6-1934

Preliminary Floatation Tests on the Beneficiation of a Low-Grade Montana Bituminous Coal.

William Packwood Given

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Preliminary Flotation Tests on the Beneficiation of a Low-Grade Montana Bituminous Coal

by

William Packwood Given

of

Portland, Oregon

Montana School of Mines
Butte, Montana
June, 1934
PRELIMINARY FLOTATION TESTS ON THE BENEFICIATION OF A LOW-GRADE MONTANA BITUMINOUS COAL

by

William Packwood Given

of

Portland, Oregon

A thesis submitted to the Department of Ore Dressing of the Montana School of Mines in partial fulfillment of the requirements for the degree of Bachelor of Science in Metallurgical Engineering.

Butte, Montana
June, 1934
PREFACE

A seeming paradox revealed by a few minutes perusal of this report is the apparently unwarranted proportion devoted to the introduction. Owing, however, to the fact that few at this institution are familiar with coal it is the writer's belief that this amount of introduction is necessary to give the reader an essential acquaintance with the subject. While not complete, it nevertheless represents the essence of many articles on coal which would require a great deal of time on the part of the reader if he were to search out each article and read it himself. In addition, it was necessary for the writer in acquainting himself with an entirely new subject to spend a large portion of the time allotted to research in becoming familiar with the coal literature. Further valuable time was lost correcting mistakes which greater experience would have prevented. For these two reasons, the introductory matter is legitimate in a Senior thesis as it provides a more exact measure of the amount of work performed by the student.
ACKNOWLEDGEMENTS

With due gratitude the writer wishes to acknowledge the ever-ready assistance and advice of Professor A. M. Gaudin, under whose direction this research was conducted. As he was well-versed in the treatment of coal at the time this work was started the student was saved many missteps which, it would later be found, were pointless.

The writer is also indebted to Mr. Plato Malozemoff for his excellent work in editing this report.
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PRELIMINARY FLotation TESTS ON THE BENEFICIATION
OF A LOW-GRADE MONTANA BITUMINOUS COAL

By William P. Given

INTRODUCTION

ORIGIN OF COAL

Coal is an aggregation of vegetal matter with varying small amounts of mineral and animal matter which have been so changed by the processes of sedimentation, decay and metamorphism that it has become a dense, dark, combustible substance. It occurs in beds varying in thickness from one foot or less to over 300 feet. The horizontal extent of a bed is sometimes continuous over an area as large as the State of Montana.

The theories concerning the formation of coal, which are at present most acceptable, are well outlined by White (15). The material under this section has been largely drawn from his articles.

Coal originated as a rich vegetal swamp growth. The swamps in which these plants grew are of low relief and generally occur in broad
estuaries or along a sea-coast.

The debris from the plant growth, spores, twigs, leaves and trunks fall to the water surface. The various parts of the plants then undergo a selective process of bio-chemical decay.

First to be attacked are the softer and more delicate tissues; protoplasm, parenchyma, mesophyll and the like. These quickly disappear unless the water is highly toxic to the microbes which cause the decay. In decreasing order of susceptibility to decay are: the woody tissues, the spore exines or seed cases, the cuticular formations which underlie the bark, and the secreted waxes and resins.

The amount of decay is largely controlled by the level and toxicity of the water. The water level is in turn controlled by isostatic movement, by seasonal and annual variations and by encroachments of neighboring seas or rivers. The toxicity of the water is least when fresh, the greatest when it is high in the decomposition products of plant life.

A great deal of decay will occur provided there exist a low level of still fresh water and
an access to air. Advanced decay is found in some peat bogs where practically all the debris has been converted to a jelly-like mass. On the other hand with deep stagnant water we find practically all the debris well preserved as soon as it has become water-logged enough to sink from contact with the air.

The conditions of deposition are subject to wide variations. One could easily find in the same seam of coal a layer of well-preserved cell forms; above it a microscopically-homogeneous layer, indicating almost complete decay; above that a thin band of spores, accumulated, perhaps, in spring; above that a band of small bits of woody debris, fallen in the cold season. Many swamps act as settling basins for streams. Hence, thin intercalations of silt, later metamorphosed to slate, are a frequent occurrence in coal seams.

The plants present in coal seams indicate that a tropical or warm-temperature climate was prevalent during the period of coal deposition. The coal-forming swamps have often grown many thousands of years; for example, such a coal bed, almost 400 feet thick, is known in Germany.
During this period a multitude of variations might take place. Sea encroachments would kill plant life and deposit shells. Cold weather would lessen decay and the rate of plant growth. Humidity increases would increase decay, etc.

When a coal-forming swamp starts to dry, the remaining water, by evaporation, may become exceedingly concentrated in the toxic products of ulmo-humic decay, thereby stopping all further decay. It is under such conditions that White and E. Thiessen claim mineral charcoal or fusain bands are formed. (See section on the constituents of coal in this paper).

When the plant growth has finally ceased because of a change to a lower climate, aridation, or submergence, it in due time becomes covered with layers of other sediments. The coal is then subjected to metamorphising; variations in the metamorphic action produce variation in each individual coal.

THE GEOLOGIC AND GEOGRAPHIC EXTENT OF COAL

Coal beds are known to occur in every forma-
tion from the Upper Devonian to the Pleistocene, although the latter contains only low grade coal and the former contains a very limited quantity (11,20). In the later Pleistocene and the Recent rocks large beds of peat not yet changed to coal are found in many countries. The Carboniferous is the most important for high-grade coal while the Tertiary contains most of the lignite.

The Mississippian and Pennsylvanian are the most valuable coal-bearing formations in the United States. Enormous potential reserves lie in the Tertiary lignites. Table I gives the approximate known coal reserves of the world compared with those of the United States and Montana.

The extensive lignite deposits of eastern Montana and the Dakotas are in the Fort Union formation of the early Tertiary. The other areas in Montana are the Bull Mountain Field, the Assiniboine region, the Judith Basin region, the Flathead River field, the Mountain fields, the Yellowstone region (Bozeman coal) and the Red Lodge-Bridger field.

