clean coal become imbedded. These aggregates of clay and coal were light enough to cause them to report to the clean-coal product, thus interferring with elimination of the clay.

Conclusions

Experience in cleaning only three low-rank coals affords little basis for generalization, because coals are inherently variable, each one presenting its own peculiar preparation problems. However, the similarity in the characteristics of the clays associated with these three coals suggests that these properties may be common to many of the clays associated with low-rank coals.

The pronounced tendency of these clays to disintegrate in water, to form plastic masses, and to swell with resulting decrease in density, have definite implications in terms of the design and operation of preparation plants. First, water clarification will be difficult and costly, involving extra filter capacity or settling ponds. Flocculation may be a preprequisite for acceptable filter capacity or adequate settling. Second, owing to a combination of particle size, stickiness, and swelling, this type of clay cannot be eliminated in washing as completely as the usual shales. Third, the jig offers certain advantages in dealing with clays that swell. The shearing, scrubbing action of the jig bed disintegrates and suspends in the wash water pieces of clay which otherwise would report to the clean product, leaving final elimination of the clay to a subsequent liquid-solid separation. In a sense, the jig acts as a combination log washer, classifier, and gravity-concentrating device.

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