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Iowa Coal Studies

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FOREWORD

In "Technical Paper No. 2" published in 1930 we reviewed in a general way the conditions that faced the coal producing industry not only in Iowa and the United States but over the world in general. Indeed the economic situation of the bituminous miner in England and Wales who was largely dependent upon the shipping industries that were rapidly turning to oil, had become acute even before the coming of the world financial depression.

In the last half decade early trends that indicated contraction of coal markets have become more pronounced. Production of coal in the United States which was close to the 1913 level in 1930 had fallen to 70 per cent in 1934; while oil and gas had in the meantime maintained a 350 per cent advantage over the 1913 figure. Electric central stations used 24.7 per cent more fuel oil in 1933 than in the previous year but only 0.9 per cent more coal, while they burned in the same period more than 100 billion cubic feet of natural gas. Production of electricity by water power broke all previous records with nearly 35 billion k.w.h. With the introduction of the Diesel engine for railroad motive power a new threat to the interests of the coal industry is uncovered.

In a recent discussion of the use of bituminous coal for steam generation Bailey(1) states that "the three factors that have been most responsible for reducing the consumption of bituminous coal are (1) hydroelectric power generation, (2) petroleum and gas, (3) improved efficiency in combustion of coal and generation of steam.

"Improved efficiency in steam plants has no doubt been the greatest single factor in reducing coal consumption per unit of power output, for it has been reduced in the better electric stations from more than 3 lb. to 1 lb. of coal per kilowatt-hour. Similar reduction in coal consumption has taken place in practically all industrial plants, though to a lesser degree. However, if these economies in the burning of coal and in the use of steam had not been brought about, hydro and oil would have made greater inroads, proportionately, than they have. In fact, the salvation of the bituminous coal industry lies in the direction of still greater efficiency and cleanliness in the use of its product, coal. The consumption of coal per unit of power must be further decreased, and the facility and cleanliness of its handling and use be increased, to protect it against further inroads by other forms of fuel or power generation."

The situation in Iowa reflects that of the country as a whole. The natural gas lines that were approaching our borders in 1930 are now spreading a net over the state; in corresponding measure, to the extent of a million tons annually, coke and eastern coals are being displaced in the production of domestic gas, and Iowa and other Midwest coals in heat and power generation. But the coal picture as set in the Iowa frame is not altogether gloomy. In times of financial stress an acute sense of relative values is more naturally and generally developed than when economic skies are fair. In the framing of many a household budget these trying years the major item of fuel has been reduced in

Iowa homes by choosing a coal produced near at hand in preference to one on which a long freight haul has added a high overhead toll. The unusual severity of the current winter of 1935-36 has, moreover, demonstrated the importance of having a well developed coal industry at home to reduce the demands upon our transportation systems already overtaxed under emergency conditions.

Comparison of production figures for 1928 when the boom was approaching its peak, viz. 3,684,000 tons, with the estimated output for 1934, viz. 3,345,000 tons, shows that the Iowa industry has held fairly steady in spite of all the adverse economic and competitive forces that have hammered it, due no doubt to the demand for a lower priced heat unit. However the challenge to the Iowa industry is not the temporary holding of business that comes from conditions of distress but its expansion in times of prosperity when the consuming public demands a quality based on something more than heat content alone. Premium fuels whether for domestic or steam use as they are produced today result either from ordinary preparation of coals of extraordinary quality or from special care in the grading and cleaning of those that might otherwise be mediocre or inferior. The Iowa industry has but one alternative. A marked improvement in the grade of the product can be brought about only by raising the standards of preparation at the tipple particularly with reference to the steam sizes which under present methods are often weighted with material that properly belongs in the gob pile. A problem of major importance therefore is that of determining the technical possibilities of applying cleaning methods to our Iowa coals and it is this phase of the general study that we have stressed in recent months in the hope that our results might be of value as a guide to commercial development in this direction should economic conditions seem favorable.

But while certain measures must be taken to correct obvious faults in preparation if the product is to have widely extended markets it is equally important that the intrinsic virtues of our native fuels be properly understood and that the many good qualities they possess, but which are often masked by their superficial faults, be placed in a more favorable light. The information available from Government sources is meager and the little obtainable is sometimes misleading. I quote from Technical Paper No. 269 of the Bureau of Mines,(2) "Analyses of Iowa Coals" the following general statements:

"Iowa coal is low-grade and non-coking bituminous, carrying considerable sulfur in the form of pyrite and gypsum. The gypsum coats the vertical faces of the coal so that it looks somewhat as though daubed with whitewash. In many places the coal is 'bony'. The change in character takes place in a short distance, clean coal changing to shale interleaved with thin layers of coal. In general the coal is hard, slabby, or blocky, and makes a fair steam and domestic fuel, though sooty. In general Iowa coal weathers rapidly on exposure, hence does not store well, and if much slack is present it soon takes fire spontaneously. * * * * The most marked characteristic is the presence of small and large limestone bowlders or concretions called 'niggerheads'. Sometimes these form a practically continuous parting. * * * * The Bureau of Mines has made few fusibility tests of the ash from Iowa coals, but many from the western part of the interior coal field. These samples have invariably shown a very low softening temperature, ranging from 1,850° to 2,100°."

This sweeping and, in many respects, astounding indictment might well be ignored as based upon insufficient knowledge of the facts did it not come from high official sources. From the vantage point of fifteen years' study of Iowa coals we return a categorical denial of these charges and implications so far as they refer to our coals as a class. Should Iowa coal be classed as low-grade? Iowa coal is bituminous and is admittedly lower in rank that most of the coals of the Appalachian or Eastern Province where the processes of mountain making have greatly reduced inherent moisture and volatile matter, but it is higher in rank than the great deposits of lignite and sub-bituminous of Texas, Wyoming, North Dakota and other states of the plains region. Such a statement is manifestly unfair if it is made in derogation; in any case it is meaningless when made without qualifying explanation. Are they non-coking? We have proved that coals from all sections of the state produce firm, hard cokes when the treatment adapted to their peculiar chemical composition is applied. Do they appear to be plastered with whitewash? It is true of the coals in certain regions of the state that thin leaves of gypsum or calcium carbonate have formed in the vertical cleavage planes which perhaps might suggest "plaster." Such mineralization however, is not in general, excessive and while its occurrence raises the ash content slightly it could hardly be considered a fault to be advertised. Are they "bony" and do the seams run into shaly interleaves? Perhaps such deposits exist but in general the producing companies of today do not work them. Are they especially sooty? Smoke and soot producing tendency of greater or less degree is a property of all bituminous coals. Iowa coals form smoke and soot when improperly burned as do other coals of similar rank and other fuels like oil and natural gas. How much better or worse they are in this respect than any given group produced elsewhere has not been determined; certain types from the Appalachian field, however, are known from common experience to be no better. Do they store badly? Our own tests as well as those of certain large coal users of the state have proved that Iowa coal will keep indefinitely when properly graded and piled. Iowa slack coals mixed with fine dust and loosely packed, will not keep; neither will similar mixtures from Illinois, Indiana or Kentucky. Are Iowa coal beds full of "niggerheads?" No, not in general. Concretions of various minerals are found in the coal measures of the whole Interior Province but they are not especially typical of the Iowa coal seams. Finally, do Iowa ashes have especially low fusion points, say as low as 1850°? The mean ash fusion point of 19 face samples gathered recently from all the producing counties of the state is 2187°F.

To furnish a rational basis for a knowledge of the qualities of our coals and to provide the means for refuting misleading statements like the foregoing we have continued and extended our earlier studies on the basic properties of these coals, taking up in parallel investigations the determination of melting points of ash, the measurement of weathering, the determination of coking and smoking characteristics, the distribution of sulfur in the coal and the range of ignition temperatures. Each of these qualities has an important if not an obvious bearing on the value of fuel to the consumer since each is an elementary factor in governing the combustion process. As a result of these studies made usually in comparison with coals from other states, we are convinced that little fundamental difference exists in the inherent or "pure coal" qualities of most of our Interior Province coals outside those areas where movement of the earth's crust has played a part in the hardening and refining process. With this specific reservation we may say that the coals of northern and central Illinois, Iowa and Missouri lie in much the same quality level except for local variations in ash and sulfur which are extraneous to the true coal mass.

At no time in these studies have we been so optimistic as to expect unanimous approval of our methods or total agreement with our conclusions; nor does it matter so long as we have a common objective. The Iowa coal industry is too important actually and potentially, and its prosperity too vital to the welfare of the commonwealth to allow private difference in viewpoint to stand in the way of its progress. Moreover honest difference of opinion may well serve the double function of curbing the over zealous theorist and of disturbing the too complacent business man. We all agree that the coal industry is faltering and that its fundamental difficulties should be sought out and corrected if possible. We believe firmly that Iowa coals should be more widely used, not on patriotic grounds but squarely on economic considerations. But we need more facts on which to base conclusions; how these coals can be cleaned and improved; how they can best be burned; how they compare with coals from neighboring states; what size and condition is best adapted to a particular use or setting. In writing the sections of this paper that follow we have been mindful rather of the needs and problems of the producer and the consumer of Iowa coal than with the more special aspects of fuel chemistry. We claim no discoveries or new developments; our task has been rather to apply the modern methods of coal study to the problem of evaluating the fuels of the state and to report our results and conclusions in a form readily usable by the non-technical reader but still conforming to the requirements of a technical publication.

Special acknowledgment for support and sympathetic interest in the program of studies we have carried on is due President Baker and the Board of Education; Presidents Jessup and Gilmore of the University; Superintendent Smith and his staff of the heating plant who have not only cooperated with us cheerfully and generously but have made much of our work possible; President Harper and the members of the Iowa Coal Institute; Dean Williams and my colleagues of the Coal Research Committee; Drs. Kay and Lees and their successors, Drs. Trowbridge and Tester of the Iowa Geological Survey; and surely not least, the loyal students who have labored with me.

THE COMPOSITION OF IOWA COALS

It is a wise policy in beginning the discussion of any technical subject to define the terms used in that discussion and to limit the conditions and situations to which they apply; for such a course always tends to clarify the subject matter and to remove the most common cause of futile controversy, namely, lack of a mutual understanding of definitions of terms. Especially is this true in writing about coal whether from Iowa or elsewhere for the term is all embracing and includes materials differing not only in primary composition and geologic age but in the conditions resulting from variation in methods of mining and preparation.

"Run-of-mine" is the raw product that is hoisted up the shaft direct from the workings at the face of the seam. At this stage it is a mixture of various sizes of lump coal and of shale refuse from roof and floor, together with fines produced by the undercutting machine or the drill, by the shock of the powder shot or by the disintegration due to mere handling and loading. While run-of-mine is marketed as a domestic fuel from the low-volatile fields of the east it is of minor importance in the middle west, being sold mainly from wagon mines or small operations that lack screening equipment. The normal procedure on the other hand, involves a more or less elaborate classifying process in which the coal is separated into sizes ranging from lump down through the grades of egg and nut leaving finally the screenings or steam coal from 1½ or 2 inch down to dust. At all well ordered tipples, experienced pickers stationed at the conveyor tables inspect the passing stream, push off the lumps showing undue amounts of mineral impurity and pass along only those that measure up to a given standard of quality. The rejected portion may be crushed to smaller sizes and repicked and rescreened; or under ideal conditions it is crushed and routed to a washer together with the under-sizes from the screening system.

It is evident therefore, that the domestic grades whether lump, egg or nut, constitute a select fuel from which much of the mineral matter has been removed and that the degree to which this separation has been carried out determines the ultimate purity and quality of the product. Exactly what are the composition and thermal values of the domestic grades from any Iowa mine is not always easy to say because of lack of necessary survey work. While we have thousands of reports of analysis on Iowa screenings there are relatively few on the larger sizes for the obvious reason that not only is it more difficult to take a fair sample of the latter, but the opportunity for taking it is more rarely presented. On the other hand we have ample data on the quality of these coals as they occur in the mine, obtained from numerous "face samples" taken, as the term indicates, by cutting a deep groove down the face of the seam and quartering and sampling the broken material.

Now there are certain definite reasons why a prepared domestic coal should be superior in heat content and in quality to that of a sample collected in this way. First, coal in the mine seam is distinctly more moist than a commercial coal that has been exposed to the surface air for even the short time required for preparation and shipping. If in addition to such casual drying it undergoes additional curing in storage the net heat value per pound obviously rises in proportion. In the second place the hand picking done on domestic grades removes much of the free mineral that may be retained in the face sample, although clay partings of any considerable size are excluded from the latter. Finally, much of the pyrite or calcite segregated in thin plates in the bedding and cleavage planes of the coal seam loosens and crumbles in the mining operation and is largely eliminated with the undersizes at the screens whereas it is included in the mine face sample.

Results of analysis of the face therefore indicate a datum value from which the quality of domestic sizes may be computed with fair accuracy by applying corrections based on the improvement to be expected from the drying and ash removal processes discussed above. Since the publication of Technical Paper No. 2 in which are given the results of earlier sampling surveys, two series of mine face collections have been made, the first in 1932 by the late Dr. James H. Lees of the Iowa Geological Survey and the second by students of the author under his direction. Results are tabulated in Tables I and II.

In addition to the usual determinations made in the so-called "proximate analysis" the coals of the later series were tested for ash fusion and critical ignition point. Ash fusion determinations were made with the Barrett gas furnace, a late development with many points of superiority over the old melters furnace which is at present the standard American Society for Testing Materials apparatus. Work is now under way at the Bureau of Mines to determine the eligibility of the new furnace for official acceptance; our personal opinion is that it will qualify without question.

The critical oxidation or ignition temperature is that point at which the continuous combination of oxygen with the coal becomes independent of external sources of heat; in other words when it begins to burn without further kindling. These values, determined by the method of Parr and Coons,(3) were measured in the hope that they might throw some light upon the inherent quality of representative Iowa coals or upon their behavior in the furnace. In general the coals of high rank have the higher ignition temperatures but the differentiation is not sharp within narrow ranges of coal classes. The mean value for the Iowa coals listed in Table II viz. 287°F, is 26° lower than the average values on an equal number of Illinois coals from widely distributed locations, obtained by Parr.

It is apparent that while the moisture figures of the coals in the two series shown in Tables I and II agree closely some difference exists in ash and thermal values. This may be accounted for in the personal equation of the collector and to differences in judgment as to what constitutes a fair sample. It must be remembered in any case that adequate sampling of coal is difficult at best and that the precision attained falls short of that to be expected in laboratory tests and measurements. The accuracy of the analytical work may be judged by noting that duplicate samples of the coals listed in Table II analyzed by the U. S. Bureau of Mines gave mean values agreeing with ours within 1.25 per cent.

Table I. Composition of Face Samples, Iowa Coals, A Series

	Producer	Mine	Location	County	Moisture	Percentages, As Received Basis			Percentages, Dry Basis		
						Ash	Sulfur	Thermal Value B.t.u.	Ash	Sulfur	Thermal Value, B.t.u.
A1	Iowa Coal & Supply Co.	Dallas	Granger	Dallas	18.4	10.6	3.3	10,121	12.9	4.1	12,410
A2	Norwood-White Coal Co.	Moran No. 7	Moran	Dallas	19.5	12.2	1.7	9,665	15.1	2.1	12,010
A3		Orillia Mine	Orillia	Warren	17.3	6.4	2.8	10,925	7.8	3.4	13,210
A4	Red Rock Coal Co.	Red Rock	Melcher	Marion	20.3	9.6	2.9	9,865	12.2	3.7	12,457
A5	Midwest Coal Co.	Rex No. 5	Consol	Monroe	18.3	8.9	2.6	10,392	10.9	3.2	12,720
A6	Midwest Coal Co.	Rex No. 4	Miami	Monroe	20.1	12.6	4.5	9,489	15.8	5.7	11,888
A7	Pershing Coal Co.	Mine No. 12	Tracy	Marion	20.0	8.8	1.6	10,127	11.0	2.1	12,648
A8	McConville Coal Co.	North No. 1	Dennis	Appanoose	16.5	8.3	4.0	10,670	9.9	4.8	12,780
A9	McConville Coal Co.	West No. 2	Brazil	Appanoose	17.7	7.5	4.2	10,631	9.1	5.0	12,910
A10	McConville Coal Co.	Mine No. 3	Midway	Appanoose	18.3	8.6	3.7	10,415	10.5	4.5	12,750
A11	Shuler Coal Co.		Waukee	Dallas	18.7	12.4	3.8	9,847	15.2	4.7	12,111
A12	Sunshine Coal Co.	Sunshine No. 1	Brazil	Appanoose	17.2	9.4	4.0	10,425	11.3	4.8	12,592
A13	Sunshine Coal Co.	Sunshine No. 2	Centerville	Appanoose	17.4	13.2	4.6	9,830	16.0	5.6	11,900
A14	Sunshine Coal Co.	Sunshine No. 3	Centerville	Appanoose	17.1	17.0	4.0	10,152	13.2	4.9	12,246
A15	Norwood-White Coal Co.	Herrold No. 8	Herrold	Polk	16.8	11.7	4.3	10,242	14.1	5.2	12,310
A16	Central Iowa Fuel Co.	Williamson No. 4	Williamson	Lucas	19.1	9.9	3.4	10,140	12.2	4.2	12,533
A17	Scandia Coal Co.	Madrid No. 4	Madrid	Dallas	15.8	10.3	4.8	10,510	12.2	5.7	12,843
A18	Keating Coal Co.	Penn Mine	Rector	Marion	15.3	8.8	3.5	10,940	10.3	4.1	12,910
				Mean values..	17.9	10.0	3.5	10,243	12.2	4.3	12,512

Table II. Composition of Face Samples, Iowa Coals, B Series

Lab. No.	Producer	Location	County	Moisture	Percentages, As Received Basis			Vol. Matter	Fixed Carbon	Ash Fusion Temperature Deg. F.	Percentages, Dry Basis			Unit B.t.u.	Volatile Matter	Fixed Carbon	Coal Ignition Temperatures Deg. F.
					Ash	Sulfur	B.t.u.				Ash	Sulfur	Dry B.t.u.				
B1	Nodaway Coal Co.	Nodaway	Adams	21.7	14.6	5.2	8,884	29.6	34.1	2,100°	18.6	6.6	11,300	14,380	37.8	43.6	257°
B2	Pearson Coal Co.	Clarinda	Page	19.5	15.3	4.1	9,058	31.5	33.7	2,080°	19.0	5.1	11,250	14,330	39.2	41.8	282°
B3	Sims & Wymore Coal Co.	Hepburn	Page	21.3	16.2	3.1	8,832	30.4	32.1	2,250°	20.6	4.0	11,220	14,580	38.5	40.9	279°
B4	Empire Fuel Co.	Centerville	Appanoose	19.4	9.3	3.3	10,110	32.4	39.0	2,082°	11.5	4.2	12,550	14,470	40.0	48.5	284°
B5	Scandia Coal Co.	Madrid	Boone	16.2	13.8	4.5	9,882	30.9	39.1	2,212°	16.5	5.4	11,800	14,550	36.9	53.4	302°
B6	Penn Coal Co.	Knoxville	Marion	19.1	9.5	5.0	10,150	32.9	38.5	2,165°	11.8	6.2	12,550	14,590	40.7	47.5	291°
B7	Rowley Coal Co.	Munterville	Wapello	15.5	12.3	4.1	10,440	33.8	38.4	2,175°	14.6	4.8	12,350	14,840	40.0	46.4	307°
B8	Hawkeye Coal Co.	Blakesburg	Wapello	14.1	17.2	5.5	9,890	33.0	35.7	2,260°	20.0	6.4	11,510	14,940	38.5	41.5	284°
B9	Smoky Hollow Coal Co.	Albia	Monroe	19.2	12.1	3.9	9,780	30.0	38.7	2,255°	15.0	4.8	12,100	14,610	37.0	48.0	282°
B10	Centerville Coal Co.	Centerville	Appanoose	16.9	9.7	3.6	10,400	32.0	41.4	2,195°	11.7	4.3	12,520	14,470	38.4	49.9	286°
B11	Columbus Coal Co.	Centerville	Appanoose	16.0	10.2	5.0	10,460	32.8	41.0	2,200°	12.2	5.9	12,450	14,530	39.0	48.8	284°
B12	Central Fuel Co.	Chariton	Lucas	18.1	14.6	7.0	9,546	27.6	39.7	2,195°	17.9	8.5	11,660	14,790	33.7	48.4	304°
B13	Riggins Coal Co.	Harvey	Marion	19.0	11.1	3.6	9,989	32.3	37.6	2,145°	13.7	4.4	12,330	14,630	40.0	46.3	288°
B14	Oskaloosa Coal Co.	Oskaloosa	Mahaska	17.3	10.2	5.4	10,370	33.4	39.1	2,220°	12.3	6.5	12,540	14,710	40.4	47.3	295°
B15	Schaffer Coal Co.	Bussey	Marion	18.0	12.1	4.4	9,955	31.3	38.5	2,255°	14.8	5.3	12,140	14,650	38.2	47.0	300°
B16	Bennett Coal Co.	Des Moines	Polk	15.7	15.0	6.1	9,782	31.0	38.3	2,205°	17.8	7.2	11,600	14,630	36.8	45.4	291°
B17	Urbandale Coal Co.	Des Moines	Polk	18.8	10.5	5.3	10,110	33.1	37.4	2,140°	13.0	6.5	12,440	14,710	40.9	46.1	288°
B18	Boone Coal Co.	Boone	Boone	20.4	13.9	6.5	9,138	29.7	36.3	2,155°	17.4	8.2	11,480	14,430	37.3	45.3	293°
B19	Helsing Bros. Co.	Hartford	Warren	15.4	12.5	5.9	10,250	33.6	38.5	2,175°	14.8	7.0	12,110	14,670	39.7	45.5	275°
B20	Banner Coal Co.	Indianola	Warren	15.9	10.6	5.0	10,500	36.0	37.5	2,290°	12.6	6.0	12,480	14,660	42.7	44.7	291°
B21	Pershing Coal Co.	Pershing	Marion	18.3	10.2	2.9	10,240	29.5	42.0	2,085°	12.5	3.5	12,530	14,600	36.1	51.4	288°
B22	Benson Coal Co.	Boone	Boone	19.5	9.7	5.5	9,818	31.5	39.4	2,140°	12.0	6.8	12,200	14,240	39.1	48.9	291°
B23	Beck Coal Co.	Fort Dodge	Webster	24.8	9.6	5.9	8,996	30.1	35.5	2,245°	12.8	7.8	11,950	14,120	40.0	47.2	293°
B24	McGuire Coal Co.	Fairfield	Jefferson	16.2	16.0	7.4	9,438	28.7	39.0	2,275°	19.1	8.8	11,260	14,510	34.3	46.6	...
			Mean values..	18.1	12.4	4.9	9,832	31.5	37.9	2,187°	15.1	6.0	12,013	14,568	38.5	46.4	287°

As pointed out above prepared domestic grades should be distinctly better in quality than the coal as it lies in the seam. It is difficult to estimate closely the degree of improvement but if we assume an air-drying moisture reduction of only five per cent from the mean value in Table II the thermal value would be raised from 9,832 to 10,350, which may be accepted as the average heat value of Iowa domestic coal delivered to the consumer. It is obvious of course that higher values are obtained from those operations where high intrinsic coal quality is combined with especially careful preparation.

Iowa Screenings or Steam Coals

For a period of nearly five years all coal shipments to the University Heating Plant have been sampled and analyzed by a staff of chemists under the general supervision of the author. During this time a large amount of data has accumulated not only on the quality of Iowa screenings, which constitute the major portion of the receipts, but on many from Illinois, Indiana and Kentucky.

To a greater extent than in the case of prepared domestic coal the quality of screenings or "steam coal" depends upon methods of mining and preparation, in fact upon the plane of engineering standards that prevail in the mine and at the tipple. All roof and floor rock below the screen size, usually 1½ in., sent up from the mine together with fine mineral sizes from cleavage planes and thin partings are included in this fraction. Moreover the coal fines resulting from breakage due to normal handling, popularly dubbed "bug dust," are present in varying amounts and purities to add to the difficulties of the boiler plant operator who fires it.

The tabulation that follows is based upon the results of analysis of 870 cars received between September 1, 1932 and July 1, 1933. It should be noted that as a result of long wall mining employed in Appanoose County in which no powder is used the amount of screenings produced is small and most of the steam coal shipments from this area therefore, were crushed run-of-mine. The screenings actually produced however are high in ash content due to the fact that the undercutting machine works in the shale underlying the seams and produces a mass of refuse highly non-combustible in character. It is obvious from the figures of Table III that much of the steam coal sent out from Iowa mines is high in ash, much of which could be separated mechanically by cleaning processes. We have discussed in another section of this bulletin the general principles of coal cleaning and merely observe here that it seems probable that the market for a considerable part of the screenings produced will be limited to areas of fairly short radius from the mining centers unless or until means are taken to improve them by removal of excess mineral and dust.

