Jean Cutler Prior
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State of Iowa
1930

Studies of Iowa Coals

TECHNICAL PAPER NO. 2

Issued by the Iowa Geological Survey
George F. Kay, Director
James H. Lees, Assistant State Geologist

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FOREWORD

The papers contained in this bulletin have been prepared by Dr. H. L. Olin, Professor of Chemical Engineering, State University of Iowa, and by Dr. James H. Lees, Assistant State Geologist. The papers written by Doctor Olin deal with the following subjects: "Some Aspects of the Iowa Coal Problem," "Analyses of Iowa Coals," "Comparative Studies in Iowa Coal Storage," "Weathering of Iowa Coals," "Washing Studies in Iowa Coals," and "Coking of Iowa Coals." The paper by Doctor Lees has as its subject "The Geology of Iowa Coals."

In the paper "Some Aspects of the Iowa Coal Problem," Doctor Olin reviews the various trends in fuel consumption and economy that have forced a crisis in the coal mining industry in the entire country as well as in Iowa, in particular the rapidly increasing substitution of petroleum and natural gas for coal. To save for the local industry a fair share of the business that remains against the keen competition of out-of-state producers, Doctor Olin urges the necessity of scientific study of the native coals, if only to refute the false propaganda spread, in a measure, by self-interested agencies and to help restore confidence in fuels that have many virtues as well as faults.

In "Comparative Studies in Iowa Coal Storage" is described a series of tests designed to measure the rate of heating of Iowa coals in storage, particularly in comparison with western Kentucky coals under similar conditions. New methods were devised for observing change of temperature and for checking oxidation by liberation of carbon dioxide. Within the limits of the tests Iowa coals showed less tendency to heat than those from Kentucky.

In "Washing Studies in Iowa Coals" are given results of analytical studies on the possibilities of ash and sulfur elimination through washing processes. Great improvement of quality is possible in most of the cases observed and in certain cases there is promise of commercial success for washing operations.

"Weathering Tests of Iowa Coals" is concerned with a new method for measuring resistance of the coals to breakage in handling and storage. Contrary to popular opinion it appears from comparative tests on Iowa coals and a number from various sections of Illinois that the former have as firm a structure as the latter with the exception of those from the extreme south of Illinois within the zone of the so-called Ozark uplift.

In "Coking of Iowa Coals" is a report on carbonization studies made to determine coking tendencies and possibilities. Although Iowa coals have long been considered noncoking in character we have shown that under the proper conditions cokes of moderately firm structure can be obtained from them.

Doctor Lees in his paper discusses the factors that affect the characters of different coals, the general conditions of coal formation, and the particular conditions under which Iowa coals were formed. He has also described briefly the character of the Coal Measures strata and has given some data regarding coal mining in Iowa. The study seems to indicate that Iowa has enough coal to last many years in the future and that all of this coal lies within the limits of economical mining.

A report, "Analyses of Iowa Coals," by Doctor Olin and Doctor Lees, part of which is republished as the second paper of this series, was distributed by our Survey in 1929.

Respectfully submitted,

George F. Kay, State Geologist.

SOME ASPECTS OF THE IOWA COAL PROBLEM

H. L. Olin

Professor of Chemical Engineering, University of Iowa

In common with the producers of coal in many other states of the Union and of foreign countries as well, the operators of Iowa have suffered a sharp loss in tonnage output since the high peak of the War period. The rise and decline of this major industry that has increased the wealth of the state of Iowa alone by more than a billion dollars since its beginnings in 1840 are strikingly shown by the index curves of Figure 1 wherein production at a given time is plotted as percentage of average tonnage put out over an initial time interval, in this case the period 1910-1914. These plots of operations in Indiana, Illinois, Iowa, West Virginia and Kentucky indicate that in all but the last two states named, where labor is largely non-union, production has either dropped severely in the last decade or has failed to maintain the normal increase to be expected with growth of population and expansion of industry. In other words, the coal industry as a whole is ailing, if not actually ill.

For the proper interpretation of these statistical facts, which superficially seem to indicate that the general demand for fuel energy is diminishing, two highly significant trends in fuel consumption must be considered. Briefly stated the first is the moderate but steady improvement in the efficiency of steam power plants which makes possible the production of more and more energy from a given weight of coal and the other is the actual and potential competition of other forms of fuel in all the fields of power generation and heating. We are indebted to Mr. F. G. Tryon, Statistician of the Bureau of Mines, for an admirable review of the trend of coal demands, adapted from an address delivered at the Carnegie Institute of Technology and published in the Department of Commerce Bulletin "Coal in 1926" and acknowledgment is here made to him for some striking illustrations and figures that follow in support of the statement made above.

As an example of improvement in power generation he cites the old atmospheric engine which consumed 30 pounds of coal per horsepower hour. Watt with his steam engine reduced combustion to 10 and then to 6 pounds. In 1820 the *Savannah*, the first ship to cross the ocean under steam, burned about 10 pounds but in 1907 the *Lusitania* was using only 1.4 pounds per unit. Tryon points out moreover that while this 86 per cent reduction required 87 years for accomplishment the public power utilities have, by reducing consumption from 2.4 pounds in 1919 to 1.46 pounds in 1926, crammed a decrease of 39 per cent into the space of seven years.

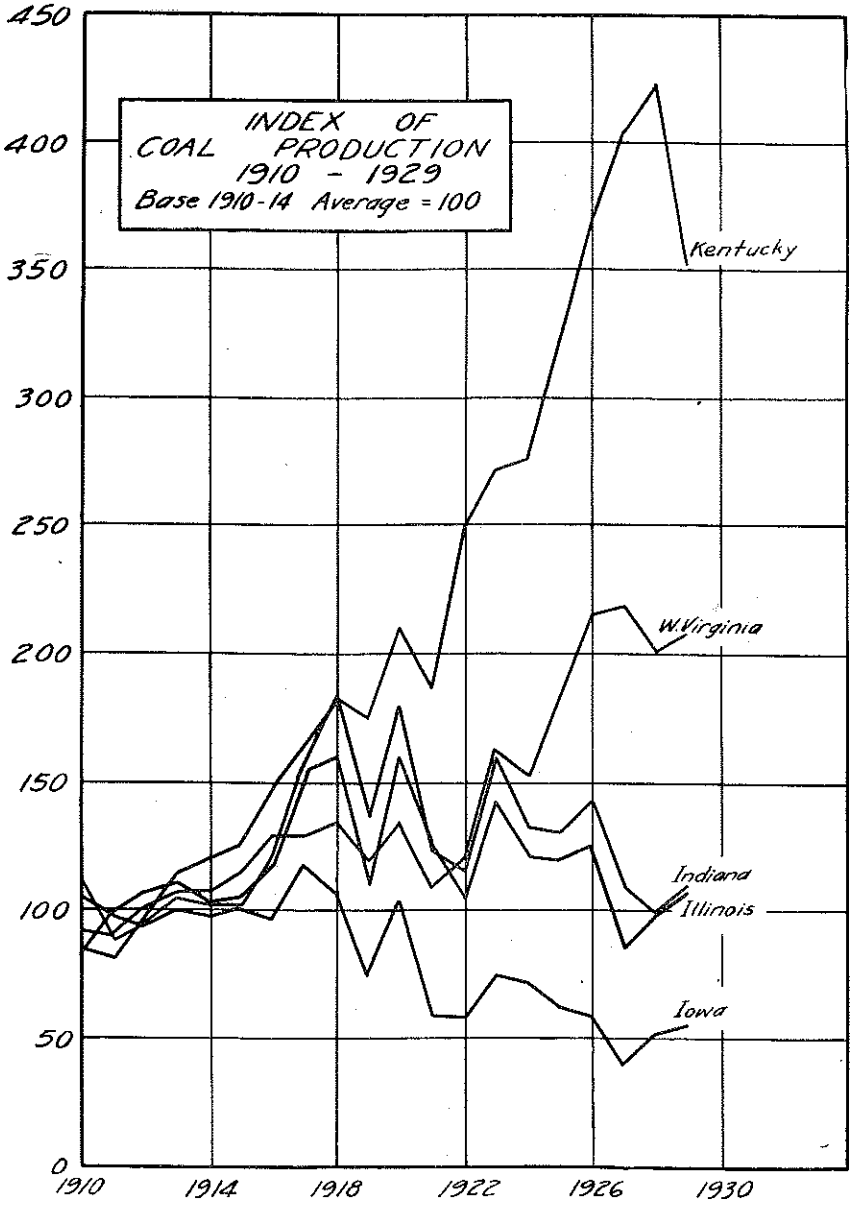

FIG. 1. Index curves of coal production.