The Bull Mountain field has coal varying from lignite in the Tertiary rocks to sub-bituminous
### TABLE I

**COAL RESOURCES OF THE WORLD (11,20)**

(in millions of metric tons, 1 metric ton = 1.1023 short tons)

<table>
<thead>
<tr>
<th></th>
<th>Anthracite</th>
<th>Bituminous</th>
<th>Sub-bituminous and lignite</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total for world</td>
<td>496,846</td>
<td>3,902,944</td>
<td>2,997,763</td>
<td>7,397,553</td>
</tr>
<tr>
<td>Asia</td>
<td>407,637</td>
<td>260,098</td>
<td>111,951</td>
<td>1,279,586</td>
</tr>
<tr>
<td>Africa</td>
<td>11,662</td>
<td>45,123</td>
<td>1,054</td>
<td>57,839</td>
</tr>
<tr>
<td>Europe</td>
<td>54,346</td>
<td>693,162</td>
<td>36,270</td>
<td>5,103,528</td>
</tr>
<tr>
<td>Oceania</td>
<td>659</td>
<td>133,491</td>
<td></td>
<td>170,410</td>
</tr>
<tr>
<td>South America</td>
<td>21,842</td>
<td>600</td>
<td>20,200</td>
<td>30,900</td>
</tr>
<tr>
<td>North America</td>
<td>19,824</td>
<td>2,241,030</td>
<td>2,811,903</td>
<td>5,074,928</td>
</tr>
<tr>
<td>United States</td>
<td>19,824</td>
<td>1,955,521</td>
<td>1,963,452</td>
<td>3,833,657</td>
</tr>
<tr>
<td>Montana</td>
<td></td>
<td></td>
<td>2,653$</td>
<td>357,921</td>
</tr>
</tbody>
</table>

*including 5,266 million metric tons of sub-bituminous coal.
and low-bituminous in the older formations. There are 20 seams over two feet thick and the "Mammoth" seam runs from 8 to 15 feet in thickness.

A field which has been largely worked is the Red Lodge-Bridger field where coal has been mined for a good many years. There are seven seams running from 3 to 12 feet in thickness. The coal is high-grade sub-bituminous, fairly high in moisture, and it soon breaks down or "slacks" when exposed to air.

The highest rank coal in this state is that in the Great Falls and Lewistown fields in Cascade and Fergus Counties. This coal is low-grade, bituminous, and for a number of years was mined and coked at Belt to supply the Anaconda smelter. This is the only coking coal in the state. Its high ash content does not warrant its extensive use. This formation is of upper Cretaceous age.

The other fields in Montana are either small or undeveloped and supply only local demands. Table II gives some analyses of typical Montana coals. The high moisture content of the lignite is worth noting. This cuts the fuel value of the coal considerably and necessitates drying before use.
<table>
<thead>
<tr>
<th>Location and rank of coal</th>
<th>Moisture percent</th>
<th>Volatile matter percent</th>
<th>Fixed Carbon percent</th>
<th>Ash percent</th>
<th>Sulfur percent</th>
<th>Heat value bitu/lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Culbertson district, lignite</td>
<td>40.8</td>
<td>25.2</td>
<td>27.8</td>
<td>6.2</td>
<td>0.7</td>
<td>6.150*</td>
</tr>
<tr>
<td>Glendive district, lignite</td>
<td>34.6</td>
<td>35.3</td>
<td>22.9</td>
<td>7.2</td>
<td>1.1</td>
<td>7.090</td>
</tr>
<tr>
<td>Miles City, district, subbituminous</td>
<td>29.2</td>
<td>26.2</td>
<td>35.4</td>
<td>9.2</td>
<td>0.8</td>
<td>7.670</td>
</tr>
<tr>
<td>Havre district, subbituminous</td>
<td>25.6</td>
<td>23.9</td>
<td>39.2</td>
<td>7.3</td>
<td>0.6</td>
<td>8.290</td>
</tr>
<tr>
<td>Cut Bank district, bituminous</td>
<td>6.6</td>
<td>40.3</td>
<td>39.2</td>
<td>13.9</td>
<td>3.1</td>
<td>10.950</td>
</tr>
<tr>
<td>Lewiston district, bituminous</td>
<td>8.0</td>
<td>26.6</td>
<td>56.1</td>
<td>9.3</td>
<td>4.4</td>
<td>11.510</td>
</tr>
<tr>
<td>Sand Coulee district, bituminous</td>
<td>6.0</td>
<td>28.4</td>
<td>51.5</td>
<td>14.2</td>
<td>2.4</td>
<td>11.150</td>
</tr>
<tr>
<td>Roundup, district, subbituminous</td>
<td>13.4</td>
<td>32.4</td>
<td>47.8</td>
<td>6.6</td>
<td>0.4</td>
<td>11.120</td>
</tr>
<tr>
<td>Bear Creek district, subbituminous</td>
<td>10.7</td>
<td>34.1</td>
<td>46.1</td>
<td>9.1</td>
<td>1.5</td>
<td>10.800</td>
</tr>
<tr>
<td>Red Lodge district, subbituminous</td>
<td>11.7</td>
<td>36.1</td>
<td>40.2</td>
<td>12.0</td>
<td>1.1</td>
<td>9.790</td>
</tr>
<tr>
<td>Trail Creek field, bituminous</td>
<td>12.4</td>
<td>36.8</td>
<td>42.3</td>
<td>8.5</td>
<td>0.6</td>
<td>10.950</td>
</tr>
<tr>
<td>Missoula field, lignite</td>
<td>24.7</td>
<td>29.3</td>
<td>36.1</td>
<td>19.9</td>
<td>0.9</td>
<td>6.750</td>
</tr>
<tr>
<td>Bridger district, bituminous</td>
<td>9.8</td>
<td>21.6</td>
<td>46.2</td>
<td>16.4</td>
<td>0.6</td>
<td>10.240</td>
</tr>
<tr>
<td>Electric field, bituminous, coking</td>
<td>4.0</td>
<td>22.5</td>
<td>59.3</td>
<td>14.2</td>
<td>0.6</td>
<td>12.760</td>
</tr>
</tbody>
</table>

*Heat value with products of combustion at room temperature.*
CLASSIFICATION OF COAL BY RANK

The word rank is used to designate the differences in coal that are due to the progressive change from lignite to anthracite, a change marked by loss of moisture, of oxygen and of volatile matter. This change is generally accompanied by an increase of fixed carbon, of sulphur, and of ash. When, however, one coal is distinguished from another by the amount of ash or sulphur it contains, this difference is said to be one of grade. Thus "a high-grade coal" means one that is relatively pure, whereas "a high-rank coal" means one that is high in the scale of coals, or, in other words, one that has suffered devolatilization and that now contains a smaller percentage of volatile matter, oxygen, and moisture than it contained before the change occurred.