Distribution of Ash in Coal Fines

Second in importance only to the ash content of a steam coal is the size and uniformity of the particles composing its mass. Regardless of the types of stoker equipment employed a free and uninterrupted draft through the fire bed must be maintained and this is completely possible only when the coal as fired is at least moderately free from excessively

Table III. Average Compositions of Iowa Steam Coals

Mine Reference Number	County	No. of cars	Moisture per cent	Ash per cent	Sulfur per cent	Thermal value	Classification
1	Appanoose	17	17.2	16.7	4.3	9295	Mixed crushed
2	"	59	17.3	14.6	4.6	9544	Run and screenings
3	"	9	17.5	14.0	4.3	9694	Run and screenings
4	"	2	16.6	20.8	5.0	8773	Screenings
5	"	13	17.0	14.3	4.5	9803	Mixed
6	"	21	16.8	12.5	4.4	10049	Mixed
7	"	42	16.8	14.4	4.4	9717	Mixed
8	Boone	3	16.8	19.7	5.0	8869	Screenings
9	"	6	15.9	17.9	4.7	9318	Screenings
10	Dallas	2	18.4	18.3	3.4	8904	Screenings
11	"	76	17.7	14.3	3.3	9628	Screenings
12	"	118	17.1	17.2	4.7	9266	Screenings
13	Mahaska	79	16.0	11.9	5.3	10232	Crushed run
14	Marion	135	17.0	15.8	4.2	9526	Screenings
15	"	45	19.3	14.0	3.0	9475	Screenings
16	"	2	20.0	17.5	4.5	8838	Screenings
17	"	112	18.3	13.4	5.1	9626	Screenings
18	"	10	19.3	13.5	4.1	9558	Screenings
19	Monroe	1	19.6	15.1	3.3	9326	Screenings
20	"	18	15.7	16.3	5.1	9643	Screenings
21	"	1	17.5	20.5	5.5	8728	Screenings
22	"	76	16.9	16.9	4.4	9321	Screenings
23	Polk	21	15.5	16.3	5.4	9666	Screenings
24	Warren	2	15.6	15.7	5.0	9648	Screenings

small fines or bug dust. The problem of handling it on the stoker is made more difficult when the fines become segregated in handling and a draft setting suitable for a mass of coarse material suddenly becomes inadequate to care for a slug of dust. Removal of this dust at the tipple has been frequently urged by engineers as an economy measure to raise the combustion efficiency of the fuel as a whole.

While the percentage of extremely fine dust in the screenings is fairly large in many cases and its rejection would entail some loss in tonnage, ash contents are invariably higher than the average of the whole and net losses would therefore be more apparent than real. The ideal solution of the problem would perhaps involve a cleaning process to remove the major part of the mineral matter which is distinctly heavier than the coal dust. On this point Mr. John M. Drabelle(4) of the Iowa Electric Light and Power Company says, "I believe that a material improvement could be made by some form of dry pre-treatment to remove the fines without raising the hazard of winter freezing."

In Table IV are presented the results of two series of sieve analyses of Iowa screenings from different localities showing weight percentages within given size ranges and the ash percentage of each. It is apparent from the mean values of the first set of data that the portion passing the

Table IV. Results of Sieve Tests on Typical Iowa Screenings

(All Percentages on Dry Basis)

SERIES I

Reference Number	Mine	County	A		B		C		D	
			Wt. per cent	Ash per cent	Wt. per cent	Ash per cent	Wt. per cent	Ash per cent	Wt. per cent	Ash per cent
			above .185 (4 mesh)		.185 to .093 (8 mesh)		.093 to .046 (16 mesh)		through .046	
591	Waukee	Dallas	71.8	22.3	9.8	22.8	5.7	21.2	12.7	26.7
683	Waukee	Dallas	84.0	18.5	6.2	24.2	3.4	26.6	6.7	31.4
582	Dennis	Appanoose	76.7	14.6	9.2	25.0	5.0	25.6	9.2	35.3
661	Dennis	Appanoose	76.6	13.4	8.6	15.5	5.4	20.8	9.3	27.4
681	Dennis	Appanoose	89.0	9.4	5.1	14.3	2.6	20.0	3.4	26.2
775	Dennis	Appanoose	88.6	11.2	4.0	19.0	2.8	23.4	4.7	28.0
581	Herrold	Polk	76.5	21.4	9.9	24.0	4.8	25.4	9.0	30.0
633	Herrold	Polk	69.7	19.0	11.6	19.0	6.6	20.6	12.1	25.5
659	Herrold	Polk	58.3	23.1	13.4	18.7	9.8	20.7	18.5	25.0
587	Rex No. 4	Monroe	72.2	16.1	11.2	16.2	5.9	17.2	10.8	21.2
618	Rex No. 5	Monroe	63.0	19.1	12.9	19.7	8.1	21.9	16.0	27.9
636	Rex No. 5	Monroe	60.5	17.8	14.6	16.7	8.4	20.4	16.1	24.9
649	Rex No. 5	Monroe	53.0	20.7	16.2	21.3	10.7	22.0	20.1	27.2
648	Rex No. 5	Monroe	40.0	19.8	19.0	21.2	14.5	22.3	26.2	26.7
666	Rex No. 5	Monroe	59.8	19.5	16.4	19.1	7.1	21.8	16.7	25.2
667	Rex No. 5	Monroe	66.0	17.4	13.5	19.6	7.0	20.0	13.5	26.2
634	Moran	Dallas	65.7	18.0	12.2	19.0	7.7	22.0	14.4	23.8
655	Orillia	Warren	52.0	23.4	16.3	20.0	10.5	23.2	21.1	26.3
656	Tracy	Marion	81.3	17.4	7.0	20.1	4.1	22.6	7.6	26.4
680	Tracy	Marion	88.2	15.6	4.4	17.7	2.7	21.3	4.8	27.0
688	Tracy	Marion	66.0	17.9	12.9	21.0	7.5	24.8	13.4	27.7
669	Madrid	Boone	70.5	18.5	11.3	22.0	6.9	23.8	11.5	27.2
751	Madrid	Boone	58.4	21.6	14.2	24.6	9.1	26.8	18.3	32.9
		Mean values	72.1	18.0	11.3	20.0	6.8	22.3	12.8	27.2

Table IV—Continued

SERIES II

Screen Size	Avery Mine, Monroe County		Dennis Mine, Appanoose County		Herrold Mine, Polk County	
	Wt. per cent of fraction	Ash Content of fraction	Wt. per cent of fraction	Ash Content of fraction	Wt. per cent of fraction	Ash Content of fraction
— 100 mesh	1.16	34.15	2.20	33.75	1.56	27.15
40 x 100	1.45	33.25	3.35	32.80	4.86	31.80
20 x 40	1.39	30.80	4.88	31.35	4.68	31.18
8 x 20	3.50	26.75	14.39	26.63	12.89	24.34
3/16 x 8 mesh	5.85	22.80	15.79	17.85	14.10	25.77
⅜ x 3/16	11.45	21.19	23.39	16.28	18.95	21.78
¾ x ⅜	24.20	18.25	25.60	13.41	10.13	17.64
1½ x ¾	50.40	17.37	10.40	11.67	32.83	23.23

Table V. Fusion Points of Screenings Ash

State	County	Number of samples	Mean fusion points Degrees F.
Iowa	Appanoose	15	2106°
Iowa	Mahaska	11	2125°
Iowa	Monroe	16	2112°
Iowa	Dallas	5	2032°
Iowa	Marion	9	2112°
Iowa	Polk	6	2080°
	Weighted mean		2130°
Indiana	Buckskin	2	2230°
Indiana	Gibson	2	2185°
Kentucky	Hopkins	4	2141°
Illinois	Henry	4	2074°
Illinois	Saline	3	2258°

16 mesh sieve, 12.8 per cent by weight, is highly undesirable not only because of its fineness but by reason of its high ash content. The second set shows clearly the high percentage of mineral in the dust, which is mainly the portion separated as sludge in the coal washing process. We may say parenthetically that from this sludge a 50 per cent yield of coal of low ash content can be recovered leaving a secondary sludge of more than 50 per cent ash to be rejected. Whether highly mineralized screenings could be more economically consumed in the powdered form remains to be proved; while there is little doubt that they could be burned effectively and completely the opinion prevails that the wear on the pulverizing machinery would be unduly great and that the fly ash problem would be much aggravated. Work on the grindability of Iowa coals is in immediate prospect and from the results we hope to obtain data from which costs of pulverizing these coals for dust combustion may be estimated. Ash fusion points of typical Iowa screenings from the principal producing centers of the state are given in Table V.

Heat Content in Relation to Coal Price

This discussion of Iowa coal quality would fail in its major purpose if no mention were made of its value to the consumer as a producer of heat and of its adaptability to the firing equipment in general use. We

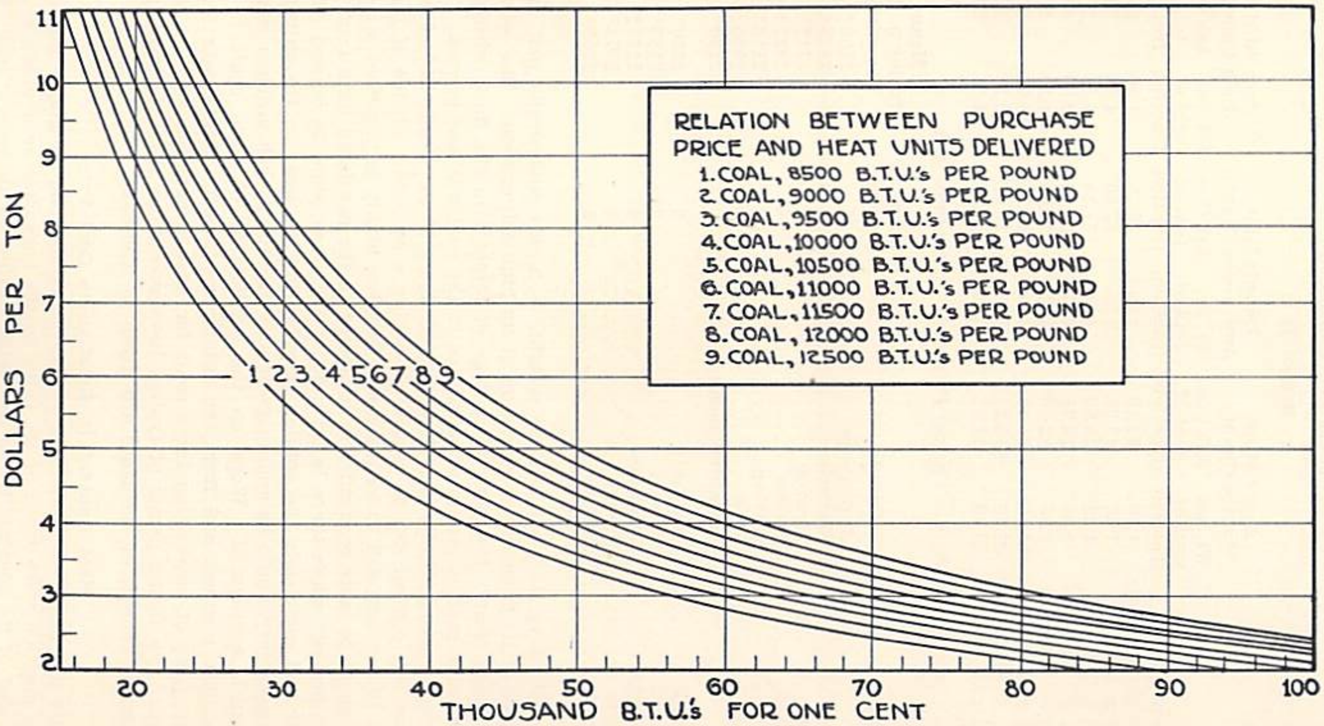


FIGURE 1—Heat Cost Curves

have always maintained that the majority of Iowa consumers of domestic coal who seek primarily the greatest possible returns in heat value, can be most economically served by the prepared coals produced within the state. It is clear that those who demand the luxury service that only oil, gas, coke or certain hard clean-burning coals of the Appalachian fields can furnish are asking for more than mere thermal energy; they seek a convenience of firing and a cleanness of handling that none of the midwest coals can supply with the equipment in common use. Such fuels are of course always available and as living standards go up their use will expand. But for the consumer interested primarily in thermal content the longer freight hauls from distant producing centers tend to raise costs beyond the economic limit.

The point under discussion is shown graphically by Figure 1 wherein the cost per ton of coals ranging in heat value from 8,500 to 12,500 B.t.u.'s per pound is set against the number of heat units obtained for one cent. To illustrate its use let us say that at southern Minnesota and Dakota points eastern "dock" coal of 12,500 B.t.u.'s coming by way of Duluth sells at $11.00 per ton. Reference to the proper curve shows the consumer receives 23,000 B.t.u.'s for a cent. But Iowa coal (assumed to rate 10,500 B.t.u.'s but possibly better because of the drying conditions of the box car shipment) at $7.50, the prevailing price, provides 30,000 units for the same money. In eastern Iowa competition is more severe because of the proximity of the Illinois and Indiana fields and perhaps most of the Mississippi River points find out-of-state coals the cheaper. But even in this neutral zone the balance may still be favorable to the home product. At Cedar Rapids, for example, Franklin County, Illinois, domestic grades with thermal values of 12,000 to 12,200 and priced at $8.25 yield 29,000 B.t.u.'s or less for a cent; Iowa coal retailing for $7.00 is seen to provide nearly 30,000. Comparisons made at places further west nearer the Iowa producing regions show, of course, a convincing advantage in favor of the Iowa fuel.

The reason for this sharply rising scale of costs is obvious. Coal, like brick and cement is a "heavy" commodity whose delivered price is vitally affected by costs of transportation since on long hauls the freight charges often far exceed the price of the coal at the tipple. It follows therefore, that only exceptionally high intrinsic quality can economically justify long shipment into other coal producing territory and that the balance between such merit and the net cost of the delivered fuel should receive careful consideration.

It should be recognized especially that the major difference between the so-called "quality" coals coming from the east and the general run of mid-west bituminous coal, assuming of course that the ashy material has been reduced to the economic minimum in each case, is that of volatile matter. But the volatile constituents that ordinarily cause smoke and soot formation are in themselves fuels of high thermal content and if completely burned are valuable components of the coal. Indeed some of the Eastern low volatiles are distinctly lower in heat content than the good high volatiles.

A fair illustration of the combustion requirements for volatile matter may be taken from the case of petroleum fuels. Any of the middle fractions commonly used as fuel oils or even many of the crudes if burned without carefully controlled atomizing and air mixing form heavy black smokes (witness the results of oil well fires) but when properly fired produce a clean steady flame.. On the same principle the modern mechanical coal stoker by use of a continuous feed and a constant and adequate air supply brings about the combustion and profitable utilization of the rich hydrocarbons that under inefficient firing are worse than wasted. The public attitude toward antiquated methods and equipment is rapidly becoming more critical. Not more than half a century ago many of the large cities of the world disposed of sewage in open street gutters; the change in public opinion that brought reform in this matter will doubtless soon control the discharge of smoke sewage into the open air. In the measure that such change is brought about will much of the quality advantage of Eastern coals be flattened out and Western producers may well turn their attention to promoting the use of firing devices that will burn their product to the best advantage.

Sources of Coal Studied

In the course of these studies which have extended over many years practically all the Iowa producing centers of any importance have been covered either by face sample analysis or by tests of commercial shipments. In this period mines that once were important producers have been worked out and closed and others have been brought in. The State Mine Inspector's report for 1935 shows that within the year 414 mines in 25 counties were in operation for varying lengths of time. It would indeed be a large task to survey them all.

Figure 2 indicates the locations of the shipping points and mines from

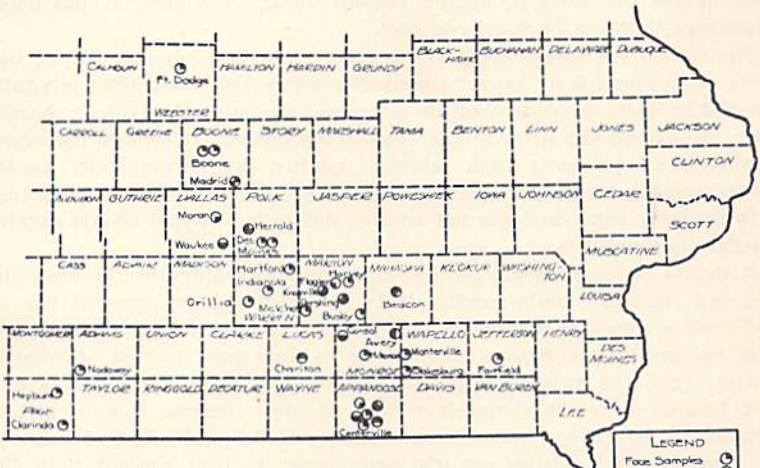


FIGURE 2—Sources of Coals; University of Iowa Studies

which the coals discussed in this report were received. The legend shows in simple code the nature of the tests to which the particular samples from the localities indicated were subjected. These are explained in detail in the pages following and it will be sufficient to say here that the shading of the first quadrant of the circle indicates that a face sample was taken directly at the mine and that a report of its chemical analysis appears either in Table I or Table II. A second quadrant spot designates the location of a mine from which 1½ inch screenings samples were selected for sieve analyses. In this case the coal was separated into five classes according to screen size ranging from 1½ inch to minus 20 mesh and each subjected to float and sink tests. The third quadrant shading locates the origin of shipments put through machine washing tests; the fourth, commercial screenings given float and sink tests on the overall sample without sieve classification (Table VII).

STUDIES IN THE WASHING OF IOWA COAL

The beginnings of coal washing date back more than a century to continental Europe where the first machines used were crude devices patterned after those employed in ore concentration and designed to improve the quality of the finer grades of certain friable coals that carried high mineral fractions. The bare fact that after a hundred years the art of coal washing is still so relatively little practiced in spite of apparent need is internal evidence that coal preparation like every other human activity is subject to the laws of inertia and that reform comes only in response to the pressure of insistent demand. Among the first to apply such pressure were the iron smelters in their effort to improve their furnace coke and in the years that followed other industries fell into line; but even up to the present as a modern fuel engineer(5) observes, "the practice of washing is regarded as a troublesome and expensive operation."

In all fairness to the coal producers however, it must be recognized that economic considerations determine the final course of action and that profit from extra pains taken in preparation must accrue to the producer as well as to the consumer if the practice is to survive. As a summation of 70 years of evolution in coal preparation Prochaska(5) in the introduction to his book, "Coal Washing," sets forth the following principles:

"The preparation of coal shall, by the cleaning of the raw material and the production of suitable and well screened sizes, secure a maximum price per ton of output."

"To arrive at this result three points must be kept in view: (a) highest possible purity of coal; (b) smallest possible loss of coal; (c) low cost of production."

"As the foregoing three demands are conflicting, it will be necessary for the proper and economical installation of a preparation plant to find in each case the best relation between the three factors."

From the consumer's standpoint the disadvantages of the presence of excessive mineral in the coal are easily catalogued. (1) Incombustible matter reduces the gross heat value; (2) it increases the weight of material per unit of heat that must be handled and transported; (3) it interferes with the processes of combustion and renders less available the heat actually generated; and (4) it increases the grate losses through escape of unburned fuel substance.

The truth of the first and second observations is readily seen since the mineral matter is an inert waste that not only contributes nothing to the heat value of the fuel but adds to its dead weight. Its deleterious effect upon the combustion process while not so obvious has nevertheless been amply proved by carefully controlled tests in the boiler plant. Perhaps the most widely quoted are the results of Abbott(6) of the Commonwealth Edison of Chicago who studied the effects of varying amounts of ash in the fuel upon the evaporation efficiencies and the horsepower generated with a given unit, and from these results estimated the relative value of the fuel. Assuming an Illinois coal of 12 per cent ash to have a base value of 100 he concluded that a coal with 40 per cent ash as shown in Figure 3 was entirely valueless, not of course, because no fuel

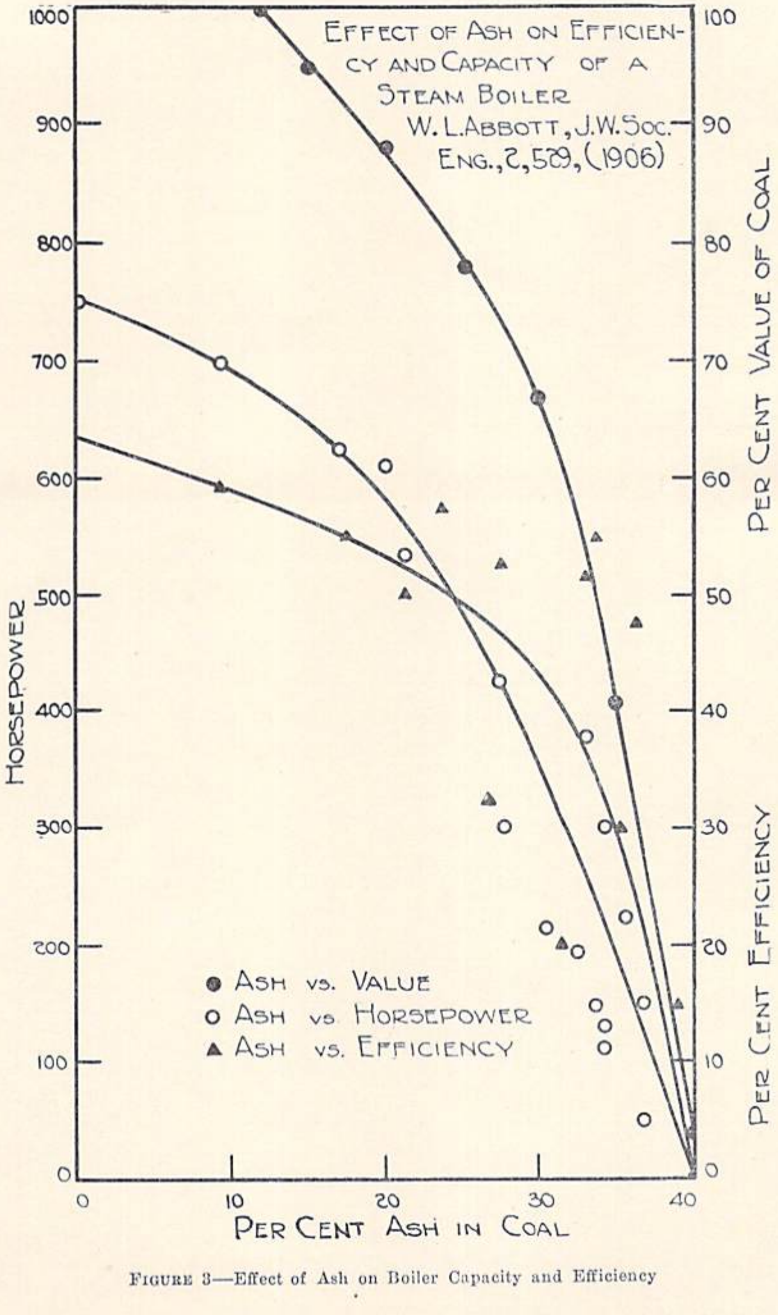


FIGURE 3—Effect of Ash on Boiler Capacity and Efficiency

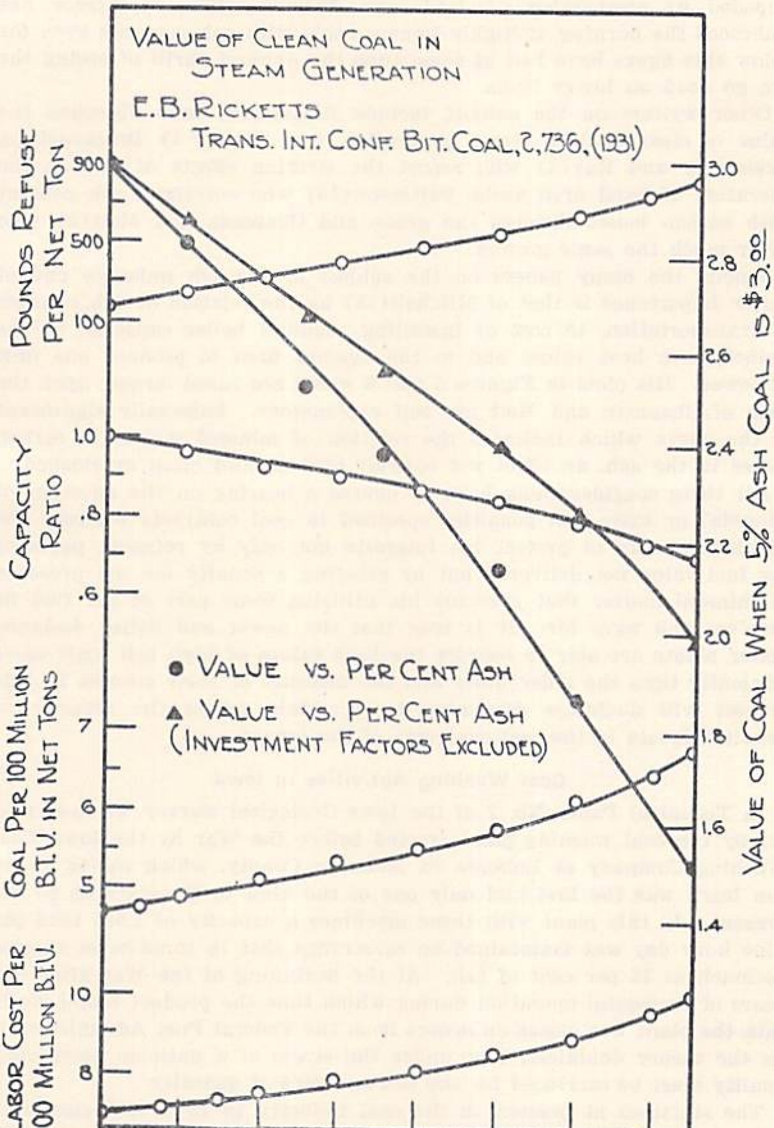


FIGURE 4—Coal Ash vs. Boiler Operation

was present in the mixture but because the mass of mineral effectively impeded its combustion. Indeed most firemen whose experience has embraced the burning of highly impure coals with ash contents even far below this figure have had at some time the dubious thrill of seeing the fire go dead on heavy loads.