In locomotive performance on Class I railroads the consumption of coal per thousand gross ton-miles was 176 pounds in 1917 and 137 pounds in 1926, a decrease of 22 per cent. Indeed the Union Pacific has a new locomotive that has been running on 70 pounds although this has been possible only under the specially favorable conditions of heavy trains and long hauls and should not be taken as indicative of normal rail performance. Similarly the consumption per passenger-train car-mile was 19.4 pounds in 1917 and 15.8 pounds in 1926, a decrease of 19 per cent. In 1917 the production of a ton of pig iron required 3,524 pounds of coking coal; in 1926 15 per cent less or 3,004 pounds only were used, nor does this saving include the value of gas, tar and light oils recovered as by-products from the modern coke oven which has largely superseded the old bee-hive type, and which replaces an equivalent amount of coal. There is furthermore a steady improvement in the power plant of the private manufacturing establishment, which is being brought about as in the case of the public utility by more or less drastic revamping of equipment and by the application of modern combustion principles and scientific control. With the rapid spread of super-power systems with their enlacing network of lines, the inefficient plant, public or private, will soon be as obsolete as the horse and buggy.

It does not follow of course that this rapid rate of improvement in fuel efficiency will continue indefinitely. There are practical limits beyond which economy cannot go; points where the capital cost of saving a given amount of fuel equals the value of the fuel saved and some of the industries are perhaps approaching that situation. However, one more trend which is at present only in its initial stage should be considered before leaving this subject. The heating of dwellings, which absorbs nearly one-fifth of the coal output, has doubtless far to go before it is perfect from the standpoint of either furnace design or combustion efficiency. But what promises to be the most significant advance in economy in this field comes from the rapidly increasing use of insulating materials in building construction, which in cutting down wall radiation will at the same time reduce fuel demands. The rapid expansion in the manufacture of insulating lumbers which is one of the significant movements in modern industry may be gauged from figures furnished by a leading corporation in that business. From an output of 18,000,000 square feet in 1922 they went to 332,000,000 in 1929 and are now preparing for still greater production. Many types and qualities are being put on the market, made from materials ranging from gypsum and lumber wastes to sugar cane bagasse and the cornstalk. It is fair to assume that little home building of the future will fail to take advantage of the comfort and protection which these fabrics provide and which according to reliable estimates make possible a reduction of coal consumption by 30 per cent or more.

The second significant trend as noted above, viz. the competition of other types of fuels, adds more than the other, perhaps, to the acuteness of the present coal situation. Referring again to Tryon's figures, we see that so late as 1913 the relative contributions of the two great sources of energy, coal and petroleum (including gas), to the total needs of the country, were

87 per cent and 13 per cent, respectively, calculated of course to equivalent units. Of the total for coal the bituminous fields furnished 73 per cent. In 1928 this proportion had shifted to 67 per cent for coal and 33 per cent for oil and gas, with only 57 per cent of the total supplied from bituminous sources. These figures speak with an eloquence that mere words fail to reach.

To accelerate this change in status great trunk lines are even now bringing natural gas from the vast fields of Texas and Oklahoma east to Memphis and Birmingham and Atlanta, and north to the industrial centers of Omaha, Kansas City and St. Louis. Extension of this service across Iowa, where it will bid for domestic and other heating markets, is in immediate prospect. Indeed McBride,* a leading fuel expert, says, "It is probably not too much of a generalization to say that natural gas will replace substantially all manufactured-gas supply in the area west of the Mississippi and south of the Ohio, and even in the northeastern territory manufactured gas is threatened with replacement by the gaseous byproducts of the petroleum refinery." In this connection, however, it must be noted that much of this natural gas will probably be used to enrich the blue water gas made from coal or coke, to produce a mixture satisfactory for domestic or industrial use.

In this brief summation of the status of coal production and of the forces that are shaping it, we have used facts and figures that may be verified from accessible statistics. We have purposely avoided a discussion of controversial questions such as those of organized labor versus open shop, railroad rates, both inter and intrastate, and many others that profoundly affect the welfare of the industry. As a coal technologist the writer firmly believes that our coal reserves constitute a permanent line of defense to which the world must ultimately retreat when all the more temporary substitutes are exhausted; not indeed back to the raw fuel but to its conversion products of oil and gas. When that time shall be he does not venture even to guess. The large scale production of fuel gas through complete gasification of coal may be nearer attainment than many of us suppose. But meanwhile the coal industry must set its house in order and make the adjustments necessary to meet the new situations brought about by the inevitable march of progress. The prospect is dark enough, but nothing can be gained by suppression of facts or by refusal to recognize them.

So much for the subject in general. What is said of coal production as a whole applies equally well to conditions in Iowa. But there is another factor that is intangible yet real, one on which no statistics can throw light because it cannot be measured by statistical methods. I refer to a mental attitude of disfavor toward Iowa coal shared by many of the citizens of the state who have never used it, a prejudice based partly upon lack of definite scientific information concerning its qualities and largely, perhaps, upon premeditated propaganda launched by agencies outside or inside the state with selfish ends in view. This more or less pessimistic impression of what Iowa coal is and what it can do is often a strange mixture of fact and fiction, of personal experience on the one hand and of hearsay gossip passed from lip to lip on the other. The writer has repeatedly been asked in all seriousness by intelligent persons whether Iowa coal can possibly be burned for domestic heating, or whether it will not fire spontaneously in the bin, or slack down to dust or jump the track in some other way in utter violation of all the rules, including those of the Big Ten.

Now in this era when even time and space are relative terms it is difficult indeed to meet such inquiries with a categorical answer. It should be noted that what is known as "Iowa coal" comes from more than 200 mines scattered over a wide area and belonging geologically to at least three different beds, the Lower Cherokee, the Mystic and the Nodaway. Unfortunately these beds (with the exception of the Mystic) are in the main discontinuous so that a mine in any given area often bears little relation physically or chemically to those near by. Considering in addition the differences in methods of mining and of coal preparation it may be readily seen that these fuels as a whole come to market with anything but uniform quality, and it is not surprising, therefore, that character witnesses in testifying for or against them may differ in their opinions on this matter as widely as in their politics or religion. In the absence of much systematic scientific data, perhaps the best answer to general questions concerning quality of Iowa coals is that, like those of Illinois, Indiana and western Kentucky, they may be classified as high-volatile bituminous; that among them are many of superior quality as measured by the standards of their class and by comparison with those of neighboring states, and others not so good; that probably all would make highly satisfactory fuels if adequately prepared at the mine and burned in properly designed furnaces.

On the basis of chemical analysis it appears that a grand average of 52 samples from different mines of Iowa falls little behind the mean of 36 Illinois coals collected over the entire state. We quote from Iowa Geological Survey Technical Paper No. 1, "Analyses of Iowa Coals," published in 1929:

Comparative Data on Iowa and Illinois Coals: Mean Values (Dry Basis)

	Volatile matter	Ash	Sulfur	Thermal values B.t.u.
Iowa (36 samples) (Olin and Kinne)	42.0	13.6	4.8	12,045
Iowa (16 samples) (Hixson)	40.1	13.7	4.9	12,552
Illinois (36 samples) (Parr)	37.3	11.0	3.7	12,725

Total moisture contents on the wet basis for the two groups of Iowa coals and that of Illinois were 16.6, 15.1 and 12.4 per cent, respectively.

It must be admitted, however, that such proximate analyses alone are inadequate for a complete characterization of a fuel of any kind and especially for one so complex as coal. They fail to indicate, for instance, whether a coal will heat and fire in storage or resist the oxidizing agencies and remain cool. Analytical results are mute as to physical strength and resistance to slacking and dusting. They show the amounts of impurities

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*Chemical and Metallurgical Engineering, January, 1930, page 37.

such as sulfur and ash, but venture no information as to possibilities of removal of such waste material. In short, supplementary studies along broad lines, both physical and chemical, must accompany mere chemical tests in order to round out the information the prospective consumer should have.