The designation "coal" includes everything from the coarse, woody lignite of eastern Montana to the highest rank anthracite in the fields of eastern Pennsylvania. While the rank of coal is largely a function of time yet conditions of pressure and temperature are also factors. For
Figure 1. Diagrams showing the chemical composition and heat efficiency of the several ranks of coal. Upper diagram, comparative heat value of the samples of coal represented in the lower diagram, computed on the ash-free basis. Lower diagram. Variation in the fixed carbon, volatile matter, and moisture of coals of different ranks, from lignite to anthracite, on the ash-free basis.
example, semi-anthracites are found in the Tertiary in Washington where the intrusion of molten magma has altered a sub-bituminous coal. Natural coke is formed under the same conditions.

As a coal increases in rank it generally becomes more compact and dense, losing more and more of the structure of the original plants. Figure I is a graph of the proximate analysis and heat efficiency of the various types of coals. Both are computed on an ash-free basis, as ash is not a determining factor in rank.

In defining rank of coal the "fuel-ratio" is convenient. The fuel-ratio of a given coal is the ratio of the weight of fixed carbon to the weight of volatile material in the coal.

In the proximate analysis of coal, the percent moisture is obtained by heating the coal at 105°C until a constant weight is obtained. The percent volatile matter, or volatile combustible matter, (V. C. M.) is determined by heating the coal in the heat of a Fisher burner until gas evolution ceases. The percent ash is obtained by heating in a muffle at a cherry-red heat. The difference between these three and one hundred per
cent is termed the per cent fixed carbon. As may be seen this analysis is purely empirical. Sulphur, iron, and other elements are determined by regular quantitative procedure.

Anthracite is generally well-known. It has a fuel ratio of not more than 50 or 60 and not less than 10. Most of it is mined in eastern Pennsylvania, where its peculiar quality is due to regional metamorphism. Largely on account of its lower heating value and fancy price anthracite is not a desirable fuel for other than domestic uses for which its cleanliness, low ash, and smokeless fire make it wanted.

Semianthracite is a hard coal, but not so hard as anthracite. It is high in fixed carbon, but not so high as anthracite. It is relatively scarce, and hence relatively unimportant.

Semibituminous coal is really a super-bituminous or sub-semianthracite coal in rank. It has a fixed carbon ratio of around 3 to 6. It is nearly smokeless when burned properly, and hence is often sold as "smokeless" coal. It is the best coal in respect to the amount of heat per unit volume, and hence is in demand for battleship fir-
ing and like uses.

Bituminous coal is coal having a maximum fuel ratio of around 3. Hence, it is a coal in which the fixed carbon and the volatile matter are about equal. It is, at present, the largest-selling coal on the market. The low-ash, coking varieties are in demand for the manufacture of coke, while those low in sulphur are specified for general industrial heating. Its plentifulness makes it a cheap fuel; it is therefore mined on an extremenarrow margin of profit.

Sub-bituminous coal is the term adopted by the U. S. Geological Survey to designate "black lignite", a term which is objectionable as the coal is not extremely woody, and because the use of "black lignite" would imply that the coal referred to is not better than the brown lignite of eastern Montana. Sub-bituminous coal slackens on exposure to air and is susceptible to spontaneous combustion. The fixed carbon ratio is low, generally being about one or less.

Lignite refers to those coals which are distinctly brown and either markedly woody or claylike in their appearance. It is intermediate in
quality between peat and sub-bituminous coal. It has a high moisture content, making the heating value per unit weight quite low and, correspondingly shipping charges high. For this reason it is generally mined for use within a short distance of the mine. It readily slacks on exposure to air and is highly susceptible to spontaneous combustion. Due to the large reserves of this fuel in the United States, a large amount of research is being done on improving its usability. (7).

There are no sharp boundaries between coals of various ranks. Several more rigid classifications have been suggested, but they suffer from undue complication (8). The above classification is adequate for general use.

CONSTITUENTS OF COAL

Upon close inspection with the naked eye a piece of coal is found to be composed of bands or laminae of varying width and character. The bright shiny bands which break with a conchoidal fracture in a direction roughly perpendicular to the bedding plane are referred to by Thiessen as
anthraxylon (16,17,18). Examination under the microscope reveals that these shiny bands were once unbroken, woody portions of trees. Anthraxylon shows annular rings, successions of pith, and stellar tissues, all features of wood structure. The amount of decay determines the degree to which the original structure is visible in the coal. When anthraxylon has been well decayed practically all of the original wood structure has been lost, and this constituent appears almost homogeneous under the microscope, even at 1000 diameters.

Acting as a matrix for the brighter pieces are the dull bands. In these bands is found a miscellaneous accumulation of plant debris, such as is found in peat bogs. Small splinters of wood, cellular structures, spores and pollen grains, cuticles and bark make up this debris, which is termed attritus.

Fusain is used to designate plant matter which is but slightly decayed. It appears porous and brown under the microscope. In it, cellular structures are often evident. (3)

The above classification is known as Thiessen's classification. It has been developed
through studies of Pennsylvania bituminous coal, hence its application to coals of other rank is rather difficult. (19)

While the classification here given is complete as far as words go, it is impossible to apply it without a great deal of study on the coals themselves. Other classification systems (14,15) have been advocated, notably vitrain, durian, clarain, and fusain, but it is the belief of the writer that they are not as useful as Thiessen's.

The ash in coal comes from three sources; the ash in the original wood, or inherent ash, the ash deposited with the coal, and the ash formed in the coal by the penetration of seepage water and subsequent precipitation.

The ash deposited with the coal, when of sufficient quantity, is often visible to the naked eye as slate. The ash brought by seepage and precipitation is often seen as thin laminae or pin-points of pyrite or gypsum precipitated by the sulphur in the coal.

The attrital matter is generally richer in sulphur than the anthraxylon, as sulphur is a
common constituent of spores and spore exines. In a coal containing pyrite or gypsum, the ash will be high in sulphur.

PREPARATION OF COAL FOR MARKET

Over 96 per cent of the coal produced in this country is sold as mine-run coal. In preparing this product the operation performed is screening into various sizes. The larger sizes are in greater demand and sell for a slightly higher price. Owing to the fact that the ash in coal, and the lower-grade coal constituents are generally more friable than the higher-grade coal, the finer sizes are higher in ash.