Other writers on the subject include Ricketts(7) who discusses the value of clean coal in steam generation (see Figure 4) Breckenridge, Kreisinger and Ray(8) who report the striking effects of ash on the operation of hand fired units, Patterson(18) who correlates ash content with carbon losses through the grate, and Chapman and Mott(9) who cover much the same ground.

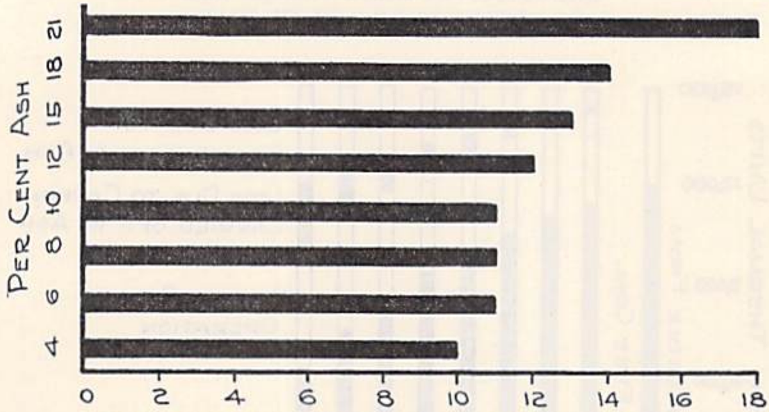
Among the many papers on the subject of the ash nuisance one of major importance is that of Mitchell(19) on the relation of ash to costs of transportation, to cost of installing required boiler capacity, to the reduction in heat values and to the amount fired to produce one unit of power. His plots in Figures 5 and 6 which are based largely upon the data of Chapman and Mott are self explanatory. Especially significant is the curve which indicates the relation of mineral matter to carbon losses in the ash, an effect not entirely obvious and often overlooked.

All these considerations have of course a bearing on the question of "double" or extra ash penalties specified in coal contracts whereby the purchaser seeks to protect his interests not only by refusing payment for fuel value not delivered but by exacting a penalty for the presence of mineral matter that prevents his utilizing some part of the fuel he receives and pays for. It is true that the newer and better designed boiler plants are able to convert the heat values of high ash coals more efficiently than the older units and the measure of their success in this respect will doubtless determine to a certain extent the severity of penalty clauses in the coal contracts of the future.

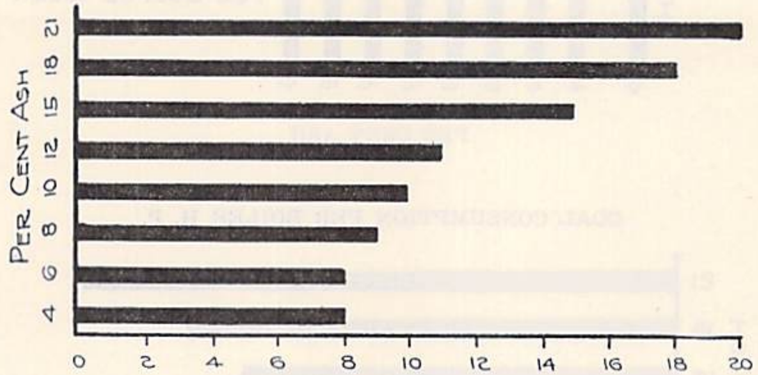
Coal Washing Activities in Iowa

In Technical Paper No. 2 of the Iowa Geological Survey we described briefly the coal washing plant erected before the War by the Iowa Coal Washing Company at Lakonta in Mahaska County, which so far as we can learn was the first and only one of the kind in the state up to the present. In this plant with three machines a capacity of 1,000 tons per nine hour day was maintained on screenings that in some cases carried as much as 35 per cent of ash. At the beginning of the War after five years of successful operation during which time the product found ready sale, the plant was closed on orders from the Federal Fuel Administrator, on the theory doubtless, that under the stress of a national emergency quality must be sacrificed for the last measure of quantity.

The situation at present in the coal industry in Iowa and elsewhere indicates a buyer's market except so far as Federal control has restricted free competition. Not only has the world business depression diminished the demand for fuel but competitive oil and gas have cut so deeply into the remaining business that the coal buyer has developed a keen sense of discrimination. The coal deposits of southern Illinois and Kentucky are of such a nature as to make the production of clean coal of all sizes easily possible with but little special preparation, while producers in



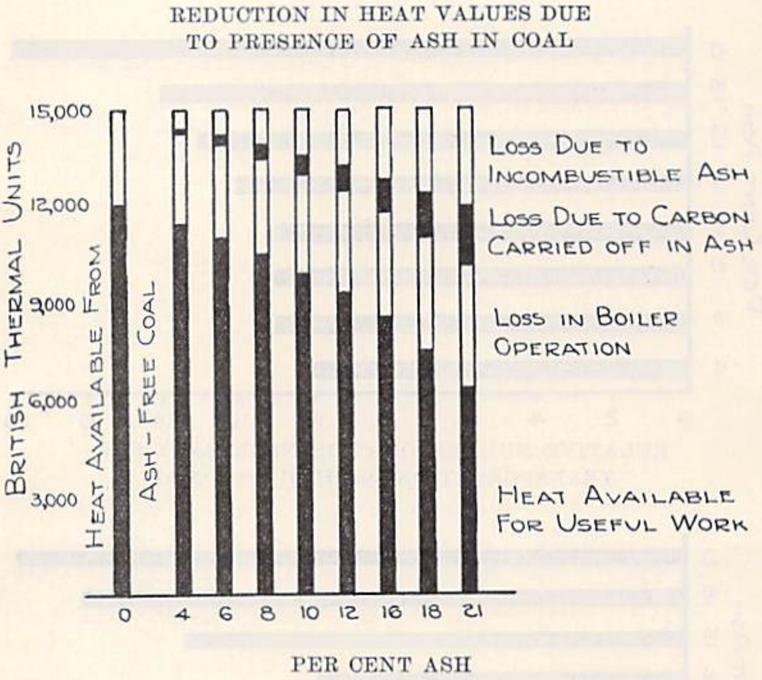
RELATIVE NUMBER OF CARS NECESSARY FOR TRANSPORTATION OF HIGH ASH COAL



NUMBER OF 500 H. P. BOILERS REQUIRED TO GENERATE 300,000 POUNDS OF STEAM PER HOUR

FIGURE 5—The Significance of Mineral Matter in Coal

central and northern Illinois, with coals naturally no better than those of Iowa, by the use of washing machinery are putting out products of high purity. It is obvious that with such competition the market for local uncleaned steam coals must be limited more and more to points of short radius from the mine where freight differences are great enough to overcome the handicap of lower quality. All of these considerations however, are only a part of the complex problem of mining, preparing and selling coal in the face of besetting difficulties, a problem that is basically economic in nature. Before it can be satisfactorily solved its technical aspects must be worked out and among these the question of the degree to which the cleaning of given coals can be theoretically car-


REDUCTION IN HEAT VALUES DUE TO PRESENCE OF ASH IN COAL

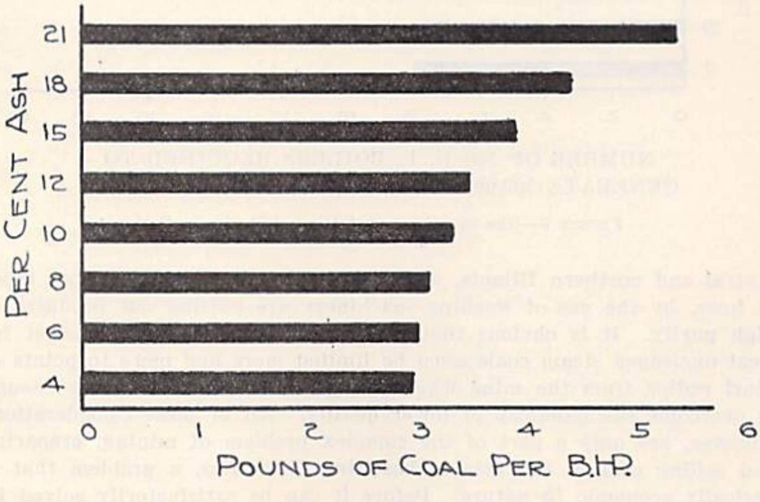

COAL CONSUMPTION PER BOILER H. P.

FIGURE 6—The Significance of Mineral Matter in Coal

ried is of major importance. It is to this phase of the work that the facilities of the University coal research laboratories have been mainly devoted for the last half decade and the results are published here in the hope that they may be of use at this time when interest in coal cleaning is steadily rising.

EXPERIMENTAL WORK

As an example of an elaborate and thorough survey for determining the potential washabilities of a coal we may cite the work of Callen and Mitchell(10) undertaken in 1928 at the University of Illinois on a number of typical mines in different parts of the state and reported in Bulletin No. 217 of the Engineering Experiment Station. To quote from the introduction, "the objects were, to select a few typical mines and study the occurrence and visible impurities in the coal and the nature of the roof and floor; to study the methods of mining, and determine what effect they had on the impurities in the mined coal; to secure adequate samples of the mined coal, and make reasonably complete study of the washability of these coals; to determine the amount and distribution of ash and the different forms of sulfur; to determine yields of washed coal, and the limits of the reduction of ash and sulfur percentages; to make some studies of the variation in fusion point of the ash of raw coal and washed coal."

With our more limited facilities we have been unable to duplicate in Iowa the ambitious program outlined above and have confined our work rather to making a survey of the washing possibilities of the coals from a few representative mines of the main producing areas of the state, which includes of course a study of ash and sulfur distribution and of net yields and losses of coal. The materials with which we worked were classified under three heads viz.: face samples from 24 representative mines collected by members of the testing staff (See Table II); raw screenings from regular shipments to the University heating plant, 2 inch and under, which were tested without rescreening; and regular commercial screenings that had been separated into 5 progressively smaller sizes, between 2 inch and 20 mesh respectively. The first series of tests was designed to provide significant information on the nature of the given coal as a unit mass regardless of screening operations that might precede washing; the second to furnish data on the cleaning of the screenings fractions only, a practice that would doubtless best meet the needs of the average Iowa producer; and the last, much more elaborate in scope since five fractions are involved, to establish variations in washability with size.

The standard procedure for obtaining a set of washability curves for a given coal involves, in simple, the immersion of a properly sized sample in a series of increasingly heavy liquids consisting of solutions of gasoline and carbon tetrachloride of varying proportions, as shown in Figure 7. If, for example, the first solution has a specific gravity of 1.3 the fractional part of the sample of lower gravity that floats is skimmed off and its weight recorded as 1.3 float. The sink portion is next transferred to a solution of gravity 1.4 and the process repeated until, say, a solution of gravity 1.6 is reached. The portion that sinks in this last medium is obviously waste matter while the float fractions from this and other cuts which may be included with the recovered fuel or not according to the standards set, are classified according to the gravity limits between which they are caught. Data from such measurements together with results of ash and sulfur analyses lend themselves easily to the plotting of curves to show relationships between contaminating minerals and specific gravities of the coal mass. Referring for example to Figure 8 a cut at gravity 1.4 separates a refuse fraction of 22 per cent by weight (reading the ordinate to the right) with an ash content of 43 per cent (reading the refuse curve marked R) while the recovery is 78 per cent, with sulfur and ash contents corresponding to the values read from curves S and A. Line D known as the ash distribution curve indicates the mean ash values of intermediate coal fractions. Thus the ash content of the cut between gravities 1.3 and 1.4 which is 11 per cent, is indicated by the point plotted second from the left. The use of these plots for the solution of practical problems is simple. Suppose that a product with a given ash maximum say 8 per cent, is demanded and that the problem involves determining the percentage of recovery that is possible with this condition. A line parallel with the X axis passing through the 8 per cent point on the A curve indicates at its intersections with the Y axis on the left the percentage of recovery and on the right the waste; intersections on the S, R and sp. gr. curves show the sulfur content of the clean coal, the ash content of the refuse and the specific gravity of the float liquid, respectively. In general by fixing the value of any one of these variables the rest are automatically set.

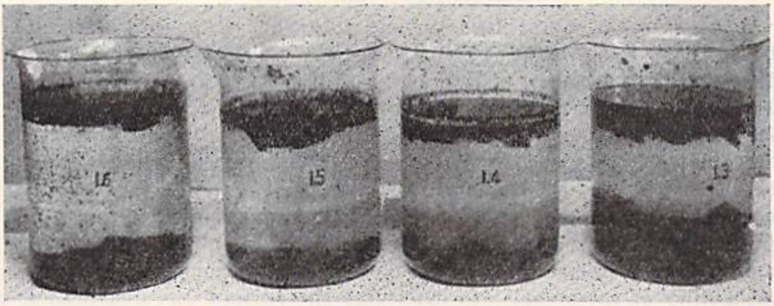


FIGURE 7—Float and Sink Apparatus

Float and Sink Tests on Mine Face Samples

The coals studied in the first series of tests were face samples collected by representatives of the University from 24 producing mines distributed over 13 counties of the state. These samples on arrival at our laboratory were broken down to a maximum of one inch in size and dried for 24 hours at room temperature. Representative portions were then subjected to float and sink tests as outlined above through solutions of successively increasing density and each fraction separated carefully analyzed for moisture, ash and sulfur. Results are shown in Table VI.

The figures submitted indicate in a comprehensive way the range of possibilities of washing these coals to a given quality standard since the percentages included within narrow specific gravity values are shown. Fortunately experience has proved that results obtained in practice with commercial machines run closely parallel with laboratory data of this kind so that the latter are definitely significant. Furthermore values for different coals vary sufficiently to show that each must be studied individually i. e. ash distribution is a property peculiar to a given seam.

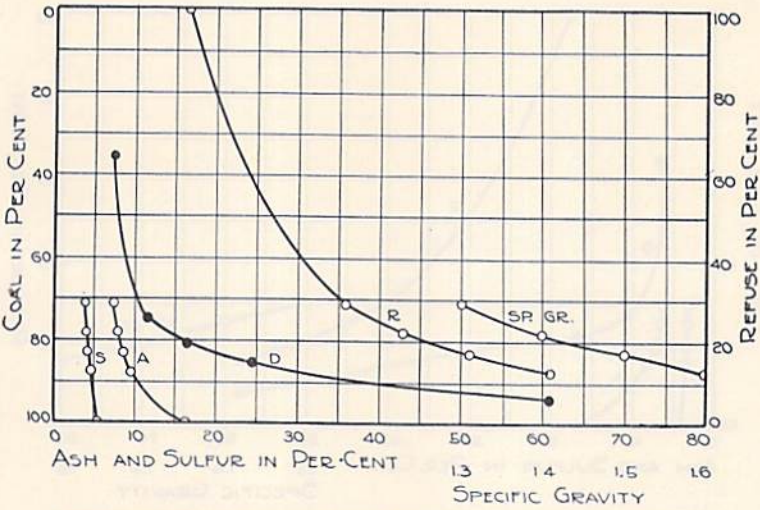


Figure 8—Washing Curves for Appanoose County Screenings (Dennis)

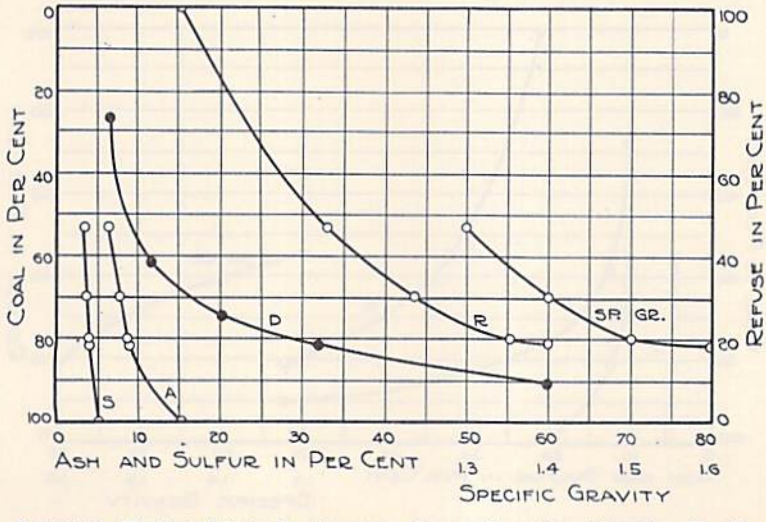


Figure 9—Washing Curves for Appanoose County Screenings (Sunshine No. 2)

Finally we have tabulated the grand averages of the 24 samples to give the mean results of the whole series. It may be seen from these calculated mean values that if the cut is made at gravity 1.5, 84.5 per cent of the raw coal will be recovered while 15.5 per cent goes to the refuse. Ash values are reduced from 15.1 per cent on the crude to 7.8 per cent on the cleaned fraction while the waste contains 49.4 per cent of ash which on the basis of 15.1 per cent of ash in the original coal represents a total removal of 50 per cent.

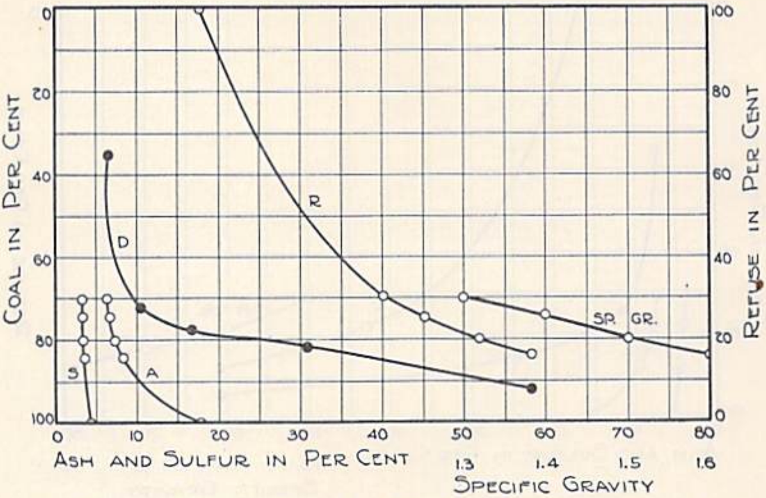


FIGURE 10—Washing Curves for Dallas County Screenings (Moran)

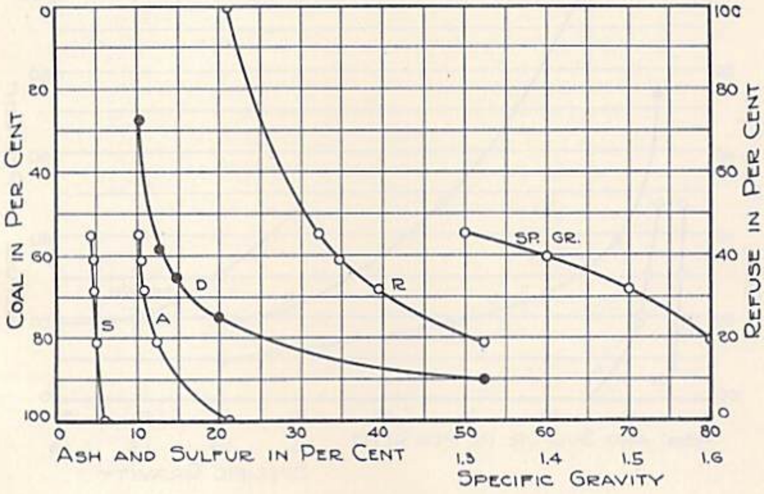


FIGURE 11—Washing Curves for Dallas County Screenings (Waukee)

Float and Sink Tests on Commercial Screenings

For the next series of tests results of which are shown in Figures 8 to 15 inclusive and tabulated in Table VII, samples were collected from shipments of screenings consigned to the University power plant, coming from nine different mines of five of the leading coal producing counties. Float and sink data on the screenings fraction are obviously important in estimating the improvements that may be made on the steam sizes as distinguished from those that go to the domestic market. Indeed current practice in adjoining states where washing is done embraces in

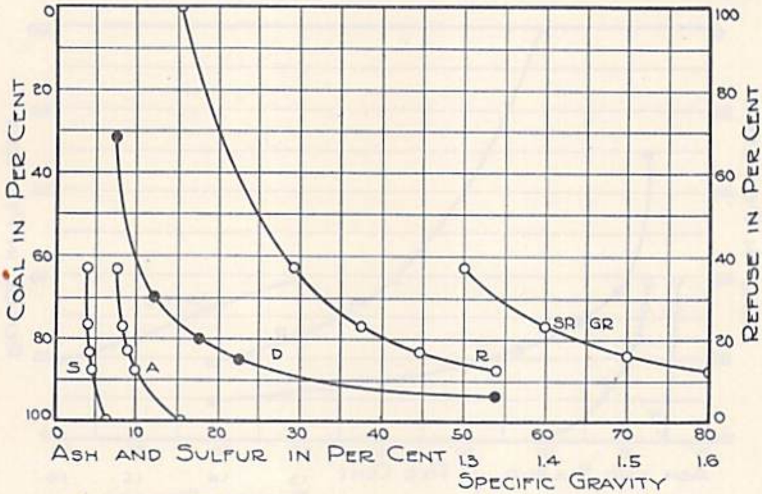


FIGURE 12—Washing Curves for Marion County Screenings (Penn)

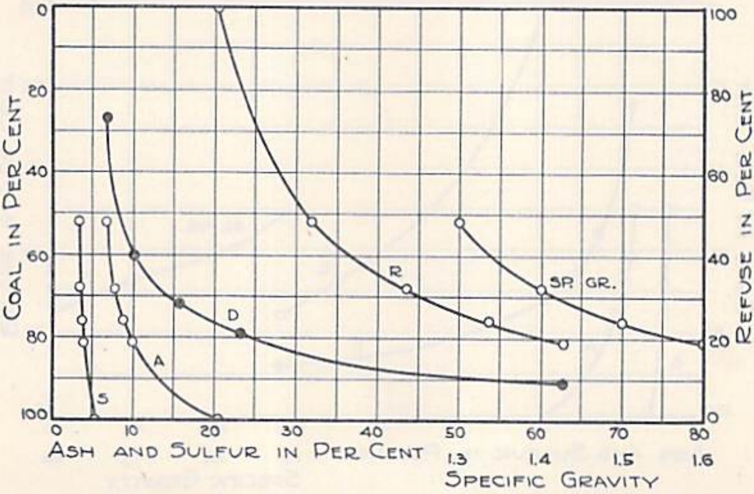


FIGURE 13—Washing Curves for Marion County Screenings (Pershing)

general the wash treatment of the smaller fractions only, with dependence upon hand picking for removal of impurities from the egg and lump. Rejects from these grades which almost invariably carry material quantities of fuel are then crushed and put through the washer to effect the final separation.

Average values calculated as before show that from raw screenings with 17.86 and 5.56 per cent ash and sulfur respectively, 76.84 per cent of marketable coal with 8.6 per cent ash and 4.2 per cent of sulfur is produced and that 23.13 per cent of refuse with 50.0 per cent ash and 10.7 per cent sulfur goes to the gob pile.