In the keen competition for a diminishing market representatives of out-of-state producers have swarmed into Iowa and we may expect many more to come. It is the writer's firm conviction that the best possible defense against this invasion is to be found in a fundamental scientific study of Iowa coal quality. He believes that with the substitution of proved fact for hazy and false tradition the Iowa consumer will begin to recognize as economically unsound a system which tolerates the importation from distant points of coals little better than those produced at home, or even inferior. Special types of foreign fuels of undisputed quality such as anthracite and low volatile bituminous coals will always be in demand for domestic use, and rightly so, but why many of the high volatiles from other fields with little less ash than Iowa coals and often with more smoke and soot should be foisted by advertising power alone is not equally clear. Furthermore if the home product cannot compete successfully on the price basis for home markets it would be interesting and profitable to investigate the problem of whether the foreign product was riding on a natural or an artificial advantage.

The papers which follow bear on work that is still being carried on and they must therefore be considered as progress reports only. Surely no one appreciates their incompleteness and the amount of work still to be done more clearly than does the director of the studies himself and it is his purpose to carry them forward with all possible speed. He wishes to acknowledge especially the indispensable help extended by Dr. Kay and his staff of the Iowa Geological Survey and by the Iowa Railway and Light Company of Cedar Rapids.

CHEMICAL AND THERMAL VALUES OF IOWA COAL

H. L. OLIN AND R. C. KINNE

In Volume 19 of the Iowa Geological Survey Hixson reported the results of proximate analyses of sixteen coal samples collected at mines located in ten of the principal coal producing counties of the state. This report was followed in 1914 by a paper in which the previous figures were republished but amplified by additional data on ultimate analyses of the same samples, together with tables showing the compositions of the ash.

In the space of twenty years since these coal samples were collected many changes have taken place in the coal mining industry of the state. Many of the mines that were the leading producers in 1909 have long since passed their peak of production or have been abandoned altogether. In any case it seemed wise to make a new survey of Iowa's coal to bring this information up to date not only with respect to the location of leading production centers, but also with respect to quality. The direct incentive for undertaking such a study was the initiation of a comprehensive program of Iowa coal research by the Department of Chemical Engineering at the University which required in preparation, accurate analytical data on present supplies.

The tables given in this bulletin are based upon the analyses of samples collected under the direct supervision of the Assistant State Geologist, Dr. James H. Lees. They were first published in 1929 in a pamphlet issued by the Iowa Geological Survey under the title of "Analyses of Iowa Coals." An unexpected demand for this pamphlet brought about its early exhaustion and the data are republished here in substantially the same form in which they appeared earlier. The method of sampling used by Doctor Lees is fully described in Iowa Geological Survey XIX, 476 (1908), and XXIV, 692 (1913), and those specially interested in its details are referred to those sources of information. In brief it involves the cutting of the face of the seam in such a way as to insure the inclusion of the varying components of the seam in their true proportions with respect to the entire face, and thus it affords the means for collecting a sample that most nearly approaches the average composition of the output of the mine as a whole. Moreover, a sample secured in this way and immediately sealed in an airtight container provides the analyst with material for determining the natural moisture content of the coal in place. This value, while not of great significance commercially because of immediate drying losses that take place after the coal is exposed to the air, has great scientific importance in its bearing on coal classification. Thus Campbell of the U. S. Geological Survey proposes a system for ranking coals based solely on the percentage of this initial moisture.

Methods of Analysis and Comparison of Results

Laboratory methods and apparatus employed were in all cases those adopted by the American Society for Testing Materials and described in the Proceedings for 1924 under the serial number D-22-24, and in U. S. Bureau of Mines Technical Paper 76. These specifications designate as official instruments the A. S. T. M. constant temperature coal moisture oven, the Fieldner electric furnace for volatile matter and the oxygen bomb calorimeter for thermal values, with all of which the Fuel Laboratory of the University is equipped.

A word may be said here concerning the comparison of the values obtained in this work with those based on the analysis of the same, or similar coals made at other laboratories.

As we have already explained, all sampling for these studies was made by a member of the Geological Survey acting of course as an unbiased referee. The method used is both the most fair and the most severe, inasmuch as it provides for the inclusion of impurities in their proper proportions and precludes the possibility of either premeditated or unconscious "handpicking," which is a major factor in vitiating results. It follows, therefore, that comparisons between our figures and

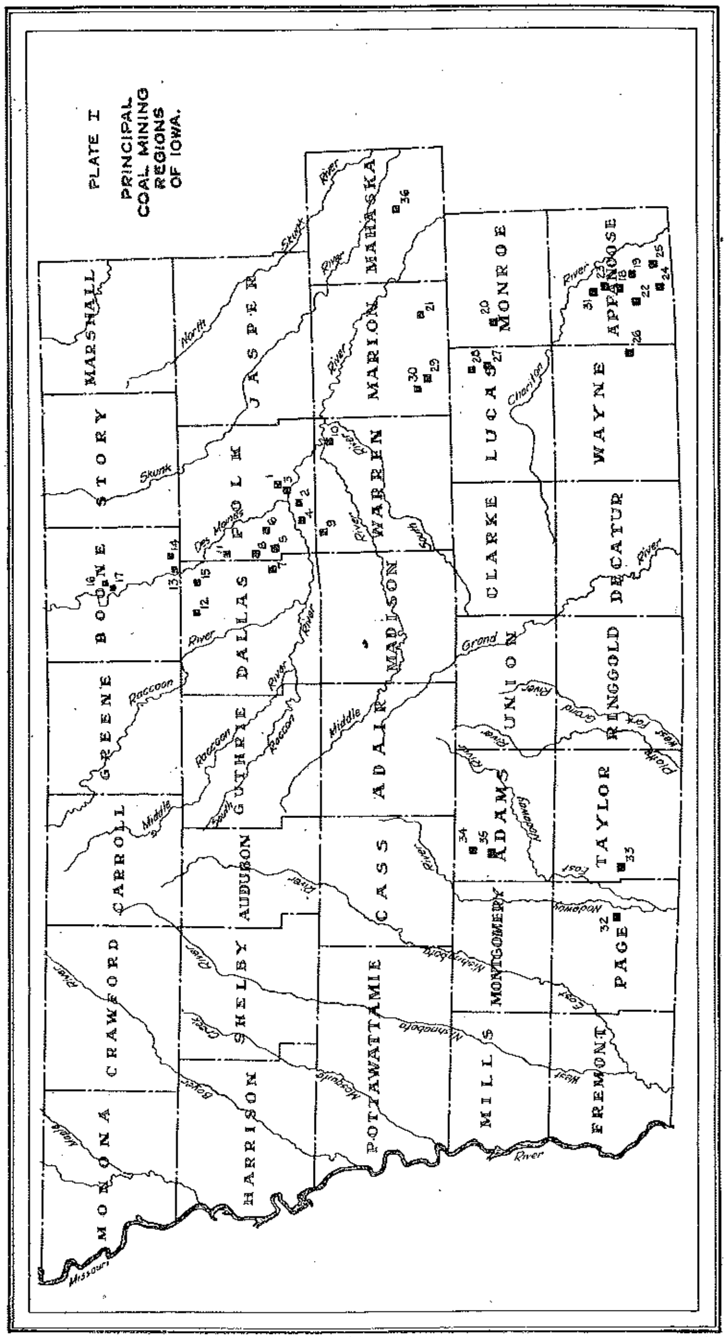

PLATE I. Map showing locations of mines sampled.

others can be made fairly, only when all are reduced to a common standard of sampling, analysis and calculation.

In Table I are given the names and locations of the mines covered in this report. Although in a general way it includes the most important coal producing areas of the state and possibly most of the larger mines it is nevertheless incomplete and data on other coals will be collected as opportunity offers.

Geographical positions of the mines included in this survey are shown in Plate I.