Cleaning of coal is effected by taking advantage of the different densities of the various coal constituents (22). Some hand-picking is done, but the majority of washing is done with water in jigs and tables. A more recent addition is the Rheolaveur, which utilizes the principle of running stream. Pneumatic separation is also becoming a common treatment, particularly for the finer sizes (2).
In increasing order of densities there are the anthraxylon, the attritus, the fusain and the ash. In the general flow sheet a concentrate is obtained from each screened size of coal. The middlings are sometimes sold as a lower grade product, or they may be reground for liberation, rescreened, and retreated. The ash tailing, when of the desired grade, is discarded.

Coal finer than 1/8 inch is known as "culm". This culm presents a serious problem in coal treatment as its size makes washing ineffective. It has been the domestic practice in this country owing to the plenitude of good coal, to keep the amount of culm as low as possible and discard it. Recently the more efficient disposal of this waste has been studied. If it is fairly low in ash it may be mixed with some binder and briquetted, at a cost of around $1.50 per ton. The Trent process (23) consists of mixing the culm with a medium-weight mineral oil. The oil wets the coaly material and forms a suspension with it, known as the "amalgam". This may be skimmed from the denser ash, which the oil does not wet and which has sunk to the bottom of the mixture.
By proper washing it is possible to get three products: a high-grade concentrate, a middling, and a tailing. The concentrate is composed largely of anthraxylon, giving a relatively smokeless, low ash, high fuel value coal. The middling contains most of the attritus, and will hence be higher in organic sulphur, ash, volatile matter, and smoke-producing constituents than the concentrate. The tailing will contain most of the ash and pyritic sulphur, and will be of quite low fuel value.

A smokeless fuel with low ash is desirable for domestic use. For coke manufacture a high concentration of anthraxylon is desired, as this constituent is the coking part of the coal. Low ash is necessary for coking coal as 10 per cent is the limiting ash content in coke (13). On the other hand, the coal rich in attritus is better for gas making and by-product recovery because of its high amount of volatile matter and organic compounds. The high-ash product represents a great saving of weight in handling the coal and greater convenience in ash removal after firing. If an average freight rate is assumed as $2.40 per ton
of coal, over $60,000,000 is spent each year in hauling coal ash (5).

Greater efficiency demands the beneficiation of the coal mined in this country. Other countries have long ago realized this. Practically all the coal mined in Germany today undergoes treatment, and each coal is assigned to that use for which it is most applicable (9,10).

**FLotation of Coal**

In Germany coal flotation is extensively practiced with marked economic success on culm, on very low-grade coal, and on those coals in which the ash dissemination is so fine as to make mechanical washing unsuitable. In this country, which has many times the coal resources of Germany, such low-grade products are either not mined or they are discarded after mining. (9,10).

Coal flotation is, perhaps, the easiest flotation separation to effect. Generally, the anthracylous matter will float with a frother alone. For a frother some coal-tar product is used, obviously because of its cheapness. Practi-
cally any saturated oil will act as a collector. Xanthates have been used in England with some success. The effectiveness of the separation will depend, of course, on the size and liberation of the coal particles. The fineness of the flotation feed can not be too small, as extremely fine coal has a tendency to flocculate into a sludge consisting of small clumps of dry coal surrounded by wet coal. This effect may be counteracted in part by weathering the fine coal for a few weeks (23).

The essential differences between coal flotation and ore flotation are: firstly, in coal flotation there is a large bulk of concentrate and a small bulk of tailing, secondly, because of the low density of coal it is possible to float a particle 1/10 of an inch in size.

Where crushing costs are not charged to the coal flotation, as in culm waste, flotation on a 1000 ton scale will cost from 7 to 10 cents per ton of feed. On minus 1/8-inch feed recoveries on fuel value run about 75% in a concentrate representing about 50% of the original bulk. About 75% of the ash will be contained in the tailing (23). These figures will, of course, vary widely
with the different coals.

Where crushing to 1/8-inch is charged to flotation, the total cost will be about 15 to 20 cents per ton.

The next problem is getting the coal in a form in which it can be sold. Briquetting by pressure alone has been found possible on some German coals that are rich in binding material. This costs in the neighborhood of 50 cents per ton (10). When a binder is required briquetting will cost closer to $1.50 per ton. In either case the coal must be dried. Drying costs from 7 to 10 cents per ton (12).

In England a large plant is under construction for the hydrogenation of coal into motor fuel (1). This process requires a finely-ground, high-grade coal. In the future an outlet for the floated coal might be found here. Another possible outlet is the Bupa motor (1), an internal-combustion engine requiring a low-ash, fine coal. Pulverized coal makes an excellent boiler fuel, as it burns with much higher efficiency than coarse coal. Flotation concentrates might be coked directly, as it is an excellent coking coal. To make any plan
for the utilization of the loose, fine concentrate feasible, the dangers of spontaneous combustion must be avoided. So far, unless pulverized coal is to be used immediately, the only safe means of storing this material is immersion in oil. This is the end-point of the Trent Process and represents not only a duplication but also the use of a more expensive fuel. The big factor in oil flotation is briquetting; flotation of coals that do not contain sufficient binder of their own may be practical either when a cheap binder is found or the technique of handling pulverized fuel becomes more highly developed.

**STUDY OF THE BOZEMAN COAL**

**IDENTITY OF BOZEMAN COAL SAMPLE**

The coal used in this study comes from the bed of low-grade bituminous coal near Bozeman, Montana. The particular sample received contained 15.2% ash and had a fuel value of 11,800 B. t. u. per pound*. The moisture content was less than 1%

*all fuel values listed in this report were obtained by means of the bomb calorimeter. The probable error is plus or minus 200 B. t. u. /lb.
per cent, but could not be determined more precisely with the apparatus available.

ASH CONTENTS AND FUEL VALUES OF SCREEN SIZES OF BOZEMAN COAL

<table>
<thead>
<tr>
<th>Screen Size mesh</th>
<th>Per Cent Ash</th>
<th>Fuel Value B.t.u./lb.</th>
<th>Per Cent retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>20/28</td>
<td>16.44</td>
<td>11,800</td>
<td>31.9</td>
</tr>
<tr>
<td>28/48</td>
<td>15.16</td>
<td>12,800</td>
<td>28.7</td>
</tr>
<tr>
<td>48/100</td>
<td>14.50</td>
<td>11,000</td>
<td>17.4</td>
</tr>
<tr>
<td>100/200</td>
<td>19.00</td>
<td>11,000</td>
<td>8.8</td>
</tr>
<tr>
<td>200/400</td>
<td>20.90</td>
<td>10,500</td>
<td>6.3</td>
</tr>
<tr>
<td>-400</td>
<td>20.30</td>
<td>11,000</td>
<td>6.7</td>
</tr>
</tbody>
</table>

MICROSCOPE STUDY OF BOZEMAN COAL

A great deal of experience is required in order that the constituents of any particular coal, heretofore unclassified, may be properly correlated with any system of classification now in use. To gain this experience a considerable amount of time allotted to research was spent in studying the various systems and applying them to coals of both known varieties. The system of Dr. Thiessen (see the earlier section Constituents of Coal) was chosen by the writer as best fitting the Bozeman coal.