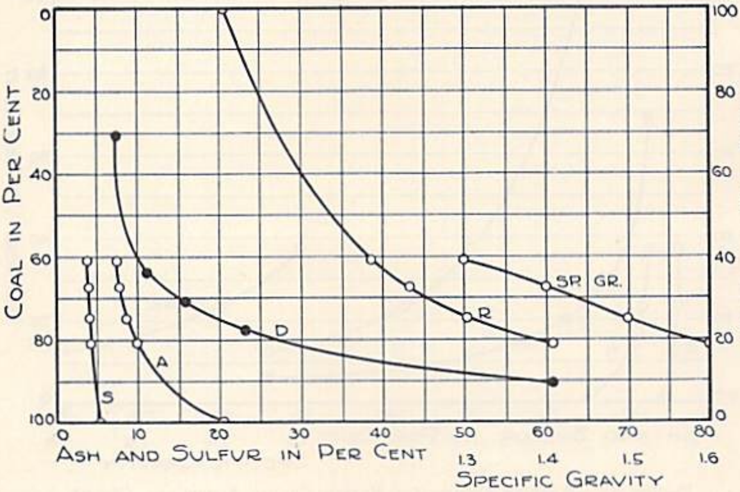


FIGURE 14—Washing Curves for Monroe County Screenings (Rex No. 5)

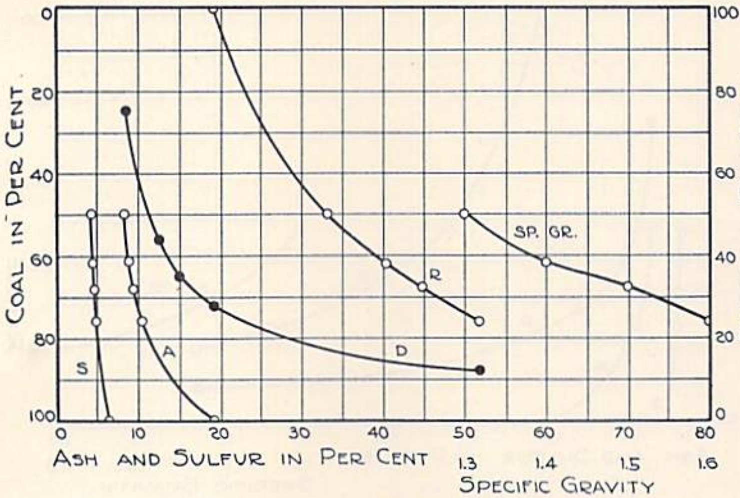


FIGURE 15—Washing Curves for Polk County Screenings (Herrold)

Referring again to the plots in Figures 8 to 15 from which the relationship between the gravity of the separating liquid and ash and sulfur values of the fractions may be read directly, it should be noted that the shape and slope of the specific gravity curve is especially significant in showing the washability of a given coal or fraction. A steep slope indicates that the densities of the different lumps or particles are nearly equal in value throughout the entire range with no definite line of demarcation between the product sought and the refuse discarded. Under such conditions large quantities of "middlings" will be produced, washed material of doubtful value, neither very good, nor bad enough to reject. On the other hand a flat gravity curve indicates that it is an easily washed coal made up mainly of a sharply differentiated mixture of clean and worthless material with only a small intermediate fraction. Judged by this criterion these screenings are all good washing coals since the gravity curve in each case has a fairly low slope. It may be seen for example that No. 8 is superior to No. 9 in this respect; in other words a smaller portion of the raw fuel must be rejected in the first case to yield a product of given ash than in the latter case.

Float and Sink Tests on Classified Screenings

In the final series, regular 1½ inch screenings from typical shipments were graded by means of a set of screens into five sizes ranging from 1½ inch down to 20 mesh and each fraction put through the float and sink process. This procedure which in effect constitutes an elaborate study of ash distribution according to size, indicates not only the location of the mineral matter but the relative ease or difficulty of its removal. Inspection of the data in Table VIII shows that with the lighter fractions ash percentages goes down with fineness of division but that in the case of the heavy portions the opposite is generally true.

Plots of these relationships are given in Figures 16 to 20. It should be noted in estimating the washing characteristics of the fractions studied that the significant portion of the specific gravity curve is limited by the points 1.3 and 1.6 and that the 1.2 point has theoretical interest only since no commercial cuts would be made at so low a figure. With this in mind the comparison of plots is simple since only relatively narrow sections need be considered. By way of further illustration the specific gravity curves of size 3/8 x 3/16 for the Monroe and the Polk Co. coals respectively, clearly indicate different degrees of washability.

Sulfur and Its Elimination

The element sulfur plays the parts of both hero and villain in the industrial drama. Through its acid derivatives on the one hand it takes an important place in the manufacture of many of the commodities of our material civilization, to such an extent, indeed, that its production curve is a ready indicator of general business conditions. In its injurious effects on the other hand as an omnipresent defiler of our coal and petroleum it merits the maledictions of a long suffering fuel industry; for damages to power generating equipment alone through the corrosive effect of these very derivatives mount annually to millions. In addition

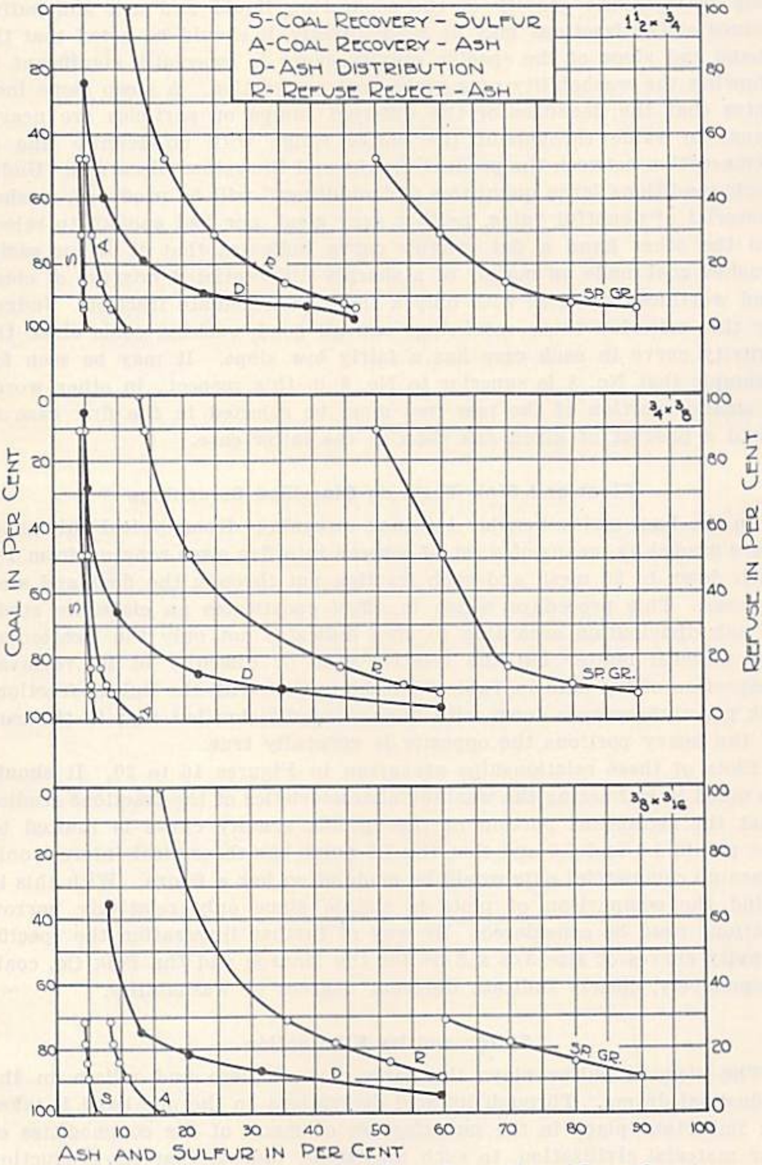


Figure 16—Washability Curves of Screen Fractions—Appanoose County Coal

to such damage the nuisance created by the pollution of the atmosphere with acid fumes from the stack is definitely real and in thickly populated areas it may become intolerable. Concretely, a plant burning daily 200 tons of a coal with 3.5 per cent of sulfur discharges into the air each hour more than a ton of sulfuric acid or its equivalent of sulfur dioxide. The coal technologist therefore is concerned with sulfur and its elimination not because it is too inert, as the ashy matter is, but because it is too active. The data presented in the foregoing tables and plots show unfortunately that no marked reduction in sulfur content may be expected from the application of washing processes to Iowa coals, a fact that is worthy of some comment.

Speaking in chemical terms, sulfur occurs in coal in three forms viz., as sulfates or salts of sulfuric acid usually compounded with lime as gypsum; as iron pyrites, the so-called "brasses"; and in organic form combined with the carbon and hydrogen of the coal substance itself. While the specific gravity of gypsum is roughly twice that of "pure" coal and its separation therefore theoretically easy this mineral is normally im-

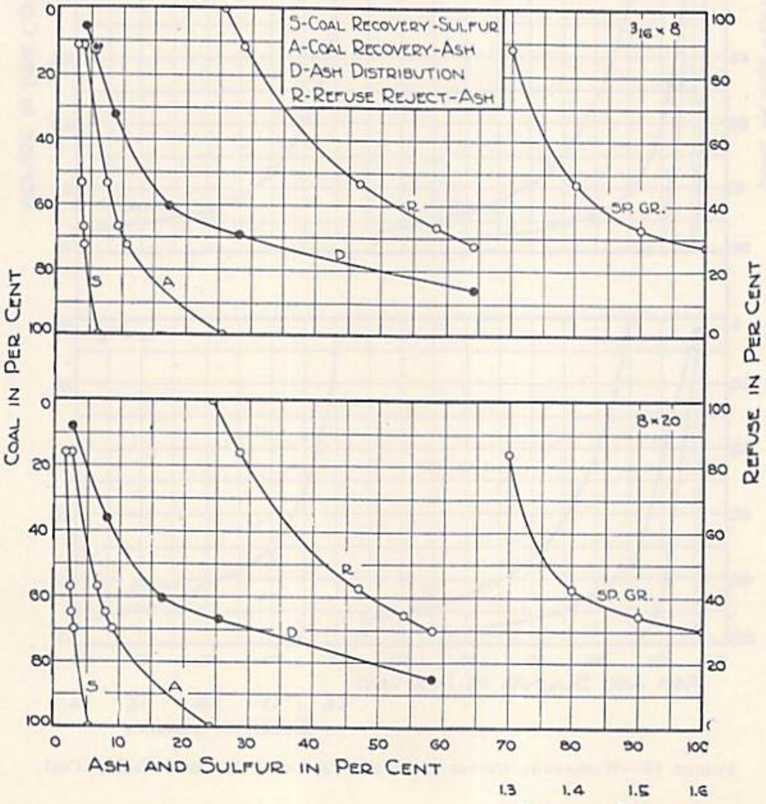


FIGURE 16—CONTINUED—Washability Curves of Screen Fractions—Appanoose County Coal (Dennis)

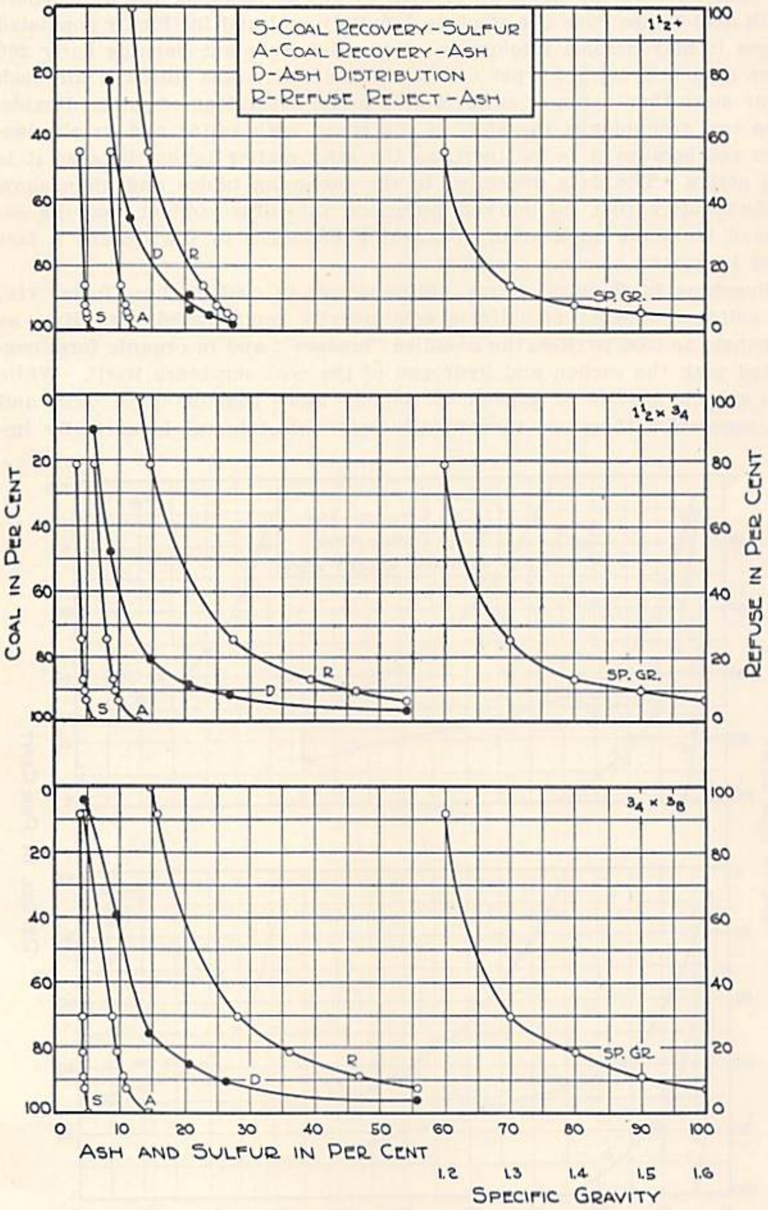


Figure 17—Washability Curves of Screen Fractions—Mahaska County Coal

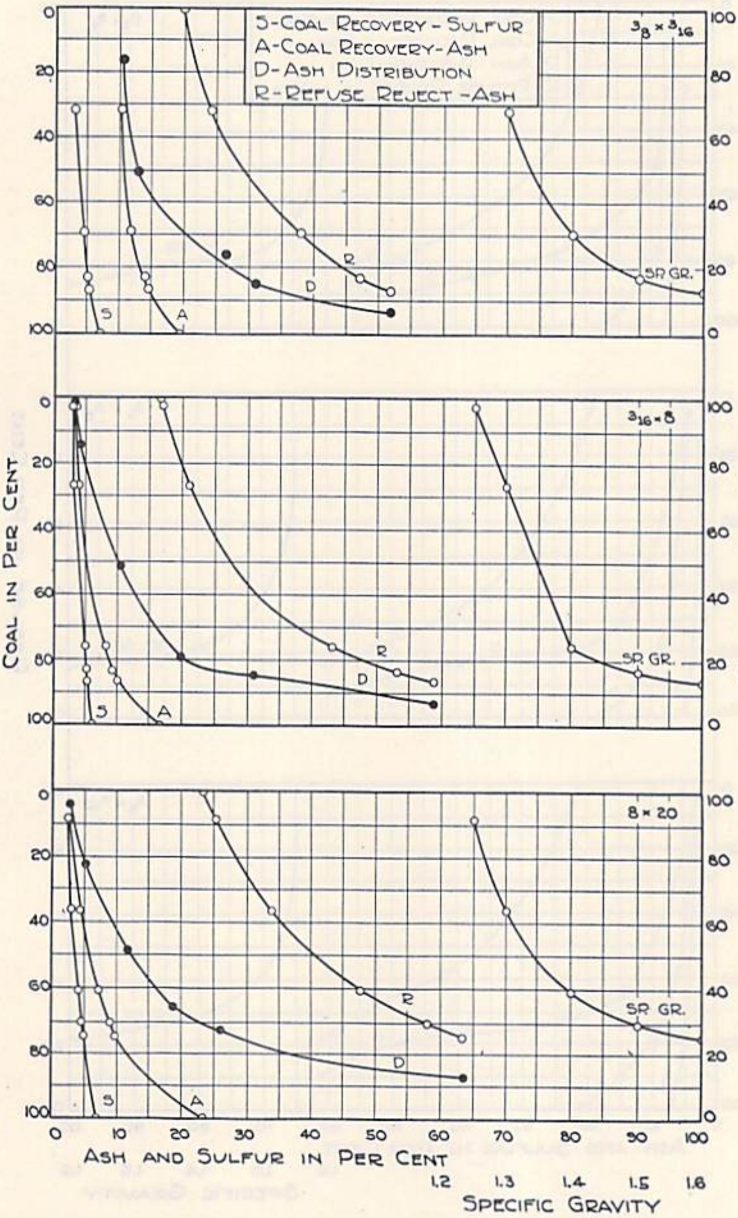


FIGURE 17—CONTINUED—Washability Curves of Screen Fractions—Mahaska County Coal (Beacon)

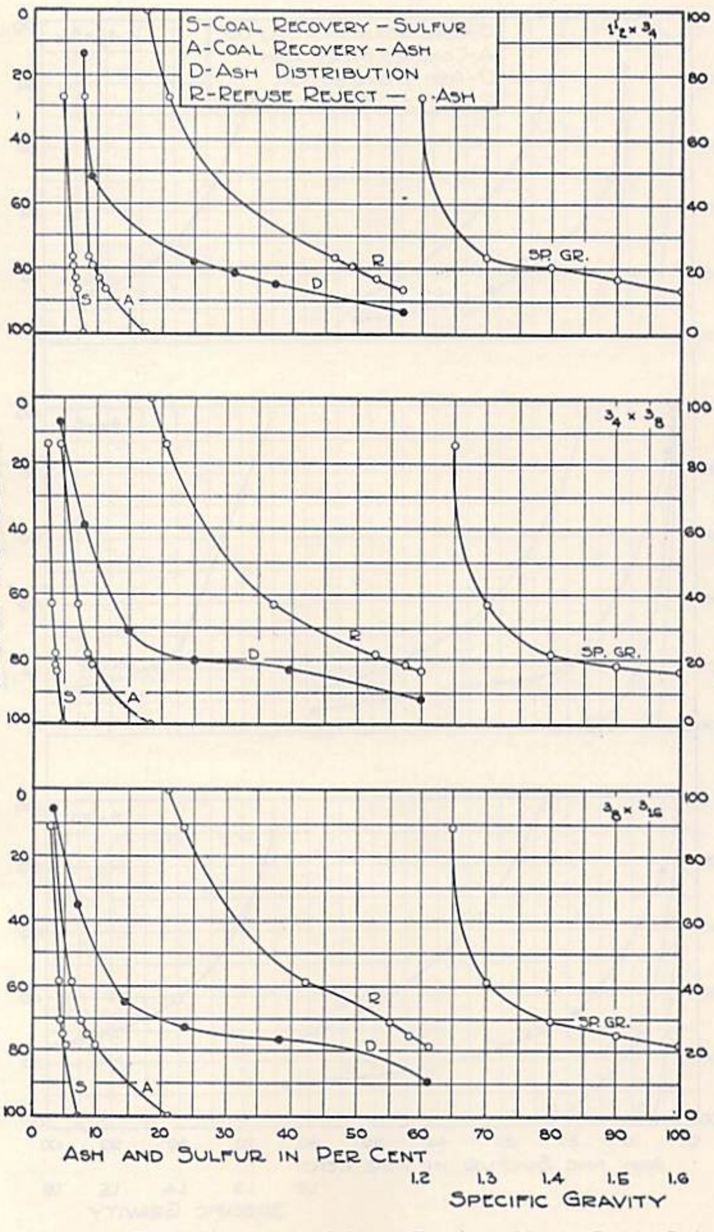


FIGURE 18—Washability Curves of Screen Fractions—Monroe County Coal

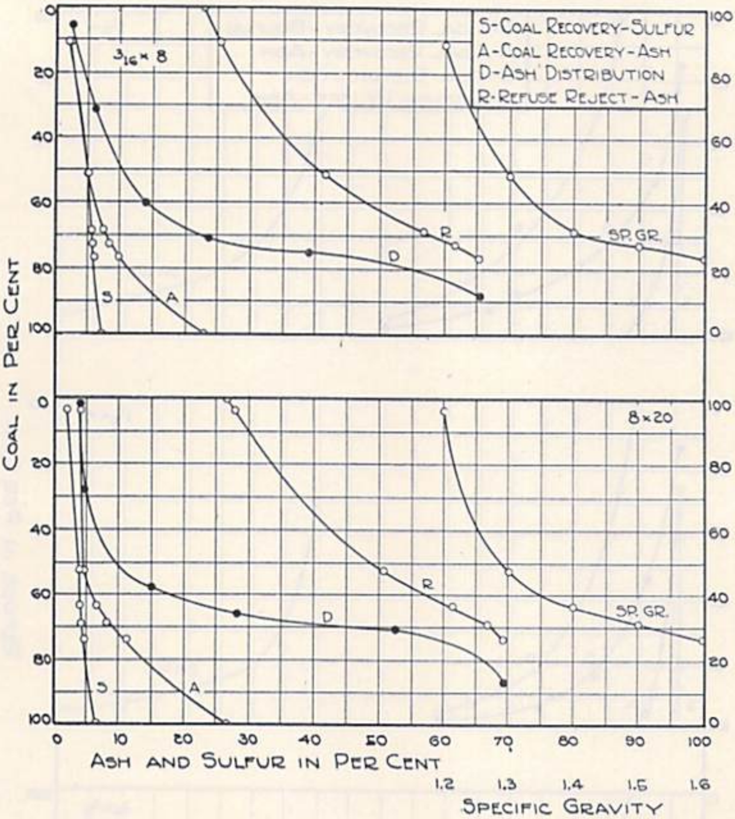


Figure 18—Continued—Washability Curves of Screen Fractions—Monroe County Coal (Avery)

bedded in the lump between bedding or cleavage planes from which it is dislodged with difficulty so that the washing operation often fails to remove it. Iron pyrites is relatively heavy (its specific gravity is 4.97) and when free to sink is easily removed. In many cases, however, it is disseminated through the mass in relatively small, even, microscopic particles and when thus imprisoned it rides away with the clean fraction. Organic sulfur is essentially a part of the coal itself and so its elimination is impossible by mechanical means; proposed chemical methods are at present impracticable and need not be discussed here.

In Table IX are presented the results of a study employing the well known methods of Parr(20), made to determine sulfur distribution in certain Iowa coals from samples that carry relatively high percentages of this element. Pyritic sulfur is shown to predominate, being equal to more than twice the sum of the organic and sulfate forms. More care in the preparation at the tipple with more effective separation of brasses would doubtless have brought down this ratio. Table X shows the rela-

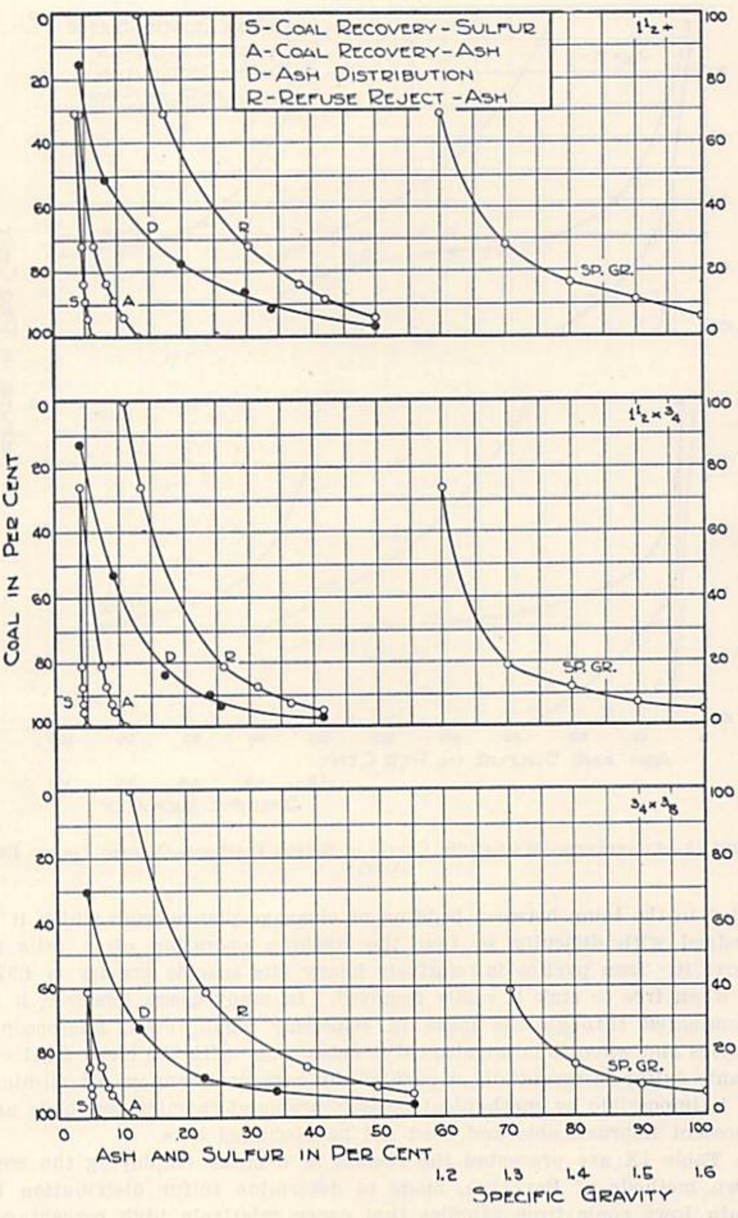


FIGURE 19—Washability Curves of Screen Fractions—Appanoose County Coal

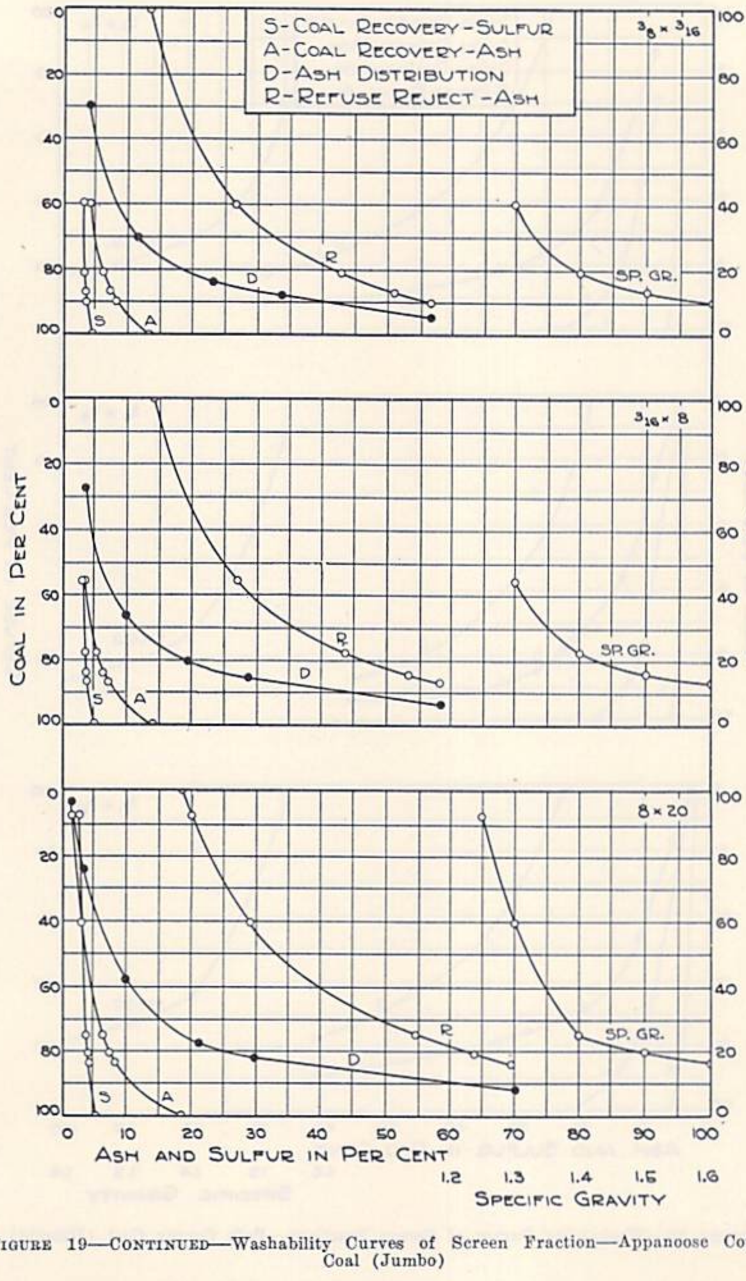


Figure 19—Continued—Washability Curves of Screen Fraction—Appanoose County Coal (Jumbo)