Table I, Names and Location of Mines Sampled

No.
1—Des Moines Ice & Fuel Co., Des Moines, Polk Co.
2—Bennett Bros. Coal Co., Mine No. 2, Des Moines, Polk Co.
3—Economy Coal Co., Des Moines, Polk Co.
4—Des Moines Coal Co., Mine No. 4, Des Moines, Polk Co.
5—Urbandale Coal Co., Des Moines, Polk Co.
6—Beck Coal & Mining Co., Des Moines, Polk Co.
7—Shuler Coal Co., Waukee, Dallas Co.
8—Gibson Coal Co., Rider, Polk Co.
9—Great Western Coal Co., Orillia, Warren Co.
10—Indian Valley Gloss Coal Co., Hartford, Warren Co.
11—Norwood White Coal Co., No. 8, Herrold, Polk Co.
12—Norwood White Coal Co., No. 7, Moran, Dallas Co.
13—Scandia Coal Co., No. 4, Madrid, Boone Co.
14—Scandia Coal Co., No. 6, Madrid, Boone Co.
15—Dallas Products Co., Granger, Dallas Co.
16—Benson Coal Co., No. 1, Boone, Boone Co.
17—Boone Coal Co., No. 1, Boone, Boone Co.
18—Old King Coal Co., Centerville, Appanoose Co.
19—Center Coal Co., Centerville, Appanoose Co.
20—Superior Coal Co., No. 19, Bucknell, Monroe Co.
21—Pershing Coal Co., No. 12, Pershing, Marion Co.
22—Numa Coal Co., Numa, Appanoose Co.
23—Appanoose Coal Co., Centerville, Appanoose Co.
24—Armstrong Coal Co., Cincinnati, Appanoose Co.
25—Iowa Block Coal Co., Exline, Appanoose Co.
26—Violet Valley Coal Co., Seymour, Wayne Co.
27—Central Iowa Fuel Co., No. 5, Williamson, Lucas Co.
28—Central Iowa Fuel Co., No. 4, Williamson, Lucas Co.
29—Red Rock Coal Co., Melcher, Marion Co.
30—Consolidated Indiana Coal Co., No. 2, Melcher, Marion Co.
31—Liberty Coal Co., No. 3, Mystic, Appanoose Co.
32—Pearson Coal Co., No. 2, Clarinda, Page Co.
33—New Market Coal Co., New Market, Taylor Co.
34—John G. Henton Mine, R. F. D. No. 1, Carbon, Adams Co.
35—Ruth Coal Co., Carbon, Adams Co.
36—Oskaloosa Coal & Mining Co., Oskaloosa, Mahaska Co.

In presenting Table II, which gives analytical data on the socalled "as received" basis, we wish first to call attention to the moisture content column. As explained above, in collecting the sample the water in the coal is carefully conserved so that it may be measured in the labortory, but it should be clearly understood that in no wise does this figure represent the moisture percentage of the coal delivered to the consumer after having been in contact with drying air for days or weeks while in transit or storage. The actual moisture value of a coal at a given time is of course dependent upon the humidity of the air and upon the time of exposure to it. It is difficult therefore to estimate how much moisture these coals would contain under marketing conditions, but it is safe to say that the percentages are vastly lower than those given for mine conditions. With lower total moisture values the percentage contents of the other constituents, and also the thermal values, increase in proportion.

Table II. Results of Analyses of Iowa Coals as Received

No.	County	Moisture	Ash	Volatile	Fixed carbon	Thermal values (B. t. u.)	Sulfur
1.	Polk	16.0	8.7	37.3	37.9	10,820	5.3
2.	Polk	16.8	14.5	35.0	33.7	9,190	5.8
3.	Polk	15.9	9.2	37.1	37.7	10,530	5.0
4.	Polk	13.8	16.9	34.3	34.9	9,040	5.6
5.	Polk	14.2	13.0	36.3	36.5	10,220	5.2
6.	Polk	16.7	15.5	33.0	34.7	9,660	3.8
7.	Dallas	14.2	12.7	34.7	38.3	10,450	3.9
8.	Polk	13.7	6.5	39.5	40.3	11,450	3.7
9.	Warren	13.1	14.6	35.4	36.8	10,210	6.3
10.	Warren	14.6	10.6	39.1	35.7	10,830	4.8
11.	Polk	13.6	14.6	36.8	35.0	10,050	5.2
12.	Dallas	16.9	12.3	33.9	36.9	9,920	3.1
13.	Boone	14.9	10.3	36.9	37.8	10,450	3.5
14.	Boone	15.1	12.5	36.9	35.5	10,050	4.1
15.	Dallas	16.2	14.0	34.5	35.3	9,690	3.8
16.	Boone	20.9	8.5	33.8	36.7	9,430	4.0
17.	Boone	19.7	9.3	36.3	34.7	9,740	4.8
18.	Appanoose	18.1	8.6	33.9	39.4	10,050	3.7
19.	Appanoose	18.0	6.5	35.7	39.7	10,430	2.7
20.	Monroe	14.8	9.8	35.0	40.4	10,700	2.1
21.	Marion	17.1	9.4	34.9	38.6	10,490	3.5
22.	Appanoose	17.6	11.0	36.7	34.7	9,880	4.5
23.	Appanoose	15.3	12.2	34.6	37.9	9,960	3.9
24.	Appanoose	13.4	10.3	35.6	40.7	10,490	4.9
25.	Appanoose	14.9	9.7	36.3	39.1	10,750	3.4
26.	Wayne	16.7	8.3	34.1	40.8	10,350	3.9
27.	Lucas	15.8	14.0	33.6	36.5	9,950	5.3
28.	Lucas	19.8	12.8	32.7	34.6	9,460	2.0
29.	Marion	18.5	10.4	32.6	38.5	10,000	2.6
30.	Marion	18.6	9.2	31.9	40.2	10,030	2.6
31.	Appanoose	15.6	11.0	35.2	38.2	9,800	3.3
32.	Page	18.4	13.7	35.3	32.6	9,440	3.4
33.	Taylor	20.2	13.3	33.6	32.9	9,080	5.5
34.	Adams	21.1	9.9	22.9	36.1	9,280	3.5
35.	Adams	20.6	12.3	33.0	34.1	9,270	3.1
36.	Mahaska	18.1	10.0	33.5	38.4	10,610	2.0
Mean		16.6	11.4	35.0	37.0	10,040	3.9

Table IV, in which the results of the preceding table are calculated to the dry basis, needs no comment except perhaps in explanation of the term "unit coal." This in brief is a hypothetical material intended to represent the pure or actual coal substance calculated from analytical data after taking into consideration corrections for moisture and ash. As developed by Parr the formula is

$$\text{Unit coal} = 1.00 - (W + 1.08\,A + \frac{22}{40}\,S)$$

where W, A and S are total water, ash as weighed and sulfur, respectively.

This "unit coal" value which represents the decomposition residue of a flora characteristic of a given period and region, should, if the history of the seam formation is normal, be fairly constant for that given seam. This has proved to be the case particularly where the coal measures are of comparatively large area, as in Illinois. A tabulation of average unit coal values of the three beds represented in this study is given below.

Table III. Average Unit Coal Values of Iowa Coal Beds

Lower Cherokee bed	14,671 B.t.u.
Mystic bed	14,345 B.t.u.
Nodaway bed	14,365 B.t.u.

Table IV. Results of Analyses of Iowa Coals: Dry Basis

No.	County	Ash	Volatile	Fixed Carbon	Thermal Values (B.t.u.)	Sulfur	Unit Coal
1.	Polk	10.4	44.5	45.4	12,900	6.3	15,110
2.	Polk	17.4	42.1	40.5	11,050	7.0	14,290
3.	Polk	11.0	44.2	44.9	12,550	5.9	14,730
4.	Polk	19.6	39.8	40.6	10,500	6.5	13,950
5.	Polk	15.2	42.3	42.5	11,910	6.1	14,760
6.	Polk	18.6	39.7	41.7	11,600	4.6	14,970
7.	Dallas	14.8	40.5	44.7	12,200	4.6	14,950
8.	Polk	7.5	45.8	46.7	13,260	4.3	14,830
9.	Warren	16.8	40.8	42.4	11,750	7.3	15,100
10.	Warren	12.4	45.8	41.8	12,620	5.6	15,110
11.	Polk	16.9	42.6	40.5	11,630	6.0	14,850
12.	Dallas	14.8	40.8	44.4	11,940	3.7	14,560
13.	Boone	12.1	43.4	44.5	12,300	4.1	14,550
14.	Boone	14.7	43.5	41.8	11,840	4.8	14,530
15.	Dallas	16.7	41.2	42.1	11,560	4.6	14,550
16.	Boone	10.8	42.8	46.4	11,950	5.1	13,990
17.	Boone	11.6	45.2	43.2	12,130	6.0	14.430
18.	Appanoose	10.5	41.4	48.1	12,270	4.5	14,270
19.	Appanoose	7.9	43.6	48.5	12,730	3.3	14,210
20.	Monroe	11.5	41.1	47.4	12,550	2.5	14,550
21.	Marion	11.3	42.1	46.6	12,650	4.2	14,800
22.	Appanoose	13.3	44.6	42.1	11,990	5.5	14,520
23.	Appanoose	14.4	40.9	44.7	11,750	4.7	14,360
24.	Appanoose	11.9	41.2	46.9	12,120	5.6	14,430
25.	Appanoose	11.5	42.6	45.9	12,630	4.0	14,790
26.	Wayne	9.9	40.7	49.4	12,420	4.7	14,330
27.	Lucas	16.6	39.9	43.9	11,810	6.3	15,020
28.	Lucas	15.9	40.6	43.5	11,810	2.5	14,510
29.	Marion	12.8	39.9	47.3	12,260	3.1	14,510
30.	Marion	11.3	39.1	49.6	12,330	3.2	14,330
31.	Appanoose	13.0	41.7	45.3	11,620	4.0	13,870
32.	Page	16.7	43.2	40.1	11,560	4.2	14,500
33.	Taylor	16.7	42.0	41.3	11,380	7.0	14,570
34.	Adams	12.5	41.6	45.9	11,760	4.5	14,000
35.	Adams	15.5	41.6	42.9	11,680	3.9	14,390
36.	Mahaska	12.2	40.9	46.9	12,960	2.4	15,140
Mean		13.6	42.0	44.4	12,045	4.8	14,555