The anthraxylon, as interpreted by the writer,
was of widely varying character. Some particles were apparently quite homogeneous. From this extreme the woody character became more and more apparent until, at the other extreme, the cellular structure was little altered. The perfectly smooth particles would seem to indicate an advanced decomposition. It might well be that they represent a dehydrated and compressed gel, originally similar to the soft ooze found on decaying wood. The practically whole cells might indicate quick submergence in water toxic to the decay bacteria. In the intermediate particles, the first evidences of structure to appear are the more resistant tissues.

The attritus, as distinguished by the writer, are those particles which are open in appearance, but give no evidence of an original cellular structure. The particles vary from a quite compact nature to an extremely loose character. Some contain quite a variety of plant parts, while others contain but one or two apparently different constituents. Identification of attritus is facilitated if one bear in mind its original definition: an accumulation of plant debris. In counting
particles, no single grain of anthraxylon in attritus was considered as a locked particle, i.e., anthraxylon plus attritus, unless the single part of anthraxylon was about one-fifth or more of the whole particle. Several particles of attritus have been photographed, including the fairly common occurrence of silica locked in the attritus. Under microscope, it could be seen that some of the occurrences of silica or silicates were apparently replacements or silicifications of some plant structures, commonly cells.

A constituent that conforms to the appearance of silica or silicates in briquets of ores has been assumed to be such in this research. It occurs in high relief, indicating its comparative hardness, and has that dull gray color which silica or silicates have under reflected light. It has not been possible to check this assumption with chemical analyses. Hereafter, when silica or silicates are referred to in this report, this is the constituent meant. Silica occurs in all sizes in the crushed coal. Free particles of silicate are abundant in the tailing from the flotation operation, while its occurrence in the concentrate is a fine dissemina-
tion.

Pyrite is more positively identified under the microscope. It is a relatively rare constituent.

The constituent that has been most doubtful is the one which will be referred to as fusain. In daylight it has a brownish color, similar to that of cedar bark. It is very soft, as the scratches in the photographs would indicate. In structure it is fine-grained and porous. It might well be that this is silt which has been deposited with the coal. Chemical analyses would help in checking this point. In either case its prominence in the tailing point to its being either low-grade coal matter or silt. The ash analysis of the tailing is too high to account for all the silica present, pointing to a high inherent ash content in this constituent.

The microphotographs on the following plates were taken from briquets of 100/200 mesh Bozeman coal. The magnification in each photograph is roughly 400 diameters.
Plate 1. A typical anthraxyIon particle. The light lines in the tracing locate some of the bolder lines in the section which are in relief. Note that these lines are roughly parallel. This particle has been almost completely decayed, leaving only these lines to indicate the original plant structure.
Plate 2. A locked particle. The parts marked C and S in the tracing were in relatively high relief, making the midground A rather indistinct. C is obviously well-preserved cells in longitudinal section. While this portion is considered anthraxylon it might well be fusain, although it does not correspond to what the writer has been calling fusain (see page 26, and plate 6). The section marked S was a silicate or silica in high relief.
Plate 2. A locked particle.
Plate 3. A particle of silica or a silicate in high relief. The flat top was obtained by polishing for 15 minutes on a brass wheel. The relief is due to buffing on a cloth wheel.
Plate 3. A particle of silica or a silicate in high relief.
Plate 4. This is a locked particle containing anthraxylon, attritus, and silica in relief. Note the nature of the attritus and the parallel trend of the bedding.
Plate 4. This is a locked particle containing anthraxylon, attritus, and silica in relief.
Plate 5. A locked particle containing attritus and anthraxylon. The lines in the tracing indicate those parts of the anthraxylon which have been more resistant to decay.
Plate 5. A locked particle containing *attritus* and *anthraxylon*.
Plate 6. Fusain particles. Each shows the fine porous structure. First interpreted as cellular, this was called fusain. It might well be a fine silt or clay.
Plate 6. Fusain particles. Each shows the fine porous structure.
Plate 7. Typical cellular structure. This type of particle was counted as anthraxylon. It might well be fusain, that is wood cells which have been little attacked.
Plate 8. A low-grade anthraxylous particle. Note the fairly prominent plant structure, indicating fair preservation. The portions in relief marked S on the tracing are silica or silicates in relief.
The flotation of coal is a recognized possibility. The problem in this work is essentially analogous to that of treating ores: getting the highest concentrate, the lowest grade tailing, and the highest recovery with the least crushing. In addition, due to the low value per ton of coal and the large bulk of concentrate, the economic problem is even more important.

Preparation of sample. In preparing this particular coal for flotation tests, it was first ground to pass a 20-mesh screen. Considerable care was exercised to prevent the production of an excess of fine material, so as to simulate the crushing done by a hammer mill. To gain this end, the crusher was set quite coarse and the minus 20-mesh coal screened out after every pass through the crusher. The coal was then screened into six sizes, viz: 2-28, 28/48, 48/100, 100/200, 200/400, and minus 400 mesh. Two-hundred-gram charges were screened twenty minutes on the Ro-tap. The 200/400 size was then rescreened for 20 minutes to clean it of the minus 400 mesh material. It was noted
that each of the sizes was contaminated with fine
dust which adhered throughout the screening. In
future work it might be well to wash the sized
coal before further testing.

The fuel value, ash content, and percent
weight of each screen size are given in Table III.