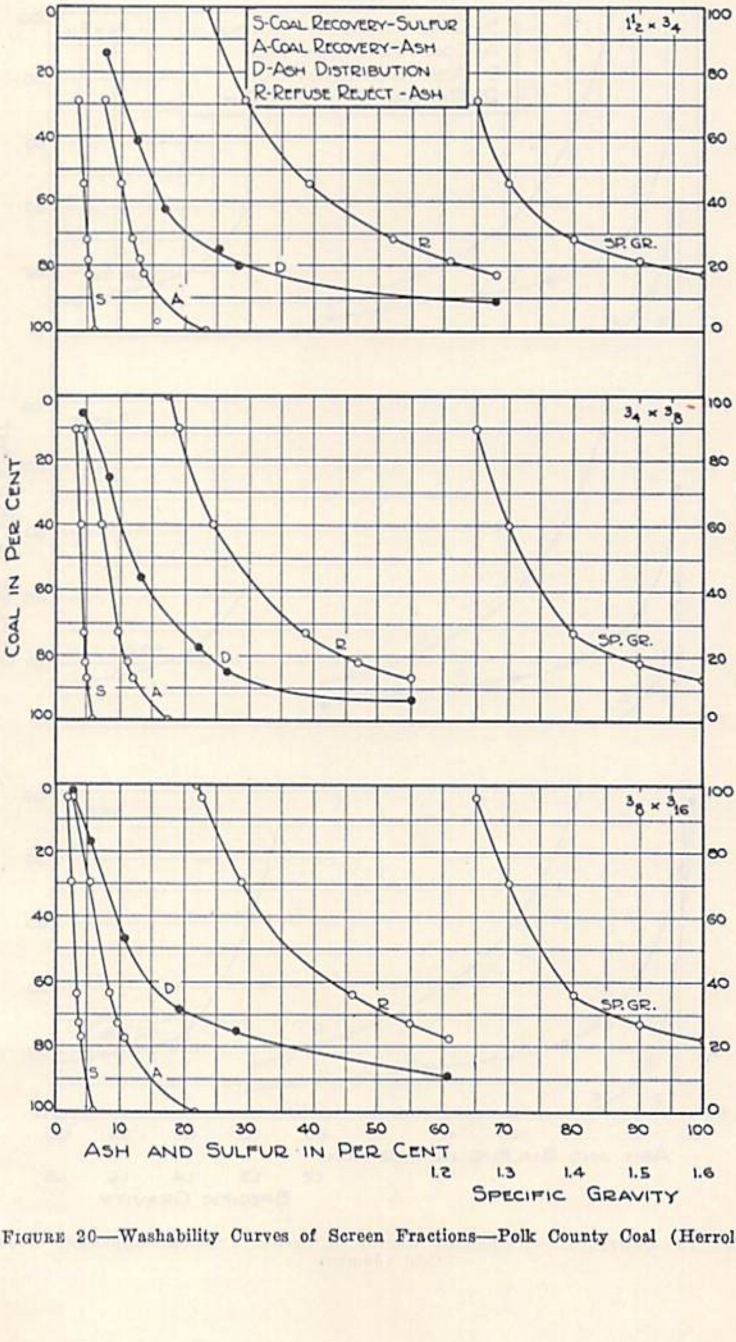


FIGURE 20—Washability Curves of Screen Fractions—Polk County Coal (Herrold)

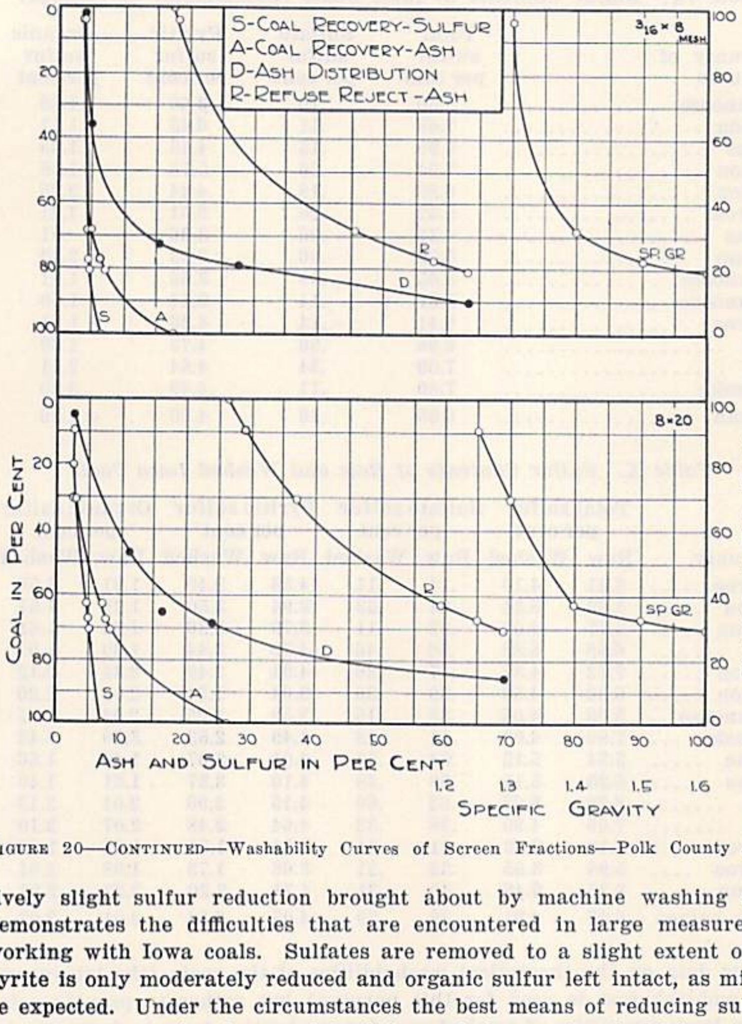


FIGURE 20—CONTINUED—Washability Curves of Screen Fractions—Polk County Coal

tively slight sulfur reduction brought about by machine washing and demonstrates the difficulties that are encountered in large measure in working with Iowa coals. Sulfates are removed to a slight extent only, pyrite is only moderately reduced and organic sulfur left intact, as might be expected. Under the circumstances the best means of reducing sulfur content appear to involve careful mining and rigorous hand picking at the tipple. In some mines the occurrence of pyrite in massive lump offers opportunity for its recovery in salable form for use in making acid; we are investigating this possibility in the case of certain Iowa mines.

Washing Studies with Pilot-Plant Machinery

As a part of the general study of the washing characteristics of the coals of the state and coordinate with the three series of laboratory tests reported in the preceding section, a fourth group of investigations was carried out with the use of a pilot size machine with a capacity of four tons per hour. The aim in this phase of the work was definitely not to

Table IX. Sulfur Contents of Iowa Coals (Commercial Screenings)

County of Source	Total sulfur per cent	Sulfate sulfur per cent	Pyritic sulfur per cent	Organic sulfur per cent
Appanoose	5.50	.10	3.60	1.80
Marion	7.65	.11	6.43	1.11
Dallas	5.99	.15	4.45	1.39
Marion	7.94	.26	5.78	1.90
Marion	6.88	.18	4.44	2.25
Monroe	5.32	.20	3.51	1.61
Dallas	4.32	.05	3.36	.91
Marion	5.72	.06	3.33	2.33
Appanoose	5.65	.08	3.66	1.91
Appanoose	5.67	.14	3.54	1.99
Monroe	6.41	.14	4.36	1.91
Polk	6.98	.56	4.73	1.69
Polk	7.09	.34	4.64	2.11
Mahaska	7.80	.11	4.49	3.20
Mean	6.35	.16	4.30	1.86

Table X. Sulfur Contents of Raw and Washed Iowa Coals

	Total sulfur per cent		Sulfate sulfur per cent		Pyritic sulfur per cent		Organic sulfur per cent	
County	Raw	Washed	Raw	Washed	Raw	Washed	Raw	Washed
Monroe	6.41	4.10	.14	.11	4.36	2.40	1.91	1.59
Dallas	5.63	5.34	.34	.33	3.94	3.50	1.39	1.51
Marion	5.77	4.08	.22	.11	3.79	2.36	1.76	1.61
Polk	6.98	5.82	.56	.46	4.73	3.44	1.69	1.92
Marion	7.72	4.87	.47	.26	4.91	2.49	2.34	2.12
Marion	6.32	4.50	.59	.36	3.64	1.94	2.09	2.20
Appanoose	5.08	4.05	.38	.15	2.58	1.25	2.04	2.65
Mahaska	7.80	6.03	.11	.08	4.49	2.53	3.20	3.42
Dallas	5.84	5.12	.34	.39	4.01	3.07	1.49	1.66
Dallas	6.20	5.15	.58	.38	4.10	3.37	1.31	1.40
Polk	6.78	5.63	.62	.60	4.15	2.90	2.01	2.13
Polk	7.09	4.90	.38	.32	4.64	2.48	2.07	2.10
Monroe	5.10	3.73	.41	.34	3.04	1.51	1.65	1.88
Monroe	5.98	3.95	.32	.21	3.68	1.73	1.98	2.01
Marion	8.35	6.48	.42	.31	4.71	3.20	3.22	2.97
Mean values	6.47	4.91	.39	.29	4.05	2.54	2.01	2.07

gather data on the theoretical washabilities of the coals (the laboratory float-and-sink test is used for this purpose) but rather to provide relatively large quantities of washed coal for combustion tests to demonstrate in a measure at least the practical advantages of coal improvement.

The machine we selected and installed was a Baum type jig in which a pulsation of the water is induced by compressed air admitted through simple valves above the water compartment. With this basic unit was included the Norton float device which automatically regulates the depth of the refuse bed in the machine thereby obviating the necessity for manual control. Dewatering of the cleaned fraction is effected with the use of sections of wedge wire shaker screen in series which deliver the product to a conveyor for elevation to the storage bin. The machine, designed and constructed by the McNally-Pittsburg Mfg. Corp. of Pittsburg, Kansas, is illustrated by Figures 21 and 22.

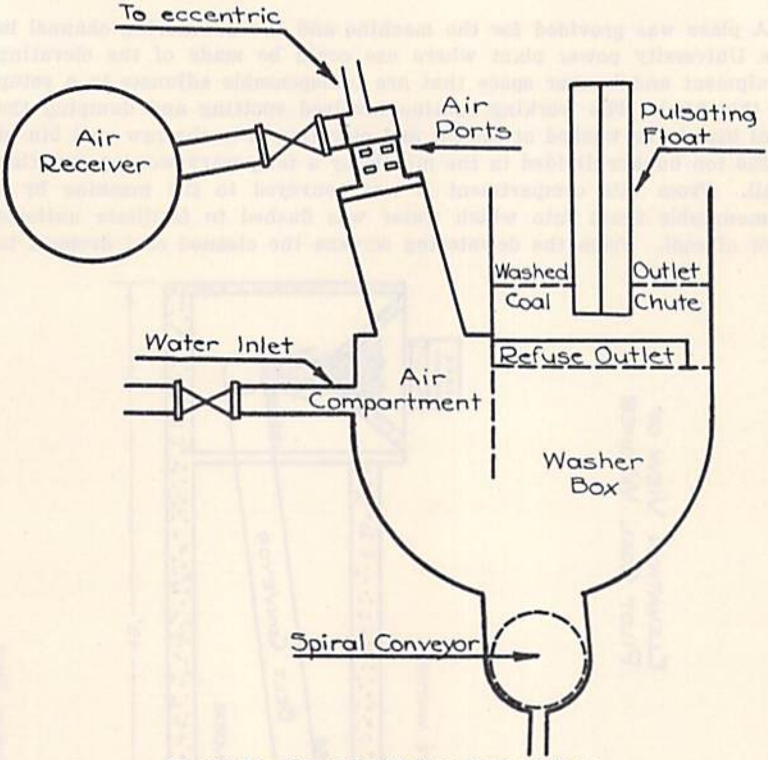


FIGURE 21—Norton Jig Washer; Sectional View

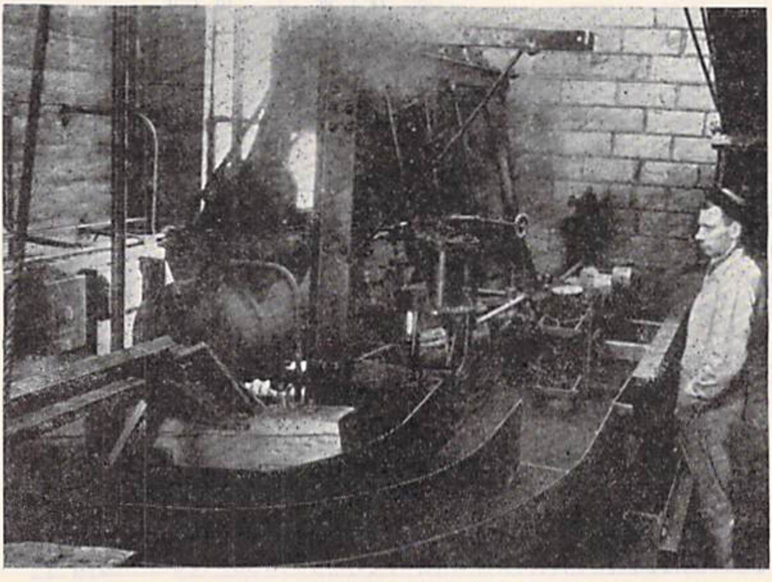


FIGURE 22—Norton Experimental Jig Washer

A place was provided for the machine and the dewatering channel in the University power plant where use could be made of the elevating equipment and bunker space that are indispensable adjuncts to a setup of this kind. The working routine involved spotting and dumping the coal load to be washed at the pit and elevating it to the raw coal bin of a 250 ton bunker divided in the middle by a temporary wooden partition wall. From this compartment it was conveyed to the machine by a demountable spout into which water was flushed to facilitate uniform flow of coal. From the dewatering screens the cleaned coal dropped to

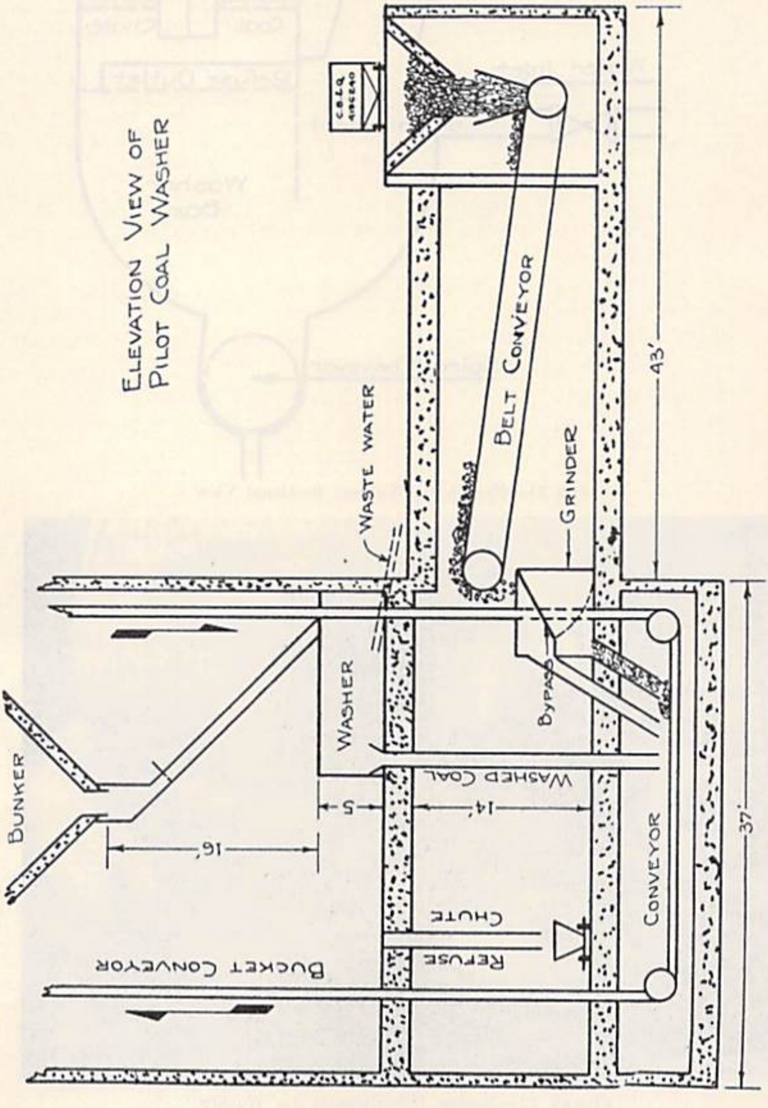


FIGURE 23—Pilot Coal Washing Plant

a conveyor system that delivered it to the second compartment of the bunker which was reserved for storage of the finished product whence it was later delivered to a larry and weighed as used.

The design of this pilot plant was further simplified by the fact that an ample water supply was available under pressure from the heating plant pumps, as well as the compressed air necessary for the operation of the jig. Refuse from the machine was removed with a relatively small amount of hand labor to a dump that dropped it to a weigh larry on the floor below while waste water carrying the fine sludge was conducted to a series of three 600 gallon tanks arranged in cascade and placed outside the building. Flow of water to the machine was measured with high accuracy by means of a standard orifice meter placed in the supply line. A sketch of the entire layout is shown in Figure 23 and a typical log sheet is reproduced in Table XI.

In the commercial operation of a full size unit washer the work of adjusting and tuning up the machinery to adapt it to the peculiarities of the given coal that is to be treated is a task requiring weeks of time, and even months may elapse before the plant is up to its optimum running condition. If any explanation is necessary for the somewhat uneven

Table XI. Typical Log Sheet—Machine Washing Studies

University of Iowa, Coal Washing Studies
H. L. Olin, Chas. Campbell and R. A. Whealy

Report on Washing Run No. 17

Date—April 27, 1933

Car Number—CMStP & P 309,142
Name Herrold
and
location of mine—Herrold, Polk Co.

Shipper—Norwood-White Coal Co.

Kind of coal—screenings

Date shipped	April 21, 1933	Net weight	101,500 lbs.
Date received	April 25, 1933	Dry weight	84,000
Date unloaded	April 25, 1933	Fired as rec'd	42,100
		to washer	41,900

. . . .

Beginning time—7:40 P. M.
Total flow gallons—33,800
Weight refuse in water—4,160 lbs.

Float and Sink Data

		Raw	Washed	Refuse
Float	1.4	82.22	92.57	2.16
Middlings		3.38	3.18	2.16
Sink	1.6	14.40	4.25	95.68

ending time—1:40 A. M.

Machine refuse, wet	4,855
Moisture, per cent	16.5
Weight, refuse, dry	4,060
Weight washed coal	43,440
Moisture per cent	22.7
Weight washed coal, dry	33,600

Total recovery ** 85.1 per cent

Analytical Data (Dry Basis)

	Refuse in water	Machine refuse	Washed coal	Raw coal
ash	22.99	62.30	12.62	20.00
sulfur	5.16	20.90	5.58	6.60
B.t.u.	10,900	3,770*	12,300	11,400

Remarks: Refuse mostly hard shale with some calcite.

*Calculated. **Including 50 per cent of sludge solids.

Table XII. Condensed Data, Norton Machine Runs on Iowa Screenings

(Recovery figures include 50 per cent of machine sludge with estimated ash content of 10 per cent)

Run Number	Mine	County	Ash, per cent in raw coal	Ash, per cent in washed product	Ash, per cent in machine refuse	Ash, per cent in sludge	Per cent recovery of cleaned coal	Ash, removal per cent	Material balance
13	Rex 5	Monroe	20.1	14.4	74.7	48.8	83.0	40.6	95.1
27	Rex 5	Monroe	20.3	12.4	66.8	48.4	85.3	41.9	93.6
19	Avery	Monroe	18.3	9.1	61.0	36.1	81.1	53.6	106.0
34	Avery	Monroe	19.8	12.1	62.8	42.0	84.5	48.9	98.6
35	Avery	Monroe	23.3	10.4	63.5	40.2	84.2	53.7	98.2
37	Avery	Monroe	18.7	11.2	62.9	48.0	83.1	52.6	103.2
33	Dennis	Appanoose	18.2	9.9	66.6	56.7	84.6	54.2	96.5
21	Sunshine	Appanoose	13.2	8.3	66.8	64.8	87.9	50.0	90.9
38	Centerville	Appanoose	12.9	7.9	62.0	24.2	90.0	45.4	99.3
28	Penn	Marion	15.7	11.8	60.8	46.3	92.3	27.8	100.0
15	Pershing	Marion	20.2	11.4	66.9	46.2	76.9	42.4	91.5
17	Herrold No. 8	Polk	20.0	12.4	62.3	36.0	85.2	46.8	99.9
20	Herrold No. 8	Polk	17.3	11.3	62.7	39.5	86.0	40.7	97.7
25	Herrold No. 8	Polk	18.4	11.5	62.8	37.4	85.5	45.9	97.1
16	Shuler (Waukee)	Dallas	19.4	14.3	66.3	38.5	84.0	38.1	97.9
18	Shuler (Waukee)	Dallas	17.7	13.7	60.8	39.5	84.2	35.6	99.3
36	Beacon	Mahaska	16.8	10.1	65.2	41.3	87.0	34.7	97.7
22	Scandia	Boone	23.0	15.3	70.8	58.9	82.1	42.5	97.3
*	Dennis	Appanoose	22.1	8.6	54.6	60.0	74.6	64.7	92.3
	Mean		18.7	11.3	64.2	44.8	84.2	45.2	97.4

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*Machine set for specially high ash removal.

results of the pilot tests shown in Table XII or for low cleaning efficiencies, let it be that in the limited time at our disposal we worked with the coals from 14 different mines. Obviously, fine adjustments for any particular coal were out of the question and separations only approximately approaching the theoretical were obtained in many cases. In other runs the proper combination was more easily found and some of our results are quite comparable with the data from float-and-sink tests. In any case the major purpose of the work, that of providing an ample quantity of washed fuel for experimental projects was readily attained.

In coal washing operations whether on the commercial or experimental scale, a material fraction of the input consisting of coal particles small enough to pass through the dewatering screens and of mineral matter so finely divided as to remain suspended in the wash water, passes out with the waste water as sludge. Industrial methods for the recovery of coal values from such mixtures vary to some extent but fundamentally all involve the use of a settling basin from which the thickened solids are withdrawn for secondary washing and separation. The latter may be done effectively with the use of the Rheolaveur trough which employs a stream of water so regulated that the heavy particles sink through the screened openings of boxes arranged below the trough bottom level while the float portion is swept forward.

Our device for collecting the sludge provided ample detention for the settling of all material of any value. Slurries were sampled and analyzed but no provision was made for mechanical separation and recovery of fuel values since the equipment necessary would unduly complicate the setup. A typical sludge from Marion County screenings has the composition shown in Table XIII.

Only the sludge from tank No. 1 which constituted the major portion, was given detailed examination, mainly because the sludges from tanks 2 and 3 were so finely divided as to have little possible commercial value.