COMPARATIVE STUDIES IN IOWA COAL STORAGE

H. L. OLIN AND C. E. SCOTT

In order to provide a measure of insurance against loss through enforced suspension of operations because of lack of coal as well as to take advantage of seasonal low prices it is common practice for the larger manufacturing corporations to lay up reserve supplies of fuel in storage. Total stocks in the hands of commercial consumers and in retail dealers' yards but exclusive of amounts in the basements of householders varied in the decade following 1916, according to the Bureau of Mines, from a minimum of 20,000,000 tons to a maximum of 63,000,000. Distributed chiefly among the electric utilities, steel plants and other industrials, these reserves constituted on the average a supply for 45 days normal operation, although the extremes ranged from as little as four to as many as 104 days.

While the necessity for heavy storage of coal may or may not be acute at any given time it must always be regarded as a first aid measure to apply in times of threatened mine trouble or transportation tie-up. It follows therefore that the question of the storability of a given coal may become, in an emergency, of paramount importance, more vital perhaps than that of thermal value or ash content, for it is difficult to look upon a coal pile smoldering like a sullen volcano as anything but an embarrassing liability.

The phenomenon of the spontaneous combustion of coal has been studied by many authorities but it is chiefly through the work of Parr of the University of Illinois that its chemical processes have been authoritatively demonstrated. He points out, in brief, that this slow combustion takes place in four stages. In the initial phase the trouble begins at relatively low temperatures with the oxidation of what, for want of a better name, have been called the "humus bodies," chemically complex substances in the coal that are extremely sensitive to oxygen. Next in order, if the heat of the first reaction has been retained in the mass, comes rise in temperature to a point where the iron pyrite or sulfur-bearing mineral undergoes a similar oxidation with further evolution of heat. The third stage begins at temperatures in excess of 120° C. with the oxidation of certain hydrocarbons and the evolution of carbon dioxide and water, followed finally above 250° C. by autogenous or self-sustained combustion independent of other sources of heat. At this point, assuming all the while that oxygen has fairly ready access to the interior of the pile, flames begin to appear and the mass is afire.

Parr concludes that the most effective system of storage is that one which can prevent the slow oxidation of the humic or unsaturated components or that can check it to such a degree that the heat is radiated as fast as generated. It is comparatively easy to store lump coal since air circulation is usually effective in keeping it cool but the major problem is encountered in the case of the steam sizes. From the results obtained by Parr and by other authorities it is generally conceded that tight packing without segregation of fine and coarse material, so that voids are filled to the maximum possible extent, is the most satisfactory method.

It is readily seen from this discussion that the solution of the problem hinges upon the completeness with which oxygen is excluded from the inner regions from which heat cannot be readily radiated and where by its retention temperature may reach the danger point. A method simple in theory but not often economically practicable involves submerging the coal under water where it would be effectively quenched by cooling even if oxygen were not completely excluded. In general, the main dependence must be placed upon air piles so constructed with close packing that diffusion of oxygen from without cannot readily take place.

If, as implied in the prefatory paper, a common popular impression assigns Iowa coal to a class by itself with regard to firing propensity, the need for research is the more emphasized, for all high volatile coals containing sulfur possess the components that start heating troubles, not merely those of Iowa alone.

EXPERIMENTAL STUDIES

These University of Iowa studies which were undertaken with the close coöperation of the Iowa Railway and Light Company of Cedar Rapids had for their first objective the plotting of a log of temperatures in a typical storage pile, in order to trace the history of the thermal disturbance from its beginning to the burning point on the one hand or to the restoration of normal conditions on the other. In similar attempts at temperature measurement the New York Edison Company used the scheme of driving rods into the piles to different depths, keeping them in contact with the coal until temperatures were equalized and then testing with the hand after their withdrawal, for the location of warm spots. Such a method has its obvious faults and limitations, first because of the time and labor involved and second because the contact of iron with the coal greatly accelerates the heating reaction. Lead, it may be said in passing, does not possess catalytic properties of this kind.

The apparatus devised for our work consisted of a three junction thermocouple of 20 B and S copper and constantine used in connection with a calibrated Englehardt millivoltmeter. The welded hot and cold junctions adequately protected with cement coating together with the connecting wires were then sheathed with lead tubing and in that condition were laid in the parts of the pile where heating was expected to occur, leaving only the cold junction and instrument leads exposed. In taking a reading with this set-up the observer merely immerses the cold junctions in a portable bath of ice water, attaches the leads to the millivoltmeter and notes the needle deflection. The method as a whole has proved entirely satisfactory and readings were quickly taken to one-half degree accuracy. A later improvement was made by substitution of a single junction chromel-alumel couple for the multiple junction copper-constantine whereby simplicity of design was effected without loss of sensitivity.

The scope of these studies in spontaneous heating was broadened by observing two piles in parallel (except in the first series), one an Iowa coal from Monroe county and the other from the well known West Kentucky No. 9 seam. Thus while general scientific data were obtained on the one hand the comparative behavior of two coals from neighboring states under identical conditions of storage was noted on the other. In the first series involving loose piling, the coal was unloaded from the cars by means of a steam shovel to form the base of the heap 20 feet in diameter. In the center of this, two feet from the bottom was placed the hot junction of the first couple. More coal was added and the next two couples were placed in position about four feet up but within three feet of the north and south edges. The last was put into place nine feet from the bottom, on the center line, and the piling was then continued until about 125 tons were in place to form a cone 12 feet high and about 30 feet in diameter. A typical storage pile is shown in Figure 1.

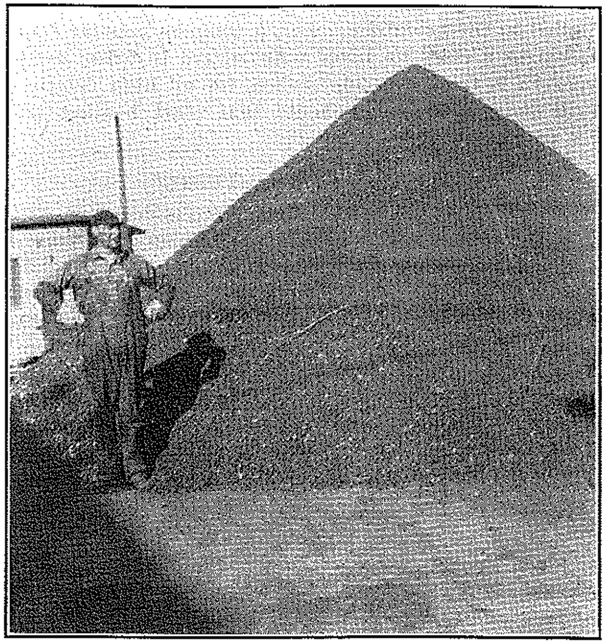

FIG. 1. View of storage pile of coal.

Inasmuch as loose packing is not an accredited method for coal storage and would not be used in practice the results of the first test have theoretical interest only. Because of delay in shipments at this stage of the work we have, unfortunately, no data on a loosely piled Iowa coal to compare with the curves in Figure 2 which represent the Kentucky product. As in the case of the three men of the nursery rime whose "tale had been longer, had the tub been stronger" this test ended in catastrophe near the end of the sixth week when the coal ignited in spite of excessively low outside temperatures. The height of the slope of the temperature curve indicates that a vigorous oxidation set in from the very beginning which even the draft through the loose structure induced by subzero weather outside utterly failed to check.