Test A: 28/48-mesh material. The first size
of coal floated was the 28/48 material. The col-
lector used was a coal tar byproduct. An attempt
was made to obtain four products, namely, an
anthraxylous concentrate, an attrital middling,
a high-fusain middling, and a high-silica tailing.
Examination of the intended high-fusain middling
showed that most of the fusain was still in the
machine, hence flotation of the third middling was
an attempt to collect the fusain. This also fail-
ed, as most of the fusain went into the tailing.
Time did not permit an accurate microscopic analy-
sis of the products. A few general facts are
worth noting. The 28/48-mesh feed is relatively
low in ash, and the concentrate has the lowest ash
content of any obtained. This is borne out by the
qualitative determination that the concentrate was
largely free anthraxylon. The anthraxylon in the
feed was also largely free. It is possible that by the careful crushing method employed the grinding was somewhat selective, being practically just sufficient to free the relatively hard and homogeneous anthraxylon from the more friable and heterogeneous attritus and fusain. At any rate, the high degree of freedom of the anthraxylon qualitatively noted in each size and in each concentrate is noteworthy. The procedure used in this test and the results obtained are given in Table IV.
TABLE IV
FLOTATION TEST A

Feed: 150 grams 28 to 48 mesh Bozeman coal
Reagents: Concentrate - 1.0#/T Barret oil #634
           0.4#/T Terpineol
First Middling - 1.5#/T Barret oil #634
               0.5#/T Terpineol
Second Middling - 1.5#/T Barret #634
Third Middling - 1.5#/T Barret #634

Conditioning: ten minutes in machine with terpineol.

<table>
<thead>
<tr>
<th></th>
<th>Concentrate</th>
<th>First Middling</th>
<th>Second Middling</th>
<th>Third Middling</th>
<th>Tailing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per cent of</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Per cent of weight of feed</td>
</tr>
<tr>
<td>weight of feed</td>
<td>15.7</td>
<td>22.1</td>
<td>19.3</td>
<td>23.2</td>
<td>19.6</td>
</tr>
<tr>
<td>Ash content</td>
<td>5.4</td>
<td>5.5</td>
<td>5.7</td>
<td>10.0</td>
<td>45.2</td>
</tr>
<tr>
<td>per cent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel value</td>
<td>13,200</td>
<td>12,800</td>
<td>12,400</td>
<td>12,300</td>
<td>11,000</td>
</tr>
<tr>
<td>B.t.u./lb.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash recovery</td>
<td>5.9</td>
<td>8.5</td>
<td>7.6</td>
<td>16.4</td>
<td>61.9</td>
</tr>
<tr>
<td>per cent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel recovery</td>
<td>16.9</td>
<td>23.0</td>
<td>19.5</td>
<td>23.2</td>
<td>17.5</td>
</tr>
<tr>
<td>per cent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The relatively low ash content of the tailing obtained is explained by the low degree of freedom for silica at this size.

Test B: 100/200-mesh material. As noted in the last paragraph above the silica was highly locked in the coarser sizes. Microscopic examination revealed that below 100 mesh the silica was much freer. The data and procedure for the first test (test B) on the 100 to 200 mesh material are given in Table V.
In this test satisfactory results are obtained. The concentrate carries a considerable proportion of the original fuel value and a small amount of ash. The tailing contains most of the ash, has a small bulk and practically no fuel value.

However, the concentrate does not have a much higher fuel value per unit than the original feed. It was also noticed that the pulp was highly flocculated. Many of these floccules were carried over into the concentrate.

**TABLE V**

FLOTATION TEST B

| Feed: 150 grams of 100 to 200 mesh Bozeman coal |
| Reagents: Concentrate - 0.40#/T Terpineol |
| First Middling - 0.50#/T Barret oil #634 |
| Second Middling - 0.75#/T Barret oil #634 |
| Conditioning: Ten minutes in machine with water and terpineol |

<table>
<thead>
<tr>
<th></th>
<th>Concentrate</th>
<th>First Middling</th>
<th>Second Middling</th>
<th>Tailing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per cent of weight of feed</td>
<td>63.6</td>
<td>24.9</td>
<td>1.8</td>
<td>8.9</td>
</tr>
<tr>
<td>Ash content per cent</td>
<td>6.7</td>
<td>25.9</td>
<td>30.1</td>
<td>86.5</td>
</tr>
<tr>
<td>Fuel value B.t.u./lb.</td>
<td>12,650</td>
<td>9,600</td>
<td>5,450</td>
<td></td>
</tr>
<tr>
<td>Ash recovery per cent</td>
<td>22.7</td>
<td>33.8</td>
<td>2.0</td>
<td>40.6</td>
</tr>
<tr>
<td>Fuel recovery per cent</td>
<td>73.0</td>
<td>21.7</td>
<td>5.3</td>
<td></td>
</tr>
</tbody>
</table>
Test 0; 100/200-mesh material. In order to counteract flocculation the coal was conditioned in the machine with water for ten minutes before the frother was added. Few flocules were found in the pulp after the conditioning. By taking less weight of the concentrate a higher fuel value was obtained, but the ash content remained the same. The first middling contained less ash than the original coal. The tailing is lower in fuel value and higher in ash than the one obtained in the previous test, though of the same bulk.

Under the microscope the concentrate is largely anthraxylon, the first middling is largely attritus, the second middling is mainly attritus-silica particles and fusain, while the tailing is silica and fusain.

Data for this test are in Table VI, and the microscope analysis of products in Table VIa.
TABLE VI

FLOTATION TEST C

Feed: 150 grams of 100 to 200 mesh Bozeman coal
Reagents: Concentrate - 0.41#/T terpineol
First middling - 0.33#/T terpineol
Second middling - 0.50#/T Barrett oil #662
Conditioning: coal conditioned with water alone for ten minutes in machine