Table XIII. Composition and Properties of Typical Machine Sludge
All percentages on dry basis

FLOAT AND SINK FRACTIONS, TANK NO. 1

	Sp. gr.	Wt. per cent	Ash, per cent	Cumulative ash, per cent
float	1.4	59.3	8.32	8.32
middlings		11.9	21.40	10.48
sink	1.6	28.8	48.40	24.40

SCREEN ANALYSIS FRACTIONS, TANK NO. 1

Screen size	Wt. per cent	Ash, per cent	Cumulative ash, per cent
20 mesh	1.8	22.20	22.20
20 x 28 mesh	13.7	17.18	17.78
28 x 40 mesh	22.3	16.85	17.23
40 x 60 mesh	26.2	18.78	17.86
60 x 100 mesh	18.2	28.60	20.23
100 mesh	17.8	51.10	25.75

From the float-and-sink data on sludge from tank No. 1 it is seen that the combined float and middlings make up 71.2 per cent of this fraction or about 50 per cent of the total sludge mass and that its mean ash content is 10.5 per cent but values as low as 8.3 per cent ash have been obtained. Such recoveries although of low screen size can properly be returned to the salable portion, since the fines after being once thoroughly wetted and separated are much less troublesome than when distributed through the main coal mass in the form of dust. These slurries obviously differ with the type of mining practiced, (long wall, for example, with its deep cutting into the floor rock produces highly mineralized fines) and in the current year's work special study will be made of them.

The Fusion Points of Iowa Coal Ash and Their Relation to the Washing Process

One of the demands made on either a steam or domestic coal is that its ash shall be sufficiently refractory to go through the combustion zone of the fuel bed without softening down to a pasty slag. While it is true that clinker formation depends to a certain extent upon the operating conditions of the furnace the major factor certainly is the chemical composition of the mineral matter, which influences the temperature at which it fuses and which becomes therefore, a matter of basic importance.

In Table II we gave in column No. 9, the ash fusion points of 24 representative coals collected over the entire producing area of the state. The mean value, 2105°F agrees satisfactorily with 2044°F, the average for 36 similar coal ashes reported in Technical Paper No. 2(23), figures which indicate that Iowa ashes definitely are in the low fusion point class. But this fact is significant only in its relation to the results obtained in firing practice and so long as normal combustion is not impeded the absolute softening point is not a matter of controlling importance.

From the viewpoint of power production the observations on slagging effect made at the University power plant constitute valuable evidence on this matter. Over a period of four years from 1931 to 1935 receipts of Iowa steam coal, screenings for the most part coming from 25 different mines, embraced a total of 150,000 tons ranging in quality from ash percentages of 10 per cent (dry basis) to extremes of 28 per cent. Whatever the effect of high mineral content in lowering boiler efficiencies may have been, at no time does it appear that undue difficulty was experienced through clogging of grates or tuyeres with pasty clinker. Indeed the modern underfeed stokers recently installed, popularly supposed to be unsuitable for use with low fusing ashes because of danger of tuyere stoppage, have worked smoothly under all circumstances, due in large measure to the elaborate water cooling system in the walls of the combustion chamber. Low fusibility of ash is more serious in coals used for domestic heating especially in the common case where the equipment used is incorrectly designed and the firing improperly done, but mechanical stokers for house heating will doubtless help solve the problem. In any case Iowa ashes are as a rule not greatly inferior to those from neighboring states in this respect. The mean fusing point of 37 Illinois coal ashes from 17 counties including Saline and Perry but excluding Franklin and Williamson is shown from data published in Bulletin No.

209 (21) of the Bureau of Mines to be 2052°F. The mean of 19 samples from the two latter counties which produce much of the best coal in the state is only 2218°F.

From the standpoint of washing technology the question of the possibility of raising the ash fusion point by the fractional removal of mineral matter is always interesting, but unfortunately there is little in the results of work done along this line up to the present to warrant much optimism. Callen and Mitchell(22) report a marked improvement in some cases but apparently a rise in fusion temperature does not follow as a matter of course. Our own results with washed Iowa coals are set forth in Table XIV. It is quite evident from the series of results presented that in washing this group of coals the ash fusion points of the product were in the main lowered rather than raised; in other words the mineral constituents removed with the refuse were more refractory than those intimately mixed with the coal substances and which were floated off with the refined fraction.

Lest it should appear to the reader that we advocate indiscriminate washing of Iowa coals, let us in concluding this subject reiterate our main purpose as stated in the introduction viz., to discuss the technical possibilities of Iowa coal cleaning, leaving the burden of decision on the individual operator, assisted by expert engineering service. In the survey made to determine the economic status of a washing plant, laboratory studies to measure the separations obtainable are a prime necessity and these we have carried out on a considerable number of representative coals. From personal contacts with the Iowa producers the writer knows that many are interested in the subject and that they are seeking information on it.

Table XIV. Ash Fusion as Affected by Washing

		Fusion points, degrees F.			
	Coal Source		float	sink	
No.	(County)	original	fraction	fraction	sludge
1	Dallas	2190	2120	2330	2185
2	Dallas	2265	2275	2330	2330
3	Dallas	2280	2230	2255	2265
4	Marion	2345	2285	2245	2320
5	Marion	2340	2240	2255	2185
6	Monroe	2375	2320	2185	2270
7	Monroe	2345	2245	2280	2295
8	Marion	2385	2280	2325	2295
9	Marion	2350	2285	2405	2300
10	Marion	2440	2365	2445	2355
11	Marion	2300	2300	2375	2435
12	Polk	2330	2285	2235	2265
15	Polk	2380	2290	2200	2165
14	Polk	2480	2345	2205	2303
15	Appanoose	2230	2225	2225	2250
16	Appanoose	2225	2240	2255	2285
17	Appanoose	2275	2265	2205	2235
18	Appanoose	2320	2340	2260	2235
19	Monroe	2165	2375	2215	2200
20	Monroe	2240	2235	2340	2370
Mean values		2313	2277	2278	2277

THE STORAGE OF IOWA COALS

In an earlier paper we outlined the theories of Parr on the spontaneous combustion of coal based upon his extensive chemical studies in this field. Briefly reviewed the process takes place in four stages, the first beginning with the slow absorptive oxidation of certain complex substances in the coal that in general are extremely sensitive to oxygen. If the heat generated in the first stage of the cycle is retained in the mass because of deep insulation or is otherwise sufficiently retarded in its escape the temperature rises to the second stage where the pyrite or other sulfur bearing mineral begins to oxidize with further evolution of heat. If this in turn escapes dissipation the third stage is reached around 250°F with the oxidation of hydrocarbons and the evolution of carbon dioxide and water. As the temperature rises from this point to 500°F the mass is fairly ignited and combustion becomes self supporting. The checking of the initial oxidation, which is simple in theory but often difficult to put into practice may be effected either by submerging the coal in water, a highly successful but expensive method, by packing the fine coal so firmly and uniformly that free access of air is prevented and the incipient reaction smothered, or by laying down piles of the larger sizes only that are self ventilating.

Far more authentic and convincing than the results of limited scale research tests in coal storage or any other line of investigation are those obtained in actual practice on the plant scale. Especially significant and apropos to this subject is the experience of John Morrell & Co. of Ottumwa who have maintained for many years, under the supervision of their chief engineer Mr. Barney Winger, a storage reserve of Iowa coal as insurance against emergencies. The coal selected, 6″ lump, is dumped from a Jeffrey traveling hoist and piled to a maximum height of 10 feet without special packing. Examination of one of the early piles made two years after it was laid down disclosed a crust of air-slacked coal 10 inches deep, under which the coal was apparently fresh and in good condition. At the end of the third year the slacking had extended to a depth of from 14 to 16 inches and four months thereafter the pile was put on the firing line. In all this time no evidence of undue heating was observed.

The stored fuel after being mixed with fresh coal in the proportion of 80 per cent to 20 per cent of the latter was burned in a powdered coal unit with results that showed evaporation of one pound less than that obtained with newly mined coal. No analytical data on the quality of the coal as laid down are available but a sample secured in June, 1936, from a section of the pile between two and three years old and tested in the author's laboratory, showed the following values: moisture, 11.3 per cent; ash, 13.6; sulfur 3.7, and thermal value 10,340 B.t.u.'s per pound, all of which indicate a highly satisfactory condition under the circumstances. Evidence of some deterioration however, is furnished by the fact that the "unit coal" value (thermal value calculated to the moisture-ash free basis) is 14,100 B.t.u.'s as compared with 14,550 which is the approximate average for freshly mined Iowa coals. It is apparent furthermore from the appearance of the fire that the fuel has lost some of its original liveliness although no trouble is experienced in maintaining boiler pressures. Altogether the showing is considered highly satisfactory and the losses whatever they may be are written off as insurance premium against tieup hazards.

Consistently good results have been obtained by the Iowa Electric Light and Power Company at their Marshalltown plant by maintaining effective exclusion of air through close packing of the pile. In the face of a threatened coal strike in the early summer of 1935 three thousand tons of Dallas County 1¼ inch screenings were put down (June 15) and firmly packed with horse drawn drags. This supply was taken over for current use about the middle of October as the strike threat vanished and consumed in normal operation of the plant without disclosure of evidence of undue heating. The division Manager(12) reports that while loosely packed screenings will kindle within ten days or so the packed heap seemed good for an indefinite period.

Since the publication of our earlier paper on coal storage in Technical Paper No. 2 two minor projects in this field have been carried out, the first with screened Iowa nut in the summer of 1932 and the second with Iowa 1½" screenings in the summer of 1935.

The first lot shown in Figure 24 consisted of about 250 tons of 2" nut from mines in Monroe, Dallas, and Polk counties with an average composition on the dry basis of 16.9 per cent ash, 4.9 per cent sulfur and with a mean thermal value of 12,237 B.t.u. No special pains were taken to pack it firmly although this was accomplished to some extent by the truck wheels in the piling operation. For the purpose of following accurately the temperature changes that might take place we buried in different parts of the pile six lead-sheathed thermocouples with instrument terminals extending to the open air. Temperatures were read daily from

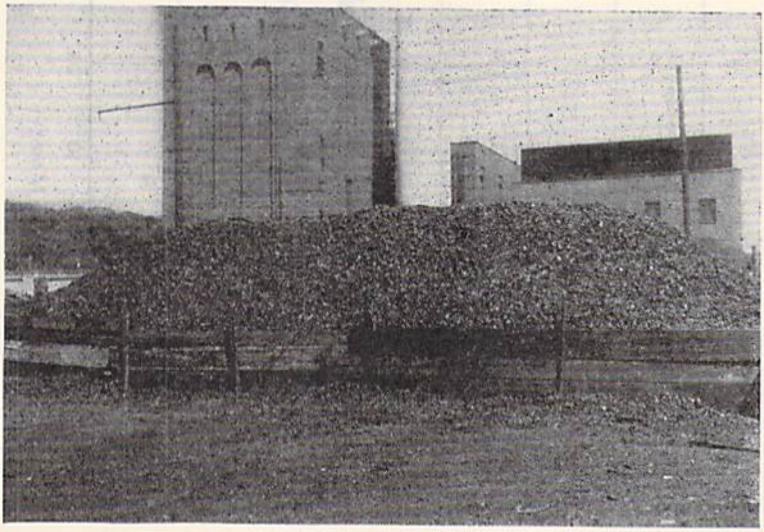

FIGURE 24—View of Iowa Coal Storage Pile—2" Nut

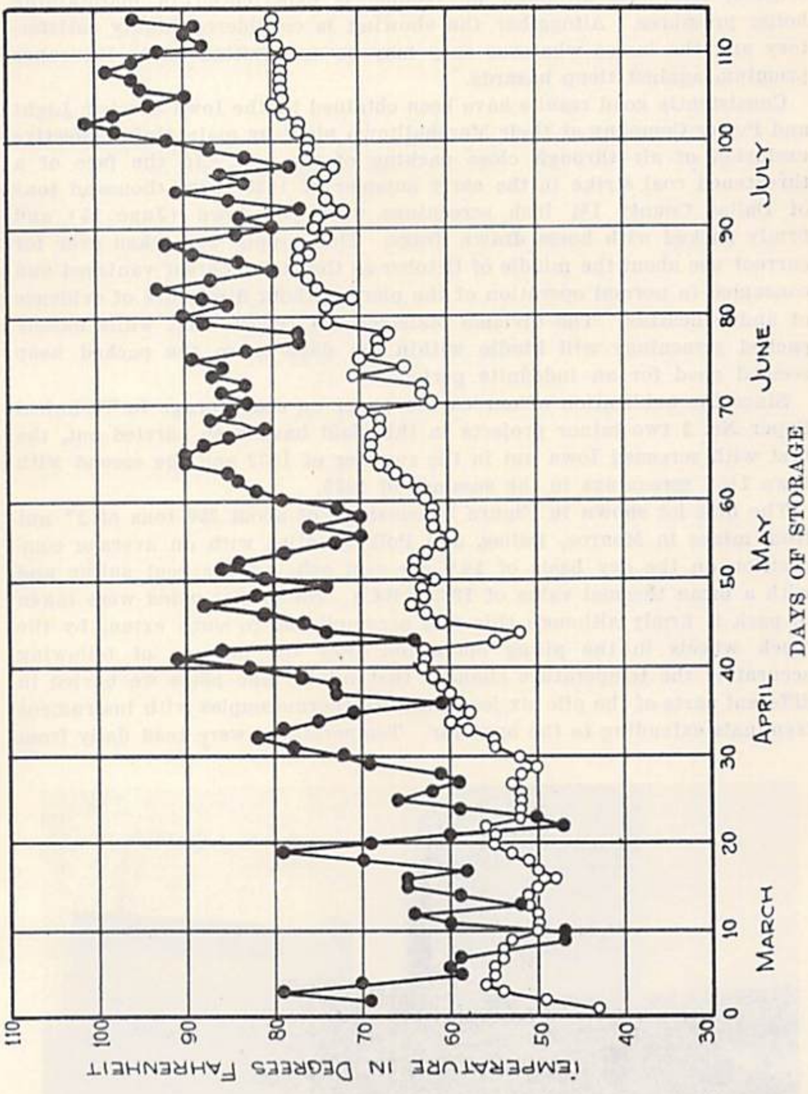

FIGURE 25—Storage Pile Temperatures, 2" Monroe, Dallas and Polk County Nut

March 4 to August 4 and the average plotted as in Figure 25. Although the pile was exposed to direct radiation from the summer sun in weather touching 100°F in the shade the maximum mean reading did not exceed 80°F nor did the temperature at any given point exceed 86°F. The test coal was picked up after four months in response to fuel demands from

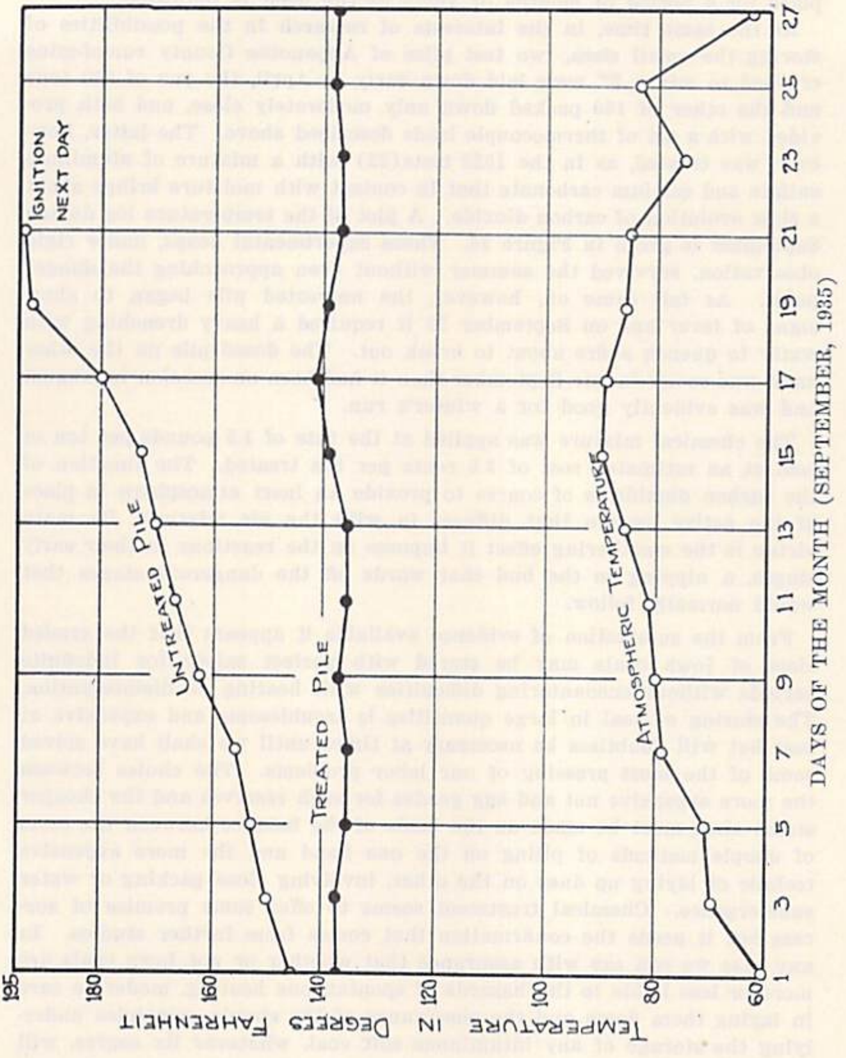

FIGURE 26—Coal Pile Temperatures After 4 Months' Summer Storage

the heating plant but the temperature log clearly indicates that conditions remained normal during the whole period.

The 1935 project was part of the general move made by the University in the early spring of that year to provide fuel supplies to meet the threat of a general coal strike that seemed imminent at the time. The greater part of the total 5,000 tons laid down consisted of 2 inch nut from Kentucky and southern Illinois mines which produce coals of recog-

nized keeping qualities; they constitute a reserve that will remain in place for a period of months or years as the need is indicated.

At the same time, in the interests of research in the possibilities of storing the small sizes, two test piles of Appanoose County run-of-mine crushed to minus 2″ were laid down early in April, the one of 300 tons and the other of 150 packed down only moderately close, and both provided with a set of thermocouple leads described above. The latter, however, was treated, as in the 1929 tests(23) with a mixture of aluminum sulfate and calcium carbonate that in contact with moisture brings about a slow evolution of carbon dioxide. A plot of the temperature log during September is given in Figure 26. These experimental heaps, under rigid observation, survived the summer without even approaching the danger point. As fall came on, however, the untreated pile began to show signs of fever and on September 23 it required a heavy drenching with water to quench a fire about to break out. The dosed pile on the other hand was cooler in late September than it had been on occasion in August and was evidently good for a winter's run.

The chemical mixture was applied at the rate of 1.5 pounds per ton of coal at an estimated cost of 3.5 cents per ton treated. The function of the carbon dioxide is of course to provide an inert atmosphere in place of the active oxygen that diffuses in with the air mixture; its main virtue is the smothering effect it imposes on the reactions in their early stages, a nipping in the bud that wards off the dangerous stages that would normally follow.

From the summation of evidence available it appears that the graded sizes of Iowa coals may be stored with perfect safety for indefinite periods without encountering difficulties with heating or disintegration. The storing of coal in large quantities is troublesome and expensive at best but will doubtless be necessary at times until we shall have solved some of the most pressing of our labor problems. The choice between the more expensive nut and egg grades for such reserves and the cheaper steam sizes must be made on the basis of the balance between the costs of simple methods of piling on the one hand and the more expensive technic of laying up fines on the other, involving close packing or water submergence. Chemical treatment seems to offer some promise of success but it needs the confirmation that comes from further studies. In any case we can say with assurance that whether or not Iowa coals are more or less liable to the hazards of spontaneous heating, moderate care in laying them down and the observance of the simple principles underlying the storage of any bituminous soft coal, whatever its source, will insure highly satisfactory results.

THE USE OF WASHED IOWA SCREENINGS WITH DOMESTIC STOKERS

The producer of coal in meeting the competition of oil and gas for household heating is learning by hard experience that the slogan of "more heat units for the dollar" has only a limited appeal and that it fails to move the householder who has decided that automatic and uniform heating with absence of soot and smoke are necessary to meeting his standards of living. It is not that cost of heat is becoming less important, but that comfort and cleanliness are being recognized as elements coordinate with it. To such a man the low volatile Appalachian coals have a strong appeal by virtue of their clean burning qualities, and from these it is a short step only to oil or gas to gain the added advantage of automatic firing. Meanwhile the coal dealer has lost another customer and the miner another week's work, for the reason that the industry they represent has been slow in promoting the use of a domestic coal appliance that should possess the essential advantages of the oil or gas burner.

But the awakening though tardy has lately been rapid and in the last half decade we have seen a phenomenal increase in the production and sale of domestic coal stoking units. The situation is well described by the Secretary of the Iowa Coal Institute in a recent office bulletin. To quote, "The apparent race among leading producers in the bituminous coal industry for better preparation of the smaller sizes—the stoker coals—is clearly justified by the soaring sales of the automatic firing devices. Operators in all fields are spending large sums in improving their preparation plants and in erecting washeries of one type or another principally for the small coal, which is being cleaned and dedusted and sprayed to produce a product as nearly uniform in size as possible and with all objectionable matter removed.

"The small coal of today is vastly different from that of a few years ago when much of it was combined with other sizes and what was previously difficult to move has become almost a premium in the market. This is especially true of the choicest qualities.

"Small coal has come into its own. It is taking the place of large lumps heretofore the best seller in many cases and now actually becoming more or less of a drug in the market. Some producers are actually breaking down the large sizes in order to obtain an increased output on the smaller coals. The reason is readily understood from the latest report of the Bureau of the Census on stoker sales for the country as a whole, which shows that during 1935 sales of machines with capacities up to 200 pounds per hour were 44,288 compared with 25,496 for 1934 and 15,418 for 1933. While sales of all classes were above those of the preceding year, the greatest advance was in stokers for residences and small buildings, or machines with a capacity of 100 pounds of coal feed per hour and less."

These general observations were amply corroborated by the great public interest aroused at an exhibition of household stokers held in Chicago in October, 1935, which attracted 60,000 visitors and at which sales were reported to be heavy. The fact that this took place in a city to which natural gas and crude petroleum had long been piped directly from the producing fields is evidence that the average consumer is not committed to a relatively high priced fuel if coal will produce nearly the same results. Briefly described, most of these devices which are now being made by more than 100 manufacturers, consist of a retort into which the coal is fed by means of a screw conveyor with delivery to the space beneath the combustion zone (i. e. the underfeed principle). The necessary air is delivered by induced draft to the tuyeres located in the upper part of the retort where it mixes to the best advantage with the rising volatiles. Each of the many machines made has of course its own special features and obviously individual worth in so great a number varies widely.

The significant and impressive facts of the situation that concern the Iowa coal industry are first, that by means of this type of stoker the high volatile coals of the state may be efficiently burned with almost complete absence of soot and smoke; second, that combustion may be controlled by a thermostatic device thereby making the heating process automatic; third, that fine screenings which in general have found their sole market at steam plants at relatively low prices, make highly acceptable domestic fuels and are consequently greatly enhanced in value. In short, except for the labor of removing ashy residues as solid clinkers and of periodically filling the hopper with fuel much of the advantage held by oil and gas is wiped out leaving a net credit of considerably lower fuel costs.

Matthew Arnold in his essay on Heine quotes a remark of the poet and philosopher who, in exile, was seeking a refuge from persecution. "I might settle in England," said he, "if it were not that I should find there two things, coal smoke and Englishmen; I cannot abide either."

Waiving the delicate question of which he considered the worse it is nevertheless easy to understand his reluctance to expose himself to an inclemency of climate aggravated by unnatural causes. And yet the damage done by smoke to the collective health and property of a community in which soft coal is the chief winter fuel is seldom fully appreciated. Indeed the absence of definite data is due largely to the lack of accurate methods of measurement of smoke concentrations and their direct effect upon life and matter. Aside from the aggravation of pulmonary disorders and the general lowering of physical tone as a result of breathing smoke polluted air, the cost of which is difficult to evaluate in terms of money, the annual soot damage to house furnishings and clothing, to stocks in stores and warehouses and to the outer walls of buildings is estimated to exceed in the average midwest city, $15 per capita. Nor can we lay the burden of blame upon the manufacturing industries. Careful soot fall studies undertaken by our laboratory show that in a certain retail business block in Iowa City, a town of relatively few factories, the maximum rate of deposit is more than 2,000 tons per square mile per year, a figure in excess of the maximum for Pittsburgh, and considerably greater than that for London or Glasgow. To Grafton, West Virginia, a railroad center 75 miles south of Pittsburgh, according to a report of the U. S. Bureau of Mines in T. P. 338, goes the dubious distinction of standing at the head of the list with a maximum rate of 7,180 tons.

By providing a ready means of smoke elimination the domestic underfeed stoker meets squarely the main advantage of the low volatile eastern domestic fuels since not only do the Midwestern coals burn as completely and as cleanly with the mechanical stoker as those of the Pocahontas type, but due to their more fusible ash, a more solid and easily removed clinker is formed around the retort. Furthermore while the high volatile constituents of Iowa coal may be a liability as smoke producers unless adequate means are used to kindle them, their rich, free burning qualities and their high thermal values are a decided asset under the more favorabl firing conditions of the mechanical stoker. In brief, the home product needs only the opportunity afforded by the newer methods of stoking to make the most of its possibilities and to hold its own against outside competition.

As previously noted the rise in demand for the small coal sizes is already affecting the production policies of the operators and doubtless future changes will be still more significant. In Iowa shaft mining, roughly one-third of the total production breaks down before it leaves the tipple to 2 inch screen size or smaller and thus becomes automatically graded as steam coal with outlets mainly to power plants. Since the production ratio of domestic sizes to screenings is constant it follows that with the arrival of cold weather the rise in domestic demand with power demand steady disturbs the market balance and with the accumulation of slow moving fines the production of active domestic sizes must lag in sympathy. It is clear therefore, that expansion of the market for fines will relieve the tension, for when sales of the latter exceed the demand for the larger sizes, simple crushing at the tipple will bring about adjustment, but for the contrary situation no ready cure is at

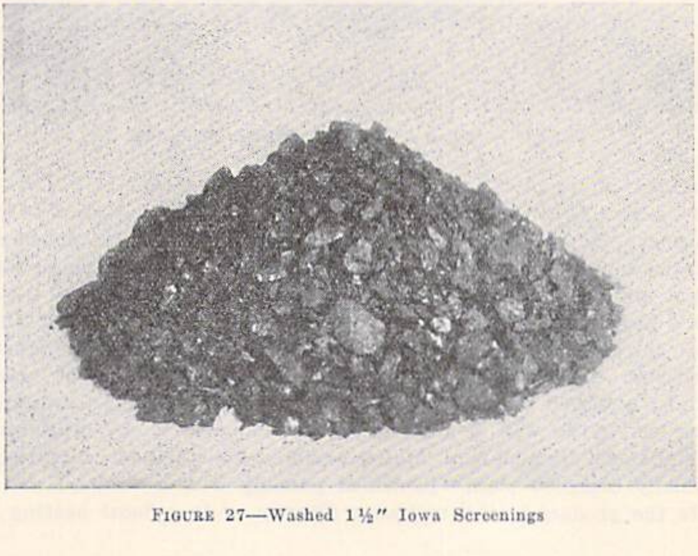

FIGURE 27—Washed 1½" Iowa Screenings

hand; from the days of Humpty Dumpty to the present no simple means have been devised for unscrambling the slack.

It need not be assumed however, that raw screenings as produced at the mine will meet the requirements of the householder who is interested in fuel cleanliness in its various aspects. While the domestic stoker is remarkably effective in its handling of low grade screenings, a fuel with an excessive amount of ash and dust would encounter scant tolerance in a well ordered home and we may expect a rising demand for a stoker fuel specially prepared by washing or screening to meet the new requirements. In Figure 27 is shown a sample of Iowa screenings that has passed the washer as cleaned coal while Figure 28 illustrates a heap of typical refuse made up of shale and pyrites that was removed in the washing process. Granting that material of this sort will pass through the stoker and the fuel bed without causing undue damage or trouble the policy of transporting this extra dead weight that yields no return is thoroughly unsound in principle.

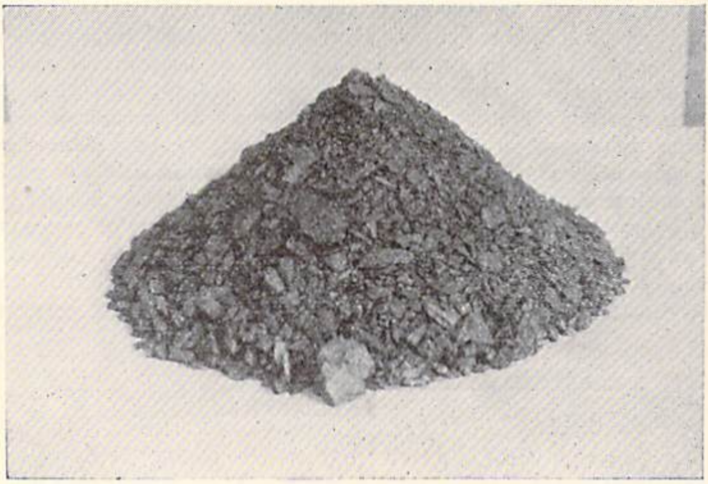

FIGURE 28—Typical Refuse from Iowa Screenings

The ideas of one of the progressive Iowa producers, Mr. L. P. Love(13) on the subject of stoker coal supply are expressed in a personal letter to the author. He proposes that the producer establish central distributing depots to supply the retailers of a given section with prepared stoker coal put up in 50 or 100 pound bags to be delivered regularly to the consumer's basement. The service to be rendered by the retailer should include the collection of empty bags and the removal of accumulated ash and clinker. A more elaborate but more complete service, in his opinion, might be rendered by an independent organization equipped to furnish heating service as well as fuel. This establishment would draw screenings shipments from nearby mining centers, prepare them adequately in a specially designed plant (furnished possibly with a washer) and distribute the product to the residence directly or to a local heating contractor who would assume the responsibility of keeping the home fires burning. Details of such a scheme might vary widely but it seems certain that the general principle must and will be shortly adopted at least in the larger cities and towns, unless indeed, the coal industry is willing to confess complete inability to render service comparable to that furnished by its chief competitors—the oil and gas interests.

So positive is the trend of public interest in this direction that engineering research organizations are taking up the formal study of the small stoker with a view to putting the principles of its design and operation and the selection of its fuels on a scientific basis. Chief among these is the project sponsored by Bituminous Coal Research, Inc., at the Battelle Memorial Institute at Columbus, organized to furnish data on the relation of size of coal, the amount of ash, and its fusibility, the amount of volatile matter and the coking tendency of the coal, to the general efficiency and performance of the stoker. In addition to formal work to be made in a well equipped laboratory during the season of mild weather, the Institute is planning to make tests on equipment already installed in private buildings this coming winter and relative costs of heating with various kinds of coal, coke, oil and gas will be obtained.

The experimental studies in this field begun at the University early in 1934, are designed solely to establish the value of Iowa screenings as stoker fuels and in no sense to investigate the merits or faults of any machine. Preliminary work embraced a census of the domestic stokers already installed in Iowa City with brief observations of the service rendered with the different fuels used. This was followed by short qualitative tests of washed screenings with two or three selected stokers located in private dwellings and apartment houses, mainly with a view to bringing out roughly the general behavior of washed Iowa coals in comparison with those previously used. Results were recorded in the form of case histories of which the following are typical:

CASE NO. 1

February 14, 1935. Test made on Econocol stoker installed in a 17 room dwelling house. Fuel regularly used was a special oil treated stoker coal from Franklin County, Illinois. Coal for test was washed Polk County screenings showing on the dry basis the following percentages: ash 13.4 and sulfur 4.6, with a thermal value of 12,250 B.t.u.

Observations: Good smokeless combustion but with clinker rather too fragile for easy removal, a difficulty obviated, however, by increasing the draft. Performance in general is comparable to that of the Illinois coal. Comment of householder: "Where can I buy some of that coal? I'd like to use it regularly."

CASE NO. 2

March 11, 1935. Test made on Iron Fireman installed in a 12 room apartment house under an old rectangular cast iron boiler. Fuel regularly used was raw screenings trucked in from Mahaska County. The test coal was washed Appanoose County screenings with 11.0 per cent ash, 4.6 per cent sulfur and 12,510 B.t.u.

Observations: Good smokeless combustion; clinkers formed were rather soft, apparently because the fusion point of the ash was high. Less fly ash deposited on heating surfaces than with the coal previously used, due possibly to removal of bug dust in preparation. Clinker contained only 0.8 per cent combustible. The householder was favorably impressed with the coal; considered it much superior to that previously used with respect to labor of firing and cleaning.

More formal work now in progress but not completely ready for publication embraces a program of study of washed screenings from a score of Iowa mines used with a modern stoker installed in one of the larger cooperative dormitories of the University, housing about 60 men. This machine, a No. 10 Kol-Master, manufactured by the Paragon Kol-Master Corporation at Oregon, Ill., with a maximum capacity of 100 pounds per hour and equipped with devices for automatic control of fuel feed and air volume may from all standpoints be considered a model for the purpose. The objective of this project as stated above, is rather to test the coals than the machine, e. g. the hardness and composition of the clinker, the cleanness and efficiency of combustion and in general, its suitability as a fuel for commercial distribution for domestic use. In our washing operations for improving the raw screenings care is exercised to remove the free mineral and the extremely fine dust but no special effort is made to obtain high ash removal at the expense of excessive loss of fuel values, inasmuch as the stoker has already proved its ability to work on high ash coals.

The assembly of boiler and stoker is shown in Figure 29. While the stoker is one of the better machines on the market the steam boiler

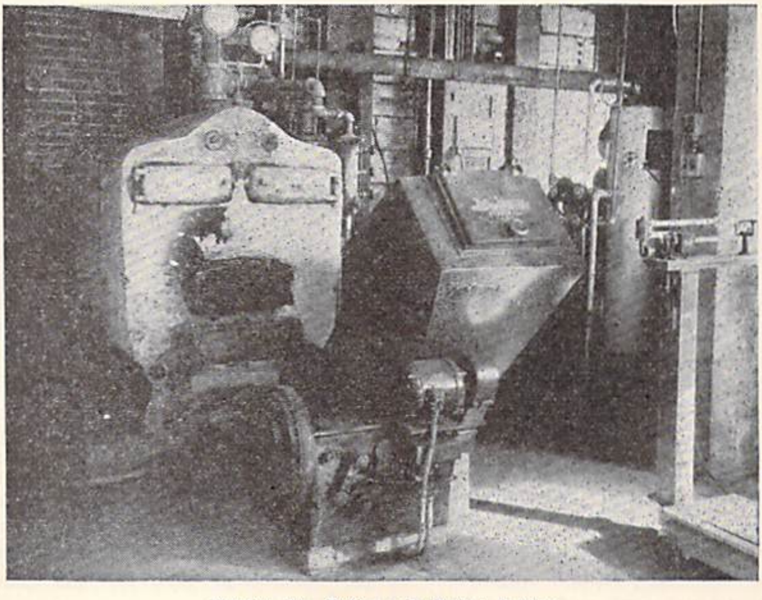

FIGURE 29—Boiler and Stoker Setting

available for use at the present time is unfortunately, not well suited for the purpose being originally designed for a hot water system. The grate area under this boiler before the installation of the stoker was about nine square feet but in the remodeling process a bridge wall was constructed in the rear so that the present radiating surface is approximately six square feet while the distance from dead plates to water shell is 20 inches.

The scope of the tests made so far on this unit is shown from the data given in Table XV. Overall efficiencies are based upon water evaporation only and this in turn is measured by metering the condensate from the return lines from the radiators. Since the boiler is not entirely adequate to absorb the heat generated, stack temperatures and stack losses are therefore high. For the same reason in part at least, radiation losses from the boiler and setting are unduly large, but much of the heat classified under this head is ultimately utilized since convection from the furnace room contributes much to the heating of the building. Other factors that have lowered efficiencies are (a) radiation from bare steam pipes with refluxing of water directly back to the boiler without metering; (b) losses due to unburned carbon with the formation of a certain amount of soot and smoke, and (c) the sensible heat loss from clinker, not of major importance perhaps. It should be understood in judging these results that the work was done under rather difficult practical conditions and not in an ideally equipped laboratory. Whatever the shortcomings of the boiler may be the stoker has worked admirably on a wide variety of Iowa screenings, washed and unwashed, and the residents of the house have enjoyed during the most severe weather of the record winter of 1935-36 not only an adequate but an automatically regulated heat supply. In preparation for still more systematic work the coming winter season we are installing a new steel boiler of the Kewanee firebox type together with adequate instruments for use in controlling the operation of the setup. Under the new conditions we confidently expect to obtain efficiencies well up in the seventies.

Referring to Table XV it may be seen that test No. 10 gave results superior to the others shown as indicated by high overall efficiency—59.0 per cent—and by an equivalent evaporation of 6.1 pounds. It is evident, however, that the rate of firing was considerably lower than that applied in any other test of the series; in other words the slow feed was better adapted to the low rating of the boiler and the economy was correspondingly higher. With the higher rates of Nos. 6, 7, 8 and 9 efficiencies are lower although consistency is not always maintained. From careful observations of the stoker itself we are convinced that with a modern boiler of adequate size high economies could be obtained and that even as it is, the results are highly superior to those possible under hand firing when 35 per cent was all that could be reasonably expected. This judgment is confirmed in part by the opinions of engineers who have examined our setup and in part by the results of Randall(24) who obtained with Illinois coals burned under optimum conditions in a hand fired unit mounted in a specially equipped laboratory, efficiencies of approximately 42 per cent.

Table XV. Domestic Stoker Firing Tests

No. 2881 Holland Boiler with No. 10 Paragon Kol-Master Stoker

Number of test	1	3	4	6	7	8	9	10
Date	12-7-35	12-29-35	12-30-35	1-10-36	1-11-36	2-26-36	2-11-36	2-25-36
Duration of test (hrs.)	11	4.5	4	12	12	9	11	12.5
Outside air temp. °F.	50	...	30	30	30	—10	—5	32
Inside air temp. °F. (air feed)	62	65	65	77	77	75	67	77
Coal, size and kind	Washed scgs.	scgs.	scgs.	scgs.	Washed scgs.	scgs.	Illinois nut	scgs.
Ultimate Analysis as fired percentages:								
Free Moisture	14.7	17.2	17.2	17.7	17.1	16.8	16.1	10.5
Ash	13.3	15.4	15.4	15.3	13.0	15.0	11.1	18.2
Sulfur	3.5	4.8	4.8	3.9	3.1	5.7	0.6	5.5
Carbon	56.8	51.9	51.9	52.4	55.2	51.8	60.3	54.5
Hydrogen	4.1	3.8	3.8	3.8	4.0	3.8	3.8	4.0
Nitrogen	.8	.7	.7	.7	.8	.7	1.2	.8
Oxygen	6.7	6.0	6.0	6.1	6.4	6.0	6.8	6.3
Thermal value (B.t.u.)	10,320	9,650	9,650	9,650	9,930	9,740	10,400	10,030
Total wt. of coal fired, lbs.	1,332	393	316	1,110	1,058	899	713	621.5
Gases leaving setting								
Temp. in Deg. F.	800	750	750	730	750	920	680	485
Carbon dioxide per cent (av.)	14.1	6.5	10.7	9.8	11.2	11.2	9.2	5.5
Oxygen per cent	4.7	14.0	9.6	9.75	8.2	7.6	10.9	14.6
Carbon monoxide per cent	0.23	0.1	0.1	.16	.13	.15	.05	0.0
Steam and Feed Water:								
Steam press. lb. per sq. in. gage (av.)	3.5	0.7	0.8	.5	.5	.5	0.0	0.0
Temp. feed water to boiler, °F.	44	44	44	44	43	44	44	43
Total water fed to boiler, lbs. (total water evap.)	6,228	1,766	1,282	4,062	4,359	3,769	3,002	3,224
Hourly Rates:								
Coal burned as fired, lbs./hr.	121	87	79	92.5	88	100	64.8	49.7
Water evaporated, lbs./hr.	566	392	321	339	363	419	273	258

Heat Balance on 1 lb. coal								
Heat liberated in boiler	10,320	9,650	9,650	9,650	9,930	9,740	10,400	10,030
Heat absorbed by boiler	5,340	5,140	4,630	4,160	4,700	4,750	4,780	5,910
Per cent of total heat absorbed by boiler (over all efficiency)	51.8	53.3	48.0	43.2	47.4	48.9	46.0	59.0
Total heat loss in stack	2,619	3,990	2,671	2,950	2,880	3,153	3,114	2,933
Per cent heat loss in stack	25.34	41.34	27.65	30.6	29.0	32.35	29.9	29.2
Heat loss in dry gas	1,800	3,205	1,920	2,250	2,090	2,350	2,390	2,360
Per cent heat loss in dry gas	17.4	33.2	19.9	23.4	21.05	24.10	23.0	23.5
Heat loss due to H_2O, H_2 and CO	819	785	751	700	790	803	724	573
Per cent heat loss	7.94	8.14	7.75	7.2	7.95	8.25	6.90	5.7
Losses, radiation, etc., by difference	2,361	520	2,349	2,540	2,350	1,837	2,506	1,215
Item above in per cent	22.86	5.36	24.35	26.22	23.60	18.75	24.0	11.8
Equivalent evaporation	5.50	5.28	4.78	4.30	4.85	4.92	4.93	6.1

The following comments based upon critical observations of the behavior of the stoker in burning Iowa coals summarize our conclusions regarding their suitability for such use. They are particularly significant because no attempt has been made to secure the best supplies available; rather have we drawn upon the regular shipments to the power plant which include both well and poorly prepared steam sizes.

1. The presence of fines does not materially interfere with the proper operation of the stoker, nor does moisture up to 20 per cent. Duff or bug dust is out of place in the domestic coal bin not only because it is easily scattered through the house but because it usually has a high ash content, but so far as burning qualities are concerned the mechanical stoker will handle fines that would normally smother the hand-fired furnace fire.

2. Iowa coal ashes are sufficiently fusible to form a compact and easily handled clinker but in no case have we observed a fluxing effect great enough to obstruct the tuyeres. In test firing at high rates with continuous feed a clinker ring may form around the retort so heavy as to make its removal difficult but with normal intermittent operation no trouble of this kind has been encountered. In the use of certain Eastern coals with high fusing ashes we have observed on the other hand that clinkers are often loose and friable making the use of the shovel necessary for their removal; under optimum running conditions with Iowa coals the clinker tongs only are needed.

3. Little or no loss of fuel occurs by entrainment with the clinker, i. e. fusion of the ash takes place only after the coal is completely burned.

4. Combustion of Iowa coals with the setup in question is not entirely smokeless especially when the fuel bed is unduly disturbed but conditions in this respect are vastly better than with the best hand fired furnace using the same kind of coal. The normal stack emits only a light gray fume and even when black smoke emerges it is relatively low in quantity. The use of a prepared coal of uniform size and careful regulation of the draft-feed ratio invariably brings the smoke down to a minimum.

5. So long as smoke is formed in any amount soot will also be present since both have common origins. Boiler tubes therefore require regular and thorough cleaning although the necessity is much less pressing than with hand firing.

6. Results of studies so far as they have been carried on to date indicate little or no difference between efficiencies with washed and unwashed coals; nor should great variation of the kind be expected when a well designed machine is used under moderate load although it may become evident when ash and dust contents are excessively high. The major advantage of coal cleaning as it applies to domestic use must be sought in cleanliness and freedom from dust, in uniformity of size of coal which promotes uniformity of combustion and in the reduced amount of refuse that must be removed and handled.

THE CARBONIZATION OF IOWA COALS

In Technical Paper No. 2 we made a fairly elaborate progress report on the study of the coking properties of Iowa coals undertaken to demonstrate the possibility of coke production on the industrial scale; this brief review is designed to sum up our general conclusions. It was shown that while the old conventional methods of carbonization that are standard fcr Eastern coals failed to produce coherent cokes it was entirely possible by using a method adapted to the midwestern type with its higher oxygen content to secure a relatively dense, firm product. This process based on the principles established by Parr at the University of Illinois involves the separate, rapid preheating of the mass to a temperature near the critical fusing point of the coal and its quick transfer to a heated retort to prevent the slow oxidation of the inherent coking component and its destruction before the coking reaction could take place.

The range of territory from which samples were collected which included the counties of Adams, Appanoose, Boone, Dallas, Mahaska, Marion, Polk, Taylor, and Wayne, embraced not only the principal producing areas but covered as well the spread in coal quality from the older bituminous deposits of the Des Moines series to those of the younger Nodaway bed of the southwestern part of the state which are sometimes classed as sub-bituminous. It is noteworthy that even the latter although possessing many of the attributes of the more primitive coals such as high inherent moisture and oxygen contents, under the proper conditions produce cokes of fair quality. It is evident therefore, that the term "coking tendency" must be qualified by specifying the method used in measuring it; the coals of this state are in a real sense of coking grade.

The general appearance and characteristics of the twenty odd cokes

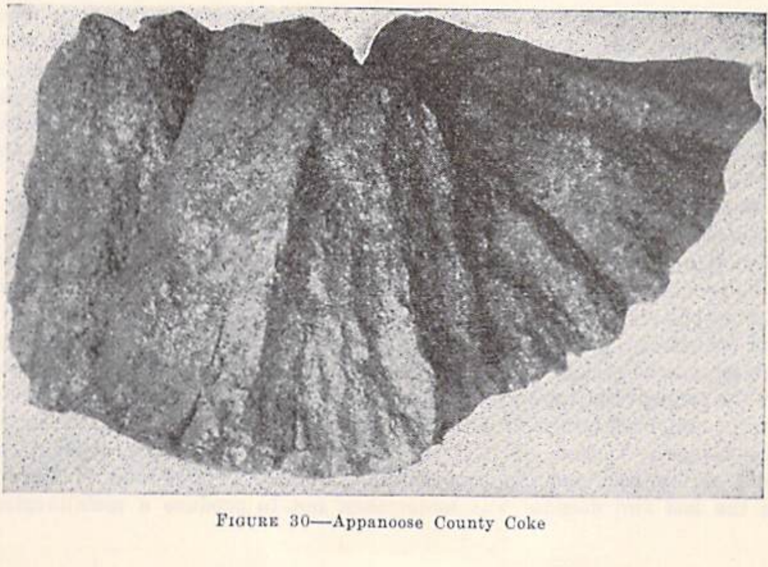

Figure 30—Appanoose County Coke

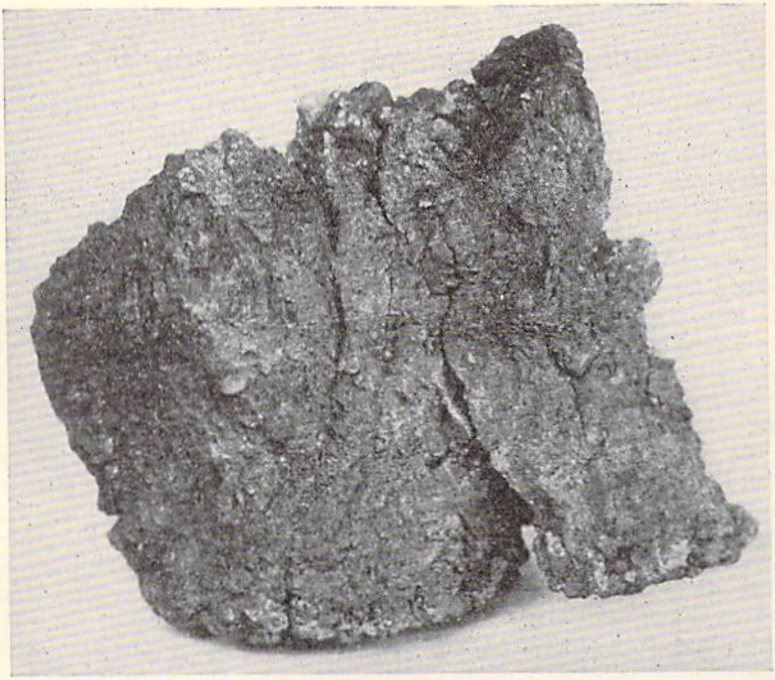

FIGURE 31—Wayne County Coke

obtained may be judged from Figures 30 and 31 which illustrate typical products from Appanoose and Wayne Co. coals respectively. They are sufficiently firm to stand considerable handling and are fairly dense (sp. gr. .678), with fine pore structures that indicate that the coals from which they were made were well balanced in composition, i. e. they contained neither so much coking material (designated as "bituminic" by Parr) as to make the residue light and frothy nor so little as to provide insufficient bonding strength. The coking period was 5.7 hours and the maximum temperatures about 800°C (1475°F), which characterizes the process as one of medium temperature carbonization.

The chemical composition of any coke depends directly of course upon the quality of the original coal and its ash content varies with the amount of moisture and volatile matter driven off. The samples in question have ash, volatile matter and fixed carbon percentages of about 18.5, 4.0 and 77.5 respectively, and thermal values of 12,450 B.t.u. In accordance with the well known principle that cokes formed at relatively low temperatures ignite at lower temperatures and burn more freely than those carbonized in the commercial coke oven at 1200°C (2200°F), all of our cokes kindle easily and maintain a free, lively, smokeless blaze on the grate or in the furnace. Indeed much of the vast amount of research done in the field of low and medium carbonization in this country and in Europe in the last two decades was undertaken not to produce a metallurgical coke but to work out a practical method for making a clean, free burning domestic fuel from the ordinary bituminous coals. That end has long been definitely accomplished so far as the technical aspects of the problem are concerned; economically the scheme is not feasible in the United States at least because of the reluctance of the consumer to pay the costs of processing since other cheaper fuels offer equal advantages in respect to cleanliness. It should be noted that shrinkage in weight due to loss of moisture and volatile matter reduces the net yield of coke to approximately 55 per cent of the raw coal charge.

Yields of gas were about 6,000 cubic feet per ton, considerably less than in standard coking practice, as should be expected at the temperatures employed. Tar production on the other hand averaged 20 gallons per ton, a figure well above that for high temperature processes. In fact the high tar yields of low and medium temperature carbonization technic have been the incentive for some of the research in this field, in the hope that from it might come developments of economic importance in motor fuel production. More than ten years ago Egloff and Morrell (14) obtained 40 per cent of gasoline in cracking low temperature tar; doubtless with the improvement in oil refining that has come since that time even more could be produced today. But the fact remains that tar is after all only a by-product and unless or until a ready market can be obtained for the coke no major developments in carbonization for producing petroleum substitutes need be expected. The composition of a typical tar produced in our work is given in Table XVI.

Table XVI. Composition of Tar, Iowa Coal Carbonization Studies

Component	Percentage of fraction	Percentage of total (dry basis)
light oil (110°C-235°C)		26.5
acids	3.4	
bases	1.1	
neutrals	21.9	
heavy oil (235°C-300°C)		15.0
acids	2.4	
bases	1.1	
neutrals	11.5	
aromatics from neutrals	25.7	
paraffins from neutrals	5.2	
naphthalene	.43	
anthracene	1.02	
pitch		53.0
melting point	170°C (338°F)	
specific gravity	1.29	
per cent free carbon	66.0	
losses		5.5

STUDIES IN THE CLASSIFICATION OF IOWA COALS

The formal, scientific study of related forms of matter, living or inanimate, if it shall be established on a firm foundation must begin with some scheme of classification of the varied materials under discussion. Witness the branch of taxonomy in the biological sciences with its elaborate classification of the flora and fauna into phyla, classes, orders, families, genera and species. In the realm of commerce a glance at the market page of the daily newspaper shows that wheat quality ranges from No. 1 to "sample" grade and that eggs go from selects all the way down to "rots and spots." It should be evident therefore that in dealing with a substance such as coal that has both scientific and commercial significance, the need for classification is especially great and that no apology is necessary for the efforts of the geologists and chemists who have long endeavored to work out systems to cover the wide range of types.

The many schemes that have been proposed differ widely and none has yet been universally or even generally adopted. Each is based upon some kind of correlation of physical and chemical properties of the different coals, among which the following may be listed: (1) percentage of moisture as mined, (2) percentages of volatile matter and free carbon, (3) hydrogen, oxygen, and carbon contents, (4) thermal values, (5) slacking index (the indication of its tendency to disintegrate on drying), (6) agglutinating index (the measure of the firmness of the coke that may be made from it under standard conditions), (7) avidity for oxygen at low temperatures, (8) kindling temperature, (9) sulfur content, (10) ash fusion temperature, and others of greater or less importance. The specifications of the American Society for Testing Materials for the classification of coals by rank, A. S. T. M. Designation: D 338-34T, are still only tentative and are therefore, subject to annual revision. In their present state the rank of a coal is determined by a correlation of fixed carbon on the dry ash-free basis with moist, ash-free thermal values, qualified by the results of slacking and agglutinating tests. Four classes are proposed, anthracitic, divided into three groups, meta-anthracite, anthracite and subanthracite; bituminous with five groupings, low volatile, medium volatile and high volatiles A, B, and C; subbituminous, grouped as A, B and C; subbituminous, grouped as A, B and C; and lignitic, distributed between lignite and brown coal.

By way of illustrating the use of the code the cipher

(62-146) ag-nw-132-A8-F24-S1.6

indicates that the coal as sampled has 62 per cent dry, ash-free fixed carbon and a thermal value of 14,600 B.t.u.'s on the moist, ash-free basis; that it is agglutinating and nonweathering by the standard tests; that it has an as received thermal value of 13,200 and an ash content of from 6.1 to 8.0 per cent, inclusive; that its ash fuses within the temperature range of 2400° to 2590°F and that its sulfur content lies between 1.4 to 1.6 per cent. By reference to a table of standards or to a properly plotted graph it may be seen that this coal is ranked as high volatile A, bituminous. Since the figures within the parentheses are independent of ash values, which vary with the care taken in collecting the sample, and are based only upon the percentage of natural mine moisture and the chemical composition of the organic matter of the coal, they constitute a measure of worth for comparison with coals from other fields much as a family name may designate the stock from which a human individual comes. The rest of the code shows up the actual worth of the commercial sample as mined by answering questions with regard to its response to weathering and burning conditions, its actual fuel value and the amount and character of its mineral impurities. In other words it shows how successfully the individual lives up to the family tradition.

In common with numerous other agencies both academic and private, our laboratory has for some time cooperated with the Bureau of Mines in the work of collecting fundamental data to be used in building up the classification structure, specializing of course on the coals of Iowa. Of prime importance is the task of gathering and analyzing face samples from the mines in current production to amplify and in some cases to replace the old results in government publications. Technical Paper No. 269 of the Bureau, "Analyses of Iowa Coals," published in 1921 (2) while still authoritative in many respects includes many results of analyses of coals from mines that long have ceased production. Indeed, some date back as much as 80 years to times when analytical technic was somewhat crude and none is less than 20 years of age. Our contributions of the last five years to the data on coal composition including figures on moisture, ash, volatile matter, fixed carbon and thermal values, are presented in Tables I and II under another head, and to these, additions are being constantly made.

We see however, that other properties not covered by the ordinary proximate analysis are significant in characterizing a given coal, properties that often are more important to the consumer than those evaluated under some formal classification code. In addition to the study of coking and slacking indices, which are recognized in the A. S. T. M. scheme outlined above, our investigations have covered a comparative study of kindling temperatures of Iowa coals and others from distant fields; the development of a tentative method for measuring the tendency of a coal to produce smoke and its application to tests of coals of widely differing character and the use of the so-called "permanganate number" as a criterion of the chemical age of a coal. Brief reports of the results of these studies are included rather to put them on official record against possible future developments in coal classification, than to serve a direct utilitarian purpose.

The Agglutinating Indices of Iowa Coals

The problem of the chemical structure of coal while one of the most tantalizing offered to the scientist is at the same time one of the most baffling and difficult of solution not merely because it lies in the complex field of cellulose chemistry but because it is concerned with the changes the original plant structures have undergone after millions of years of condensation or polymerization. In simpler terms, the easily separable compounds of the woody structure, through processes of partial decay have merged or recombined to form so-called "polymers" or substances of great molecular size. In the main, these compounds are insoluble in the ordinary solvents with which the chemist works and inert to the common reagents, except of course to oxygen at high temperatures, with the result that the experimental laboratory finds itself without a ready means of attack. Indeed because of this situation doubtless, the organic chemist has in the past rather consistently avoided the class of polymers in his formal studies and only in recent years has their importance to the petroleum industry forced them to the attention of the industrial chemist.

In the realm of coal chemistry, however, outstanding work by such men as Lewes in England, Parr in this country and Franz Fischer in Germany, to mention only a few, has gone far to put our knowledge of coal structure on a rational, scientific basis. Since their time and greatly stimulated by their example, the literature of the subject has expanded enormously and according to the latest report of "Bituminous Coal Research Inc."(15) many of the more than fifty academic and industrial laboratories in the United States engaged in coal research are working on this problem.

Of major importance to the theory of coal carbonization is the work of Lewes which was expanded and perfected by the fundamental researches of Parr. By the use of solvents such as phenol and other coal tar derivatives Parr separated the coal substance into two principal fractions, a group of insolubles whose origin is the woody portion of the original plant material and designated as lignitic residue, the other soluble and extractible, related to the resins in the wood tissue, known as "bituminic substance." He proved that the first was extremely sensitive to oxygen at ordinary temperatures and that it decomposed on the application of heat without melting and without leaving a cellular coke structure. The freshly extracted bituminic fraction on the other hand fused easily and left finally the coke button characteristic of a coking coal. The crux of the coking reaction of a coal, however, is the oxygen content of the lignitic fraction. When its oxygen percentage is high due to a retention of the oxygen of the original cellulose or to its absorption from the air the interaction of the oxidized lignitic portion with the bituminic fraction destroys the coking power of the latter and a powdery residue is left after the thermal treatment.

It follows therefore, that the firmness of the coke button produced from a fresh sample is an index of the degree to which the original plant material has lost oxygen in the long road up the fuel scale and therefore indirectly of its rank as a coal. The agglutinating test is thus logically established as a tentative method for coal classification.

The tentative method for the determination of agglutinating value as proposed by the American Society for Testing Materials and published in Part I of the Proceedings for 1934 involves briefly, the following procedure: The coal sample, air dried for 24 hours, is crushed to 200 mesh and mixed with acid washed Ottawa sand (between 45 and 60 mesh in size to which 3 drops of glycerine have been added) in the ratios of 15, 20 and 25 parts to 1 of coal. The mixture after being packed in a No.

380 cylindrical crucible for 30 seconds under a weight of 3,500 grams is protected from access of air and heated for 20 minutes in the electric furnace at a temperature of 950°C. The coke button formed is cooled and smoothed off, then subjected to steadily increasing pressure until it fails by crushing. The weight in kilograms is designated as the agglutinating index and coals having average agglutinating indices of 0.5 kilogram or more at the 15 : 1 ratio are considered agglutinating from the standpoint of classification.

Table XVII shows the values obtained with 24 Iowa coals in tests under the three conditions of sand dilution, together with corresponding values for a few out-of-state coals by way of comparison. All the coals tested without exception passed the minimum requirements by wide margins thus demonstrating conclusively their coke forming possibilities. It does not follow of course that these results indicate carbonization possibilities by the standard commercial methods; the metallurgical coals of Pennsylvania and West Virginia give indices ranging from 8 to 10 in value. On the other extreme the lignites and sub-bituminous coals of the Dakotas and Wyoming have no coking properties whatever.

Quite separate from their use as criteria of the rank of a coal, agglutinating indices have a direct bearing on the suitability of the coal for firing on a given type of grate or stoker. Apropos of this point Fieldner(16) of the Bureau of Mines observes: "Preliminary investigations have indicated that the plastic properties of bituminous coals are of great importance in fitting the proper type of mechanical stokers to different coals. It is believed that the determination of agglutinating index will in the future be as important as the determination of the fusibility of coal ash. The one test gives an indication of the clinkering properties of the coal, while the other throws light on the caking properties of the fuel bed."

"The Bureau of Mines hopes to obtain considerable information on the value of the agglutinating tests in practice during the coming year. The

Table XVII. Agglutinating Indices of Iowa and Out-of-State Coals

County of Source	Agglutinating Indices		
	Ratio 15—1	Ratio 20—1	Ratio 25—1
Adams	1.24	.74	.69
Appanoose	2.26	1.93	1.18
Boone	1.10	....	....
Lucas	3.02	1.70	1.40
Mahaska	3.44	2.35	2.97
Marion	2.31	1.55	.82
Monroe	3.46	1.62	.87
Page	.93	.52	.27
Polk	1.86	1.27	.82
Wapello	2.40	1.51	.78
Warren	3.10	1.59	1.08
Franklin, Ill.	2.44	1.71	1.01
Perry, Ill.	3.97	3.08	1.72
Henry, Ill.	4.40	3.10	1.96
Vigo, Ind.	3.85	3.30	2.10
McDowell, W. Va.	3.65	2.30	1.51
MacHenry, Ky.	4.50	3.85	2.48
Johnson, Ky.	1.65	.73	.41

Bureau's efficiency engineer for the various government heating and power plants is much interested in the possibilities of what this test may show in connection with the caking of coal in hand and stoker fired furnaces. He is observing the performance of various coals on which the agglutinating indices have been determined. At the end of another year we hope to have some data as to whether the test is of any value in predicting the caking of coals in fuel beds."

The Disintegration or Slacking of Coal

One of the most striking characteristics of a primitive coal such as lignite is its high moisture content that ranges between the values of 30 and 40 per cent when freshly mined. The significance of this moisture lies in the fact that its presence is closely linked to the physical and chemical character of the coal, particularly to the amount of colloidal matter it contains and so directly to its rank. On exposure to air lignite quickly loses the major part of its absorbed water; as a result of this drying, internal strains are set up due to shrinkage, and the mass quickly breaks down to fines. Because of the close correlation between the moisture of the seam and the rank of the coal, classification schemes based upon relative moisture values alone have been proposed although not generally accepted as being fully adequate to cover the whole range from lignite to anthracite. Moisture content is nevertheless, a vital factor in any scheme and as such enters into the structure of the A. S. T. M. method under current discussion.

Since loss of moisture causes the disintegration of the lump the degree to which this takes place, determined by what is known as the "accelerated weathering test," is used as a measure of the firmness or solidity of the coal and indirectly of its rank; e. g. the complete slacking of the lignite marks it definitely as a primitive or low rank fuel. The tentative method specifies that the selected lumps under the test are to be dried at a temperature of 30° to 35°C for 24 hours, then submerged in water for one hour and dried as before. Following this treatment they are shaken over a 0.263 in. sieve; the weight of the undersize that breaks down is a criterion of its slacking tendency.

Figures 32 and 33 show plots of slacking results obtained on a series of Iowa coals and of a number of representatives from foreign sources carried through six cycles. They agree in general with those published in Technical Paper No. 2 which were based upon a slightly different technic wherein the samples after the 24 hour soaking were dried for one hour at a temperature of 225°F under a vacuum of 28 inches. It is apparent that many of the Iowa coals with the exception of some of those from the extreme south and west compare favorably with those of Illinois in their resistance to fracture. And yet even those from the Mystic seam in Appanoose County find wide markets by virtue of the long wall mining methods employed that reduce breakage to a minimum. Coals from the Atlantic seaboard states are in general hard and firm because of the effect of the crustal movements that were associated with the Appalachian mountain building upheaval, although we find a notable exception in the Pocahontas type that is notoriously friable even though

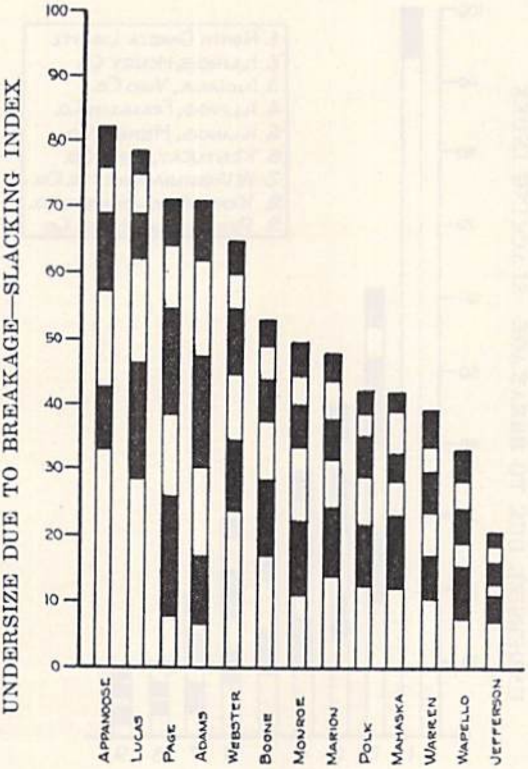

FIGURE 32—Slacking Tendencies of Iowa Coals

its moisture content is low. Lignites and the sub-bituminous coals of the Western states are in a class by themselves with respect to slacking tendency as shown by the fact that a nearly complete breakdown occurs in the first cycle.

While the slacking test is valuable as a means of rating a coal in rank and in relative durability on handling it should not be interpreted as an accurate measure of its marketability. The mining of bituminous coal, at least in its modern setup is a seasonal industry whose producing mechanism functions in the main only when consumer demand is active in order to avoid the expense of providing storage. It follows that the lag between production and consumption is generally too short to allow any considerable drying and disintegration to take place even where such potential trouble exists and that difficulty is encountered only where long storage periods are involved. In the case of the lignite and sub-bituminous ranks on the other hand, structural decay proceeds so rapidly due to high moisture content that the radius of shipment is necessarily limited and the most live and persistent research problem of the fuel industries of Wyoming and North Dakota is that of devising methods

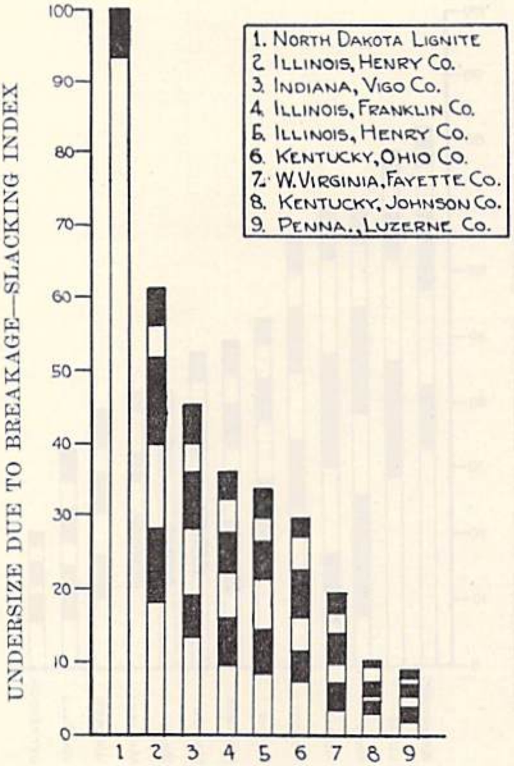

Figure 33—Slacking Tendencies of Out-of-State Coals

of processing the crude fuels by briqueting or other means to make them amenable to the demands of ordinary handling.

The Rank of Iowa Coals as Measured by Oxygen Absorption

Perhaps no chemical property of a certain class of coals is more obvious to the fuel technologist than the speed and avidity with which they absorb oxygen from the air even at ordinary temperatures, particularly when they are in finely divided condition. Through the fundamental studies of Parr already discussed under the head of Coking Indices the sensitivity of the lignins to oxygen and their relation to the bituminic fraction and to the coking properties of the coal have been clearly established. As the aging process in coal formation goes on through geologic time it appears that in the slow chemical changes involved in polymerization the lignins lose not only their inherent oxygen but much of their power for absorbing it from outside sources. It follows that because of tneir inherent chemical inertness the older coals undergo little or no damage in storage piles and that as a rule they produce the firmest cokes.

Since the extent to which oxygen attacks the coal structure is a natural function of its age or rank the measurement of low temperature oxidation should be a promising method for use in coal classification. Indeed numerous chemical methods for such studies have been proposed employing nitric acid, potassium chlorate and the like, but perhaps the most satisfactory is that based on the use of an alkaline solution of potassium permanganate. Our method which followed closely that of Heathcoat(17), involved first the extraction of the coal substance with pyridine which does not affect the lignins but which dissolves the bitumens. The solid residue was then treated with a measured excess of permanganate solution near the boiling temperature for an hour and after filtration the solution was titrated with standard sodium oxalate to determine the amount of oxygen taken up by the coal substance. This value, expressed in specific terms as the "permanganate number," is extremely high for lignites but negligibly small for anthracites. In the long range between these extremes may be fitted the bituminous grades of varying quality from the Pocahontas of West Virginia to the sub-bituminous coals of Wyoming or Montana.

In Figure 34 we have illustrated the relative ranks of a group of Iowa coals by plotting some of their characteristic properties in comparison with those of a number from out-of-state ranging in rank from lignites on the extreme left to anthracites on the right. The lower bars indicate a definite fall in mine moisture with advancing chemical age and thus support the use of the natural moisture percentage as an element in the classification structure. The volatile matter curve and its mirror image fixed carbon, is less regular inasmuch as quantity and not quality of the volatile gases given off is plotted. Doubtless the oxygen contents of the volatiles, which diminish with the maturity of the coal, would constitute a better criterion for classification purposes than volume alone and a plot based on an oxygen-hydrocarbon ratio might be more significant than the one shown.

The cross-hatched bars show a remarkable coordination between the permanganate number and the age and maturity of the coal as set by other standards and it appears to be a highly important and significant criterion of coal age and quality. Here as in the comparison of slacking and coking indices is demonstrated the wide gaps between the lignites and sub-bituminous coals occurring in the states west of the Missouri and those of the Pennsylvanian system to the east.

So far as the Iowa coals are concerned we find Nos. 4 and 5 (from Page and Taylor counties respectively) highest in the permanganate scale as we should expect from their well known weathering tendencies and their high bed moisture content. They are obviously the lowest in rank of the coals in the state and have been designated by Campbell of the U. S. Geological Survey as "sub-bituminous"; whether this name is to be permanently adopted must depend of course upon the final definition of the term. Nos. 6 to 14 which are representatives of our important commercial mines are seen to merge into line with those from Illinois; in other words there seems to be little difference in rank except in the case of those from the extreme south of that state where crustal movements during one or more of the Ozark uplifts produced a profound effect on coal quality by lowering moisture and volatile contents. Upon such

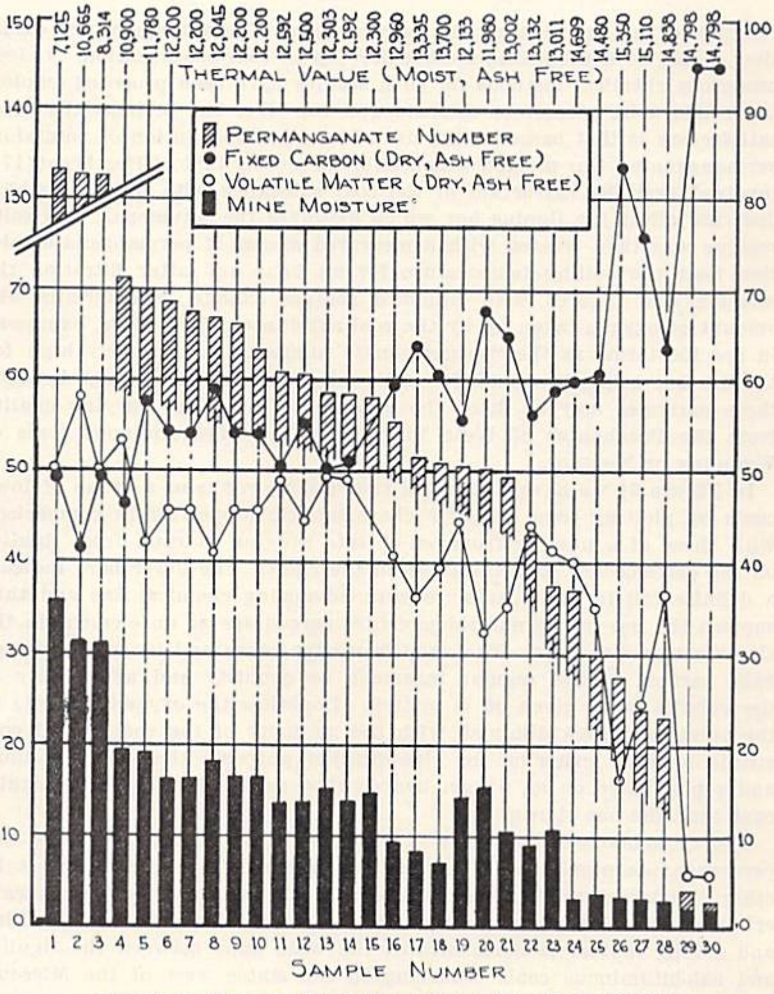

FIGURE 34—Chemical Properties of Coals (See Table XVIII)

evidence as that presented here as well as upon many other criteria we have long based the contention that Iowa coals in the main are on the same rank level as those from veins 1, 2, 5 and 7 of Illinois known as Rock Island, La Salle, Springfield and Danville respectively and that with equally good preparation they should be coordinate with them in market value. Grade as distinguished from rank is a different matter. Grade depends upon the care with which the coal is mined and prepared and upon this in turn depends ash content, size classification and general suitability for the specific purpose for which it is intended. Careless preparation may turn out a low grade coal from a high rank vein; or conversely, intelligent care may produce a highly satisfactory grade from seams of the lower ranks.

Table XVIII. Sources of Coals Used in Permanganate Number Studies
(See Figure 34)

Number	Rank	County	State	Name or Number of Seam
1	lignite		South Dakota	
2	lignite	Powell	Montana	
3	sub-bituminous	Campbell	Wyoming	Roland-Smith
4	bituminous	Page	Iowa	Nodaway
5	bituminous	Taylor	Iowa	Nodaway
6	bituminous	Appanoose	Iowa	Mystic
7	bituminous	Appanoose	Iowa	Mystic
8	bituminous	Dallas	Iowa	
9	bituminous	Appanoose	Iowa	Mystic
10	bituminous	Appanoose	Iowa	Mystic
11	bituminous	Monroe	Iowa	
12	bituminous	Mahaska	Iowa	
13	bituminous	Polk	Iowa	
14	bituminous	Monroe	Iowa	
15	bituminous	Henry	Illinois	La Salle No. 2
16	bituminous	Jackson	Illinois	Murphysboro
17	bituminous	Williamson	Illinois	No. 6
18	bituminous	Saline	Illinois	No. 5
19	bituminous	Sangamon	Illinois	No. 6
20	bituminous	Fulton	Illinois	No. 6
21	bituminous	Franklin	Illinois	No. 6
22	bituminous	Hopkins	(W) Kentucky	No. 11
23	bituminous	Christian	(W) Kentucky	Empire Seam
24	bituminous	Claiborne	Tennessee	Jellico Seam
25	bituminous	Perry	(E) Kentucky	Hazard No. 4
26	semi-bituminous	Raleigh	West Virginia	Beckley
27	semi-bituminous	Fayette	West Virginia	New River
28	bituminous	Mingo	West Virginia	Dorothy
29	anthracite		Pennsylvania	
30	anthracite	Luzerne	Pennsylvania	Northern field

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