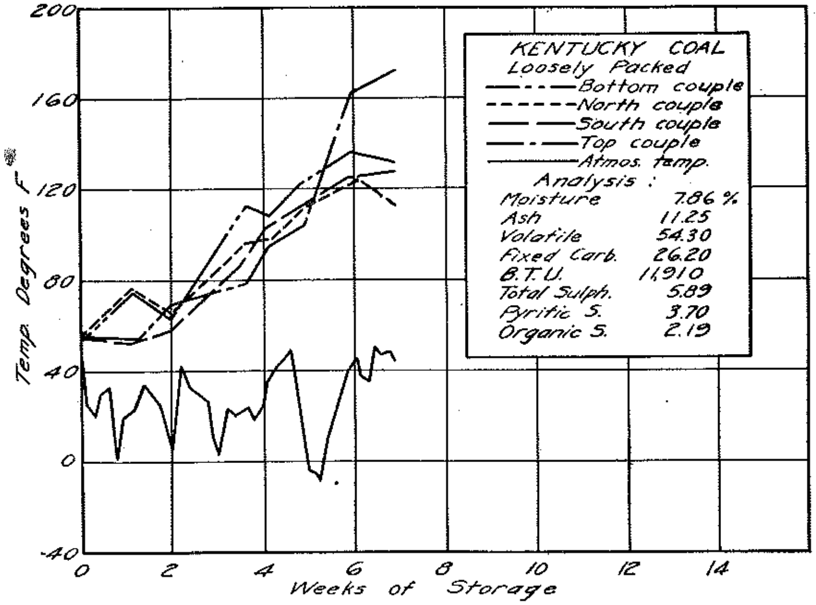

FIG. 2. Curve showing heating in loosely packed Kentucky coal.

The tests in the second series differed from those of the first only in the method of building the pile. During its construction after the laying of each course of two or three feet the half-ton bucket was used as a packing ram by letting it drop a distance of 20 feet or more. In this way air pockets were minimized and the initial supply of oxygen was reduced.

In Figures 3 and 4 we have our first opportunity to compare storage performance of these coals under identical conditions. Especially significant is the uniform and consistent rise in temperature in the different parts of the Kentucky pile with one couple indicating a danger point of 190°. The Iowa pile was cool during the entire period except at the bottom where the temperature makes a bold curve upwards. The inconsistency of this local disturbance suggests the possibility of the presence of tramp iron or the like which would bring about results of this kind, but at any rate as a unit it weathered the storm and sailed into port after 22 weeks on even keel. On comparative scores it comes out clearly the winner over its competitor not only on mean temperatures of the mass but on maximum point attained.

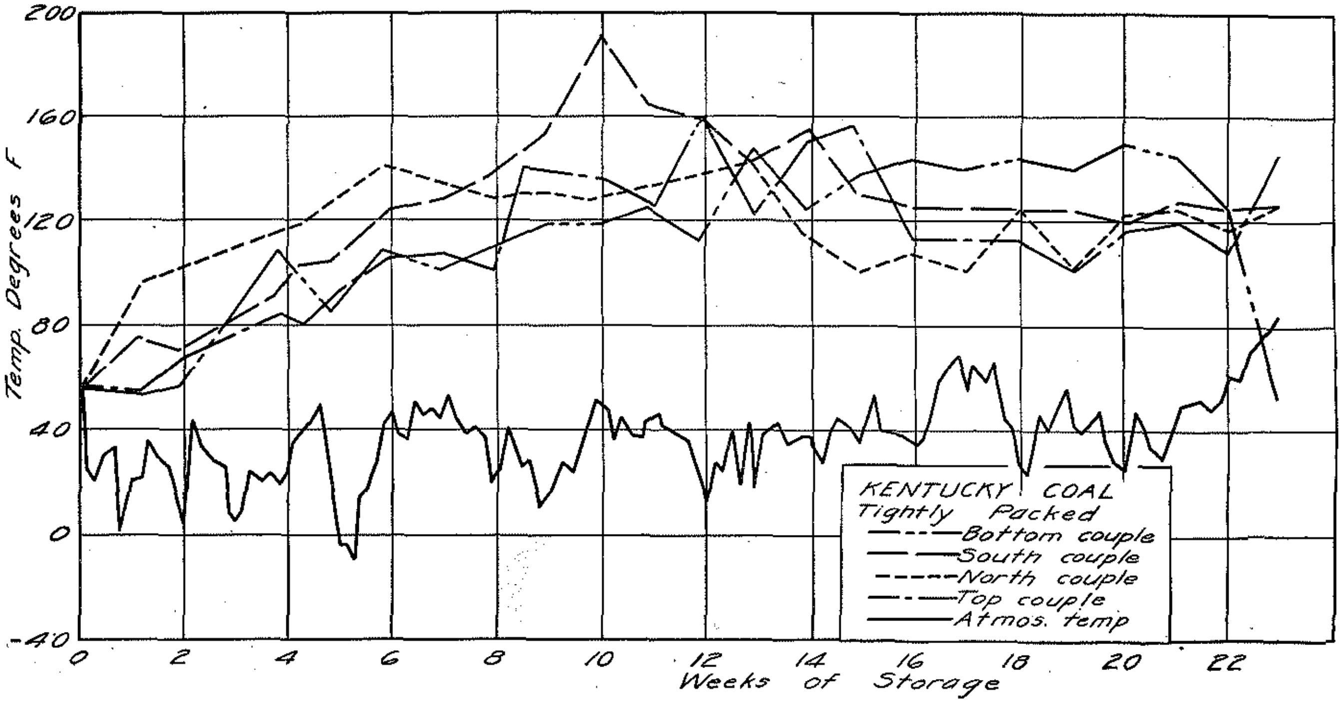

FIG. 3. Curve showing temperatures in tightly packed Kentucky coal.

FIG. 4. Curves showing temperatures in tightly packed Iowa coal.

In the third stage of this investigation a new application of an old principle was employed, which is described here because of its interesting possibilities rather than because of its proved worth. Since heating effects are produced by infiltration of oxygen to the inner regions of the pile they may reasonably be inhibited either by excluding air from without or by maintaining an inert atmosphere within the mass itself. The first method is of course employed in the tamping process while the second is illustrated by the use of a substance that maintains a slow evolution of carbon dioxide. A combination of both should logically be more effective than either.

The idea of the use of an inert gas is not new. Cox in a general study of coal oxidation proposed as an ideal method the covering of the pile with a blanket under which to confine the inert nitrogen or carbon dioxide which was to be introduced, a scheme that is obviously impracticable. Our plan involves the salting of the pile during its construction, in spots that experience has shown to be the most vulnerable, with an intimate mixture of pulverized alum and crushed limestone. These substances react in the presence of moisture to form a gas, or using chemical symbols, according to the equation

$$Al_2(SO_4)_3 + 3H_2O + 3CaCO_3 = 2Al(OH)_3 + 3CaSO_4 + 3CO_2$$

Carbon dioxide, which is an end product of the reaction, is of course a universal quencher and so long as a moderate concentration is maintained around the coal particles it is manifestly impossible for it to "run a temperature."

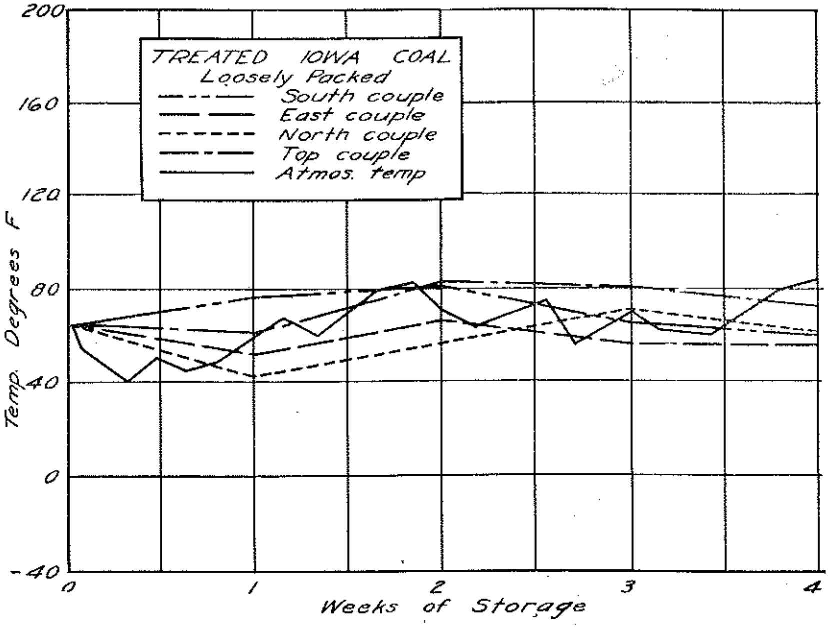

FIG. 5. Temperature curves in pile of treated Iowa coal.