<table>
<thead>
<tr>
<th></th>
<th>Concentrate</th>
<th>First Middl</th>
<th>Second Middl</th>
<th>Tailing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per cent of weight of feed</td>
<td>44.3</td>
<td>35.9</td>
<td>10.4</td>
<td>9.6</td>
</tr>
<tr>
<td>Ash content per cent</td>
<td>6.0</td>
<td>8.7</td>
<td>32.1</td>
<td>86.4</td>
</tr>
<tr>
<td>Fuel value B.t.u./lb.</td>
<td>13,100</td>
<td>12,050</td>
<td>4,280</td>
<td></td>
</tr>
<tr>
<td>Ash recovery per cent</td>
<td>15.1</td>
<td>13.1</td>
<td>17.6</td>
<td>43.6</td>
</tr>
<tr>
<td>Fuel recovery per cent</td>
<td>52.8</td>
<td>39.3</td>
<td>7.9</td>
<td></td>
</tr>
<tr>
<td>Weight of feed per cent</td>
<td>Feed</td>
<td>Conc</td>
<td>First Middl</td>
<td>Second Middl</td>
</tr>
<tr>
<td>------------------------</td>
<td>------</td>
<td>------</td>
<td>-------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Anthraxylon</td>
<td>46.6</td>
<td>76.3</td>
<td>31.7</td>
<td>15.1</td>
</tr>
<tr>
<td></td>
<td>40.9</td>
<td>73.5</td>
<td>30.0</td>
<td>13.9</td>
</tr>
<tr>
<td>Attritus</td>
<td>35.1</td>
<td>18.7</td>
<td>60.4</td>
<td>42.0</td>
</tr>
<tr>
<td></td>
<td>20.8</td>
<td>17.9</td>
<td>56.3</td>
<td>22.9</td>
</tr>
<tr>
<td>Fusain</td>
<td>8.7</td>
<td>0</td>
<td>2.7</td>
<td>34.1</td>
</tr>
<tr>
<td></td>
<td>7.6</td>
<td>0</td>
<td>2.5</td>
<td>31.4</td>
</tr>
<tr>
<td>Silica or Silicates</td>
<td>9.5</td>
<td>4.4</td>
<td>5.2</td>
<td>8.8</td>
</tr>
<tr>
<td></td>
<td>20.0</td>
<td>8.4</td>
<td>9.3</td>
<td>8.1</td>
</tr>
<tr>
<td>Pyrite</td>
<td>0.1</td>
<td>0</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
<td>0</td>
<td>0.3</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>72.1</td>
<td>24.1</td>
<td>3.3</td>
</tr>
<tr>
<td>Anthraxylon</td>
<td>100</td>
<td>25.9</td>
<td>63.3</td>
<td>3.9</td>
</tr>
<tr>
<td>Attritus</td>
<td>100</td>
<td>0</td>
<td>11.4</td>
<td>40.4</td>
</tr>
<tr>
<td>Fusain</td>
<td>100</td>
<td>21.3</td>
<td>20.5</td>
<td>10.1</td>
</tr>
<tr>
<td>Silica or Silicates</td>
<td>100</td>
<td>0</td>
<td>35.0</td>
<td>0</td>
</tr>
<tr>
<td>Pyrite</td>
<td>27.3</td>
<td>5.4</td>
<td>8.0</td>
<td>49.4</td>
</tr>
<tr>
<td>Total pyrite</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total of silica freed</td>
<td>55.7</td>
<td>86.0</td>
<td>45.9</td>
<td>38.0</td>
</tr>
<tr>
<td>Anthraxylon freed</td>
<td>66.9</td>
<td>78.0</td>
<td>76.6</td>
<td>67.2</td>
</tr>
</tbody>
</table>

Top figure in each block is per cent by volume. Bottom figure in each block is per cent by weight, using densities: anthraxylon, attritus, fusain 1.20, silica . . . . . . . . . . . . 2.40, pyrite . . . . . . . . . . . . 7.00
Figure 3. Graph of data from flotation test C.
Feed - 100/200 mesh Bozeman coal.
Test D: 100/200-mesh material. In order to further diminish flocculation, in this test the coal was conditioned with gelatine before the reagents were added. A shale oil from the vicinity of Dillon, Montana was used as a collector. The results show little improvement over the last test.

A higher fuel value is obtained in the concentrate with a considerable loss in recovery. A first middling of greater weight was made to test the advantage of cleaning the ash analyses show, the gelatine apparently aided in floating the locked particles containing silica. On the other hand the tailing obtained is higher in ash than the previous test.

The results and procedure for this test are given in Table VII.
# TABLE VII

## FLOTATION TEST D

**Feed:** 150 grams of 100 to 200 mesh Bozeman coal

**Reagents:**
- Concentrate - 0.33#/T terpineol
- 0.60#/T Dillon shale oil
- 0.40#/T gelatine

**First Middling** - 0.33#/T terpineol
- 0.50#/T shale oil

**Second Middling** - 1.00#/T shale oil

**Conditioning:** 10 minutes in machine with 0.4#/T gelatine

<table>
<thead>
<tr>
<th></th>
<th>Concentrate</th>
<th>First Middl</th>
<th>Second Middl</th>
<th>Tailing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per cent of weight of feed</td>
<td>31.8</td>
<td>56.3</td>
<td>2.4</td>
<td>8.1</td>
</tr>
<tr>
<td>Ash content per cent</td>
<td>6.2</td>
<td>14.9</td>
<td>78.3</td>
<td>86.9</td>
</tr>
<tr>
<td>Fuel value B.t.u./lb.</td>
<td>13,200</td>
<td>11,000</td>
<td>5,830</td>
<td></td>
</tr>
<tr>
<td>Ash recovery per cent</td>
<td>10.2</td>
<td>43.5</td>
<td>9.6</td>
<td>36.5</td>
</tr>
<tr>
<td>Fuel recovery per cent</td>
<td>38.2</td>
<td>56.3</td>
<td></td>
<td>9.4</td>
</tr>
</tbody>
</table>

**Retreatment of First middling.**

<table>
<thead>
<tr>
<th></th>
<th>First Middl</th>
<th>Cleaner Conc.</th>
<th>Cleaner Tails</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per cent of weight of feed</td>
<td>56.8</td>
<td>36.2</td>
<td>20.1</td>
</tr>
<tr>
<td>Ash content per cent</td>
<td>14.9</td>
<td>13.0</td>
<td>18.3</td>
</tr>
<tr>
<td>Fuel value B.t.u./lb.</td>
<td>11,000</td>
<td>11,000</td>
<td>11,000</td>
</tr>
<tr>
<td>Ash recovery per cent</td>
<td>43.5</td>
<td>24.4</td>
<td>19.1</td>
</tr>
<tr>
<td>Fuel recovery per cent</td>
<td>56.3</td>
<td>36.2</td>
<td>20.1</td>
</tr>
</tbody>
</table>

**Reagents:** 0.2#/T gelatine
- 0.33#/T terpineol

**Conditioning:** ten minutes with 0.2#/T gel. in machine

---

-36-
Test E: 200/400-mesh material. The low fuel value and high ash content of this size feed on this test are in keeping with those for previous tests. The data are given in Table VIII.

**TABLE VIII**

**FLOTATION TEST E**

Feed: 150 grams of 200 to 400 mesh Bozeman coal
Reagents: Concentrate - 0.33#/T terpineol
          0.25#/T Barret oil #662
          0.50#/T Dillon shale oil
          0.7#/T gelatine
First Middling - 1.25#/T Dillon shale oil
Second Middling - 0.75#/T Dillon shale oil
                   0.33#/T terpineol
Third Middling - 0.50#/T Dillon shale oil
Conditioning: ten minutes in machine with 0.7#/T gelatine

<table>
<thead>
<tr>
<th></th>
<th>Concentrate</th>
<th>First Middling</th>
<th>Second Middling</th>
<th>Third Middling</th>
<th>Tailing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per cent of</td>
<td>29.9</td>
<td>27.4</td>
<td>26.9</td>
<td>1.6</td>
<td>11.3</td>
</tr>
<tr>
<td>weight of feed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash content</td>
<td>8.8</td>
<td>9.2</td>
<td>18.2</td>
<td>48.0</td>
<td>84.5</td>
</tr>
<tr>
<td>per cent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel value</td>
<td>12,400</td>
<td>12,400</td>
<td>10,500</td>
<td>3,900</td>
<td></td>
</tr>
<tr>
<td>B.t.u./lb.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash recovery</td>
<td>12.9</td>
<td>12.4</td>
<td>24.0</td>
<td>37.8</td>
<td>46.9</td>
</tr>
<tr>
<td>per cent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel recovery</td>
<td>35.3</td>
<td>32.4</td>
<td>26.9</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td>per cent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Further Notes on Flotation**

The effect of pH on the flotation of this coal has not been tried, although some preliminary
work was accomplished. Using KOH and HCL, solutions of different pH values were made up. Charges of 4.5 grams of coal were added to 75 cc's of each solution, shaken thoroughly, and allowed to stand for one hour. The data obtained are graphically illustrated in Fig. 2, in which the pH of the mixture is plotted against the pH of the original solution. The wide range near the neutral point where neither acid or base has any effect is indicative of the adsorptive power of the coal. The quicker break in the basic part of the curve shows that the coal is slightly basic in reaction.

The pH of the pulp during flotation was that of tap water, viz 7.3. In the range from pH 7 down it was noticed that the coal had a tendency to flocculate, while in the basic range a good dispersion was noted.

Flotation tests were not run on the minus 400-mesh coal as it was practically impossible to disperse this size in water.
Figure 2. Curve showing adsorptive effect of Bozeman coal.

48/100 mesh coal was diluted 16 to 1 with KOH or HCl of known strength. pH was measured colorimetrically after soln. had been in contact with coal for 30 minutes.
CONCLUSIONS

From the data presented it appears that the Bozeman coal might be satisfactorily treated by:
(1) crushing the coal to, say, minus 10 mesh, care being taken to make a minimum of minus 400 mesh material, (2) sizing to three or four sizes down to 400 mesh, (3) floating each size with creosolic acid, oil, and starch, or some other cheap reagents, (4) obtaining a high-grade, anthraxylous concentrate, an attrital middling, and an ashy tailing from each size, (5) re-crushing and re-floating the higher grade middlings and tailings from the coarser sizes, and (6) obtaining three final products; viz: a high-grade, anthraxylous concentrate, an intermediate attrital concentrate, and an extremely low-grade tailing.

On the basis of 100 tons of mine-run coal an hypothetical plant might yield:

(1) 50 tons of high-grade concentrate with an ash content of 6.0 per cent and a fuel value of 13,000 B.t.u. per pound.

(2) 35 tons of attrital middling run-
ning 9 per cent ash and 12,000 
B. t. u. per pound.

(3) 15 tons of tailing running 80 
to 90 per cent ash and less 
than 4,000 B. t. u. per pound.

Fuel recoveries should run, respectively, 55, 
36, and 9 per cent. Ash recoveries should be 15, 
70, and 40 per cent, respectively. The concen-
trate is salable as a high-grade, smokeless fuel. It should also make an excellent blast-furnace 
coke or a low-temperature by-product coke, the latter an excellent household fuel (4). The mid-
dling could be used at the plant for gas and by-
product manufacture, these products could be sold 
and the residual coke could be used at the plant 
for power and heating. Some fuel value might be 
recovered from the tailing, but it should be con-
sidered as waste.

On a 1000-ton plant the over-all cost per ton of crushing, flotation, and drying should not be 
over 30 cents. The factor which would determine 
the commercial success of such an operation would 
be whether briquetting were necessary or not. 
Briquetting would add from 50¢ to $1.50 to these
costs. This would require a premium on the products, at the mine, of from 50¢, if no briquetting were necessary, to a little over $2.00 if briquetting with a binder were required. The writer has not found this premium to exist in Montana, and hence the present value of the research conducted thus far is purely academic. The future value of this research is open to speculation. As good coal becomes scarcer in this country, this particular coal might be profitably treated by flotation. Again, a means of handling pulverized coal might be found. It cannot be said, at this time, that the hypothetical plant practice given above is subject to noticeable improvement. If an even better ash rejection were possible, this treatment might be an economic success.

RECOMMENDATIONS FOR FUTURE WORK

In the event that further work is to be done along these lines there are several valuable hints which might be noted.

First, the available apparatus for obtaining fuel values is relatively inaccurate.
The fuel values of the tailings were obtained by subtraction by the writer. If there were an appreciable error in the values given the interpretation of the results might be entirely different.

Due to the lack of time and equipment analyses on volatile matter, sulphur, and fixed carbon were not obtained for any of the products nor the feed. Such results would undoubtedly be of value in interpreting the results of the work performed. For the same reason determination of the coking properties were not obtained. As part of the economic value of applying flotation to this coal lies in the effect on the coking properties, coking tests should have been made.

Microscope analyses are much more important in the study of this problem than their treatment in this work would indicate. The one analysis given is relatively inaccurate, due to imperfect polishing of the briquets. Inasmuch as the ultimate measure of separation is the complete segregation of each of the constituents, the microscope is the only means of determining the success of the separation. Every product should be subjected to an accurate microscopic analysis. In addition, by
careful work on a number of products it should be possible, by using a series of simultaneous equations, to obtain, fairly accurately the composition and fuel value of each constituent. With these results at hand the value of the best product might be forecasted.

Perhaps an unnecessary amount of crushing was done. From the previous tables it may be seen that a fair grade of concentrate is obtained on each screen size. It is probable that even coarser sizes will give a fair amount of free anthraxylon for a concentrate.

As mentioned before, middling retreatment on the coarser sizes is a fruitful ground for study.

The Bozeman coal, while refractory from the standpoint of ash dispersion, is really elementary in comparison to coals with disseminated pyrite in addition. It is also somewhat of a coking coal in the raw state. From the standpoint of difficulty of treatment of non-coking coal with finely disseminated ash and pyrite would provide a subject for more thorough research.
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