The piles were built as before but without tamping in order to make the test conditions more severe. From time to time as the coal was put on the salt mixture was added in the ratio of about 1.7 pounds per ton of coal.

Temperature curves are plotted in Figures 5 and 6. Because of the necessity for coördinating our work with the convenience of the Company's operations we were unable to make these runs simultaneously nor was it possible to continue them over so long a period as the others. It may be seen from the outside temperature logs that the Iowa coal went through a month of moderately warm weather while the six weeks' period of the other was relatively cool. In spite of weather and the loose piling the temperature rise of the first is only a few degrees above initial conditions while in the case of the second it takes a marked jump, so that honors for keeping qualities must go again to the Iowa product.

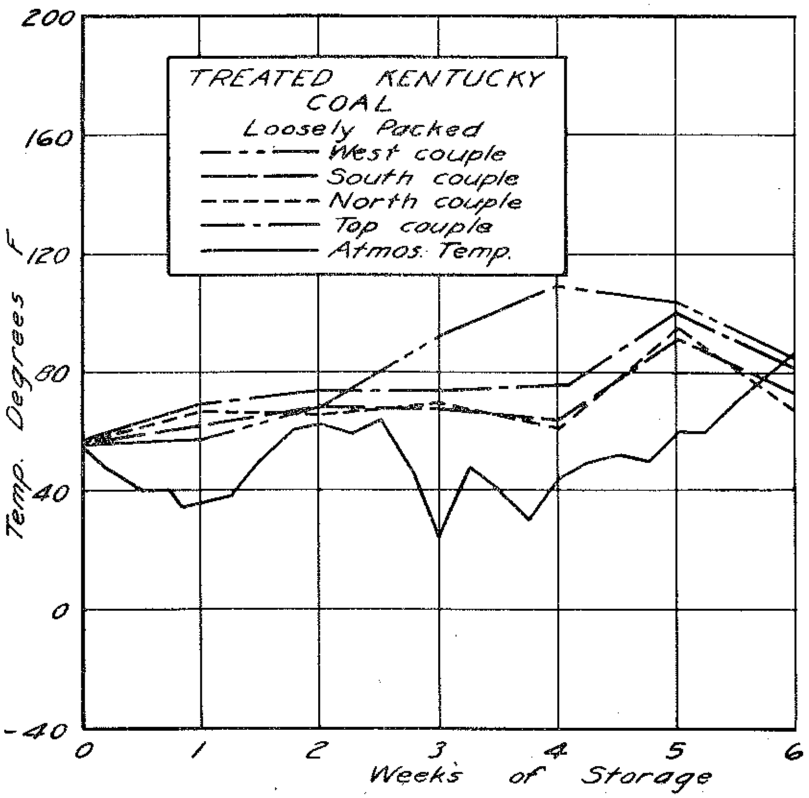

FIG. 6. Temperature curves in pile of treated Kentucky coal.

It is readily understood that experimental work of this kind that involves the use of large quantities of material and of long periods of time for observations must necessarily move slowly. A mere beginning only has been made and while indications point strongly to the inferiority of Kentucky coals in the matter of storability, much more exhaustive tests should be made to cover all the phases of the problem. Similar experiments are being planned for comparison of Illinois and Indiana coals with those of Iowa in the course of which we hope to determine not only relative values of particular fuels, of interest to the consumer, but scientific principles that have a bearing upon the problems of storage in general. For instance we should know the length of the danger period of a storage pile and the factors that govern this time. We have good reason to believe that once the crisis is safely passed a sort of immunity is built up which makes for safety thereafter, but no definite working rules are available. Doubtless a thorough study of this phase must involve a laboratory study of the equilibrium at different temperatures between the various coal substances and oxygen. We are personally interested in the possibilities of the salting process described above not only from the technical but also from the economic standpoint, for while we can estimate the cost of the materials used, roughly, as a few cents per ton of coal stored we are not certain what are the minimum quantities needed. Finally, to mention only one of many more, we should study the catalytic effects of the mineral matter of the coal substance to determine to what extent they promote or retard the oxidation and heating processes

THE WEATHERING PROPERTIES OF IOWA COALS

H. L. Olin, J. D. Waddell and J. N. Ambrose

It is a well known fact that certain types of bituminous coals and perhaps all the sub-bituminous grades and lignites show a marked tendency to disintegrate to small lumps or dust on being exposed to air and moisture, particularly if in this exposure periods of wetting and drying are alternated. This mechanical failure known as "slacking" or "weathering," or rather the rate at which it proceeds, obviously bears a vital relation to the practical problems involved in the transportation, the storage and the combustion of the fuel in question, and it becomes therefore an important factor in the rating of its commercial value. Thus lignites, because of their outstanding weakness in this respect, cannot enter the general fuel markets but must be consumed near the source of supply unless indeed they are processed in some way as by briquetting.

The relative stability of a coal or the lack of it as the case may be is intimately related to the geologic age of the seam from which it comes. The lignites, for instance, which are almost invariably found in formations younger than the Pennsylvanian, are characterized by a more or less woody structure directly traceable to the vegetation from which they were derived. Because of their relative youth they have been subjected to a less degree than the bituminous coals to the indurating forces of crustal movement and so they are soft in texture, largely colloidal in their physical makeup and high in moisture content. With the loss in moisture that follows exposure to the air the whole structure weakens under the strain of shrinkage and rapidly disintegrates to fines and dust. Closely associated with this phenomenon of slacking in a low grade coal is its tendency to oxidize and heat in storage, but as we extend our observations up the scale through sub-bituminous, the various grades of bituminous and finally to anthracite we find that the structure becomes firmer and denser, the volatile and moisture contents become lower and slacking and heating tendencies are reduced to the vanishing point.

From the standpoint of coal classification, moisture content and physical stability may be considered criteria of the relative age of a coal or at least of its progress toward maturity. Indeed Campbell of the U. S. Geological Survey proposes a scheme which differentiates the classes largely according to original mine moisture, to which perhaps most coal chemists are willing to agree but to which they would add certain other essentials. In support of his theory he has drawn contour lines of coal moisture content for the Missouri and Illinois fields. He notes that these lines are parallel to the area of the Ozark uplift, a diastrophic movement that had a profound influence on the quality of the coal within its boundaries, and that as they recede from that area they mark higher and higher moisture values. In spite of the significance of the weathering property of a coal both commercially and scientifically only a moderate amount of formal study has been made of it and no standard method for measuring it has been proposed. Studies on the sub-bituminous coals of Alberta made at the University of Alberta by the Industrial Research Department are based on the use of a constant humidity air drier in which the samples are kept for definite periods. After being removed they are immersed in water, dried a second time and then subjected to a screen analysis. This cycle is repeated under standard conditions and the undersize collected is of course a measure of slacking tendency. It is readily seen that this method not only simulates the conditions of actual weathering but that it accelerates and magnifies them so that the observation may be made within the time limits of a laboratory test.

EXPERIMENTAL WORK

In taking up the study of the weathering of Iowa coals we were governed by two motives, one the desire to place more exactly the coals of Iowa in the classification scale so far as physical tests can serve the purpose, and the other to get exact data on their weathering propensities in order to meet squarely the popular impression that they are extremely faulty in this respect. This project so far has involved the devising of a standard method for measuring slacking which was then applied to coals from the various districts of Iowa and to a number from Illinois. The work in immediate prospect will cover similar tests on a large number of samples from neighboring states in order to provide adequate data for general comparisons.

Our first apparatus was designed and constructed with a view to using the Alberta method described above, which involves the wetting of the samples in alternation with drying in a constant humidity drier. The drier shown in Figure 1 is equipped with large strips of webbing kept continually moist with a glycerine solution of the density necessary to maintain the desired humidity. The accessories include a fan, a solution pump, and the necessary hygrometers and thermometers. A fair test of this scheme, however, showed that for bituminous coals a more vigorous treatment was demanded than that afforded by ordinary atmospheric conditions of temperature and pressure. These earlier results proved that it was indeed possible to differentiate between different qualities of coals by comparative screen analyses following the wetting and drying cycles, but that the action was unduly slow for practical purposes. Without question the method has great merit as applied to the more friable lignites and subbituminous grades.

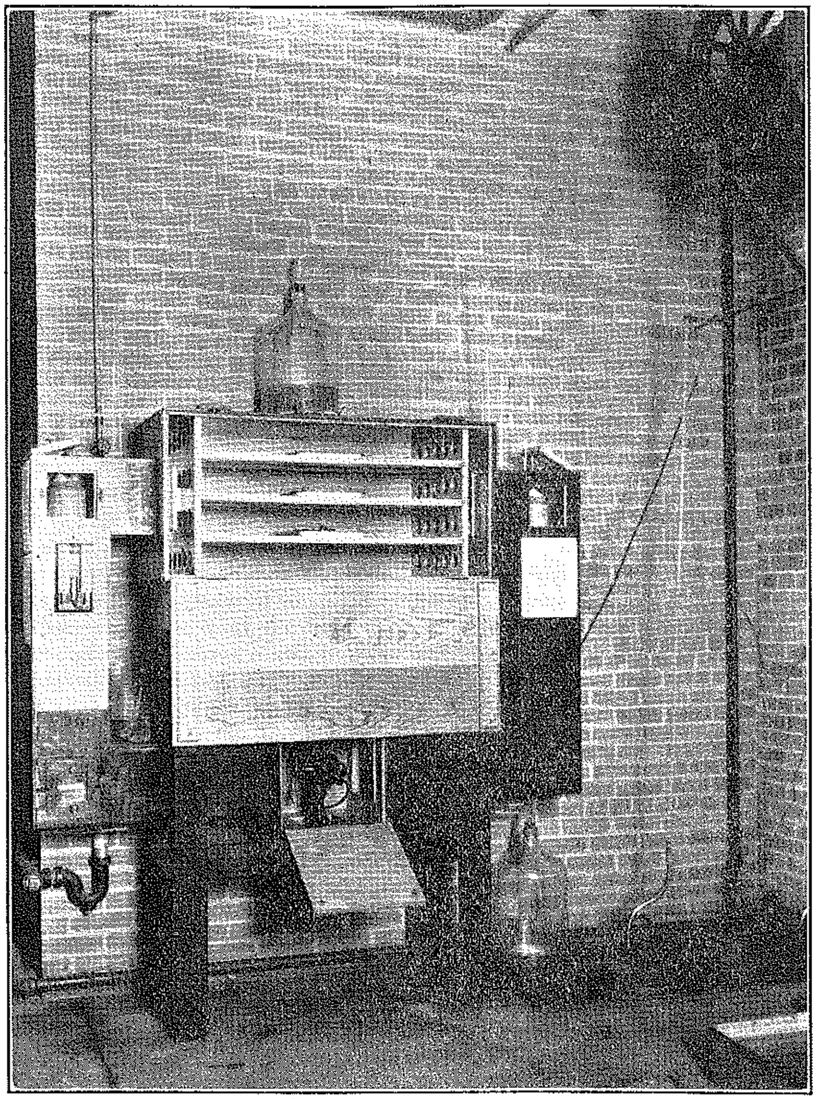

FIG. 1. Constant humidity drier for coal samples.

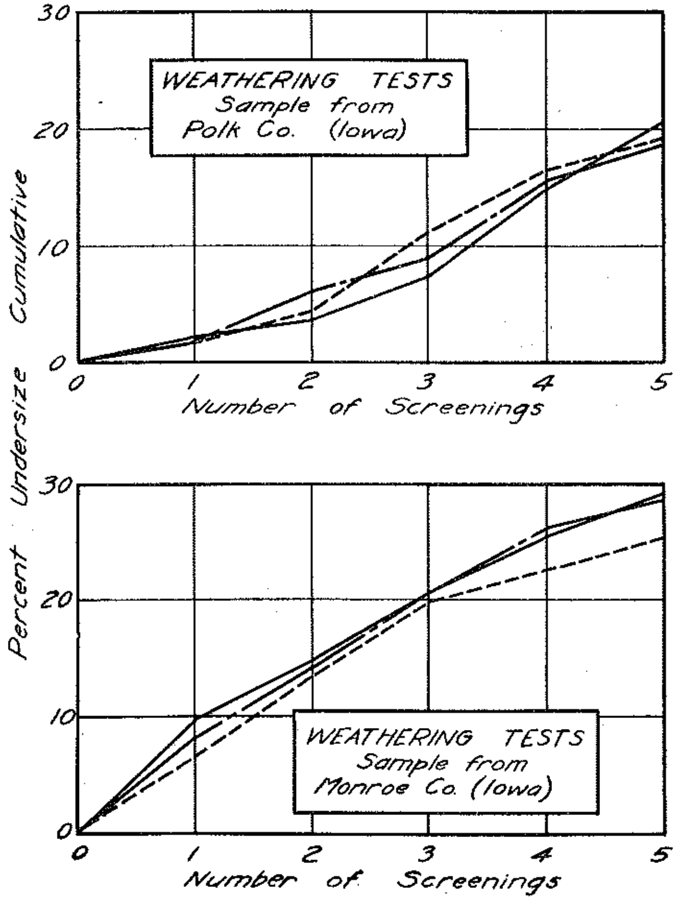

FIG. 2. Curves showing percentages of Polk and Monroe County coal passing screen.

The method finally adopted for the accelerated weathering test utilizes the principle of vacuum drying at high temperatures and was standardized as follows.

The coal used for all tests was freshly mined and sent directly to our laboratory packed in sealed carbide drums. From this fifty-pound lot were selected ten uniform lumps approximately 200 grams (about 6.5 ounces) in total weight. These were spread on a metal tray and soaked in water at room temperature for 30 minutes, then placed in a steam-heated vacuum shelf drier and dried at a vacuum of 29 inches and at the temperature of 10 pounds (gauge) steam for two hours. After a short interval for cooling, the sample was transferred to a 0.5 inch screen mounted on a mechanical shaking device with an 11 inch stroke and agitated for one minute at the rate of 180 vibrations per minute. The undersize was collected and weighed and then calculated as percentage weight of the original sample on the "as received" basis. The procedure described constitutes a cycle that was repeated five times for each coal studied.

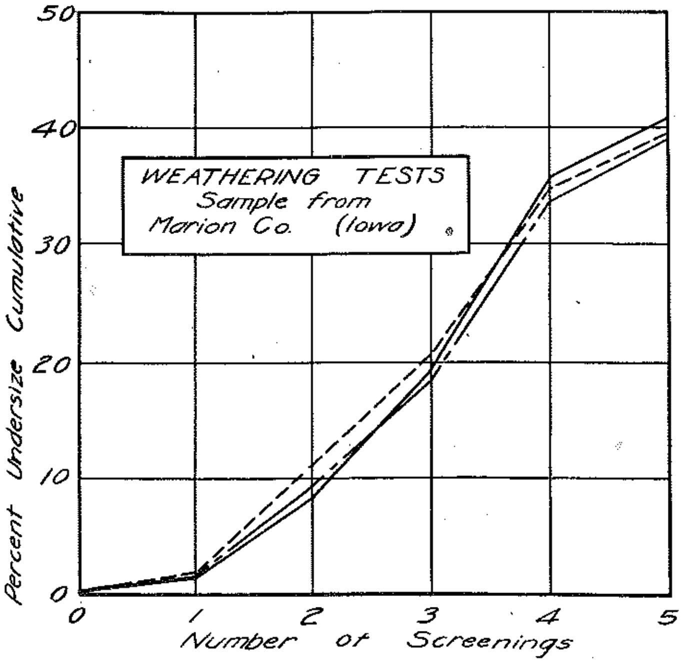

FIG. 3. Curves showing results of weathering test on Marion County coal.

The fuels investigated were selected especially to represent the three coal bearing seams of the state, the Lower Cherokee, the Mystic and the Nodaway. The geological relationships of these beds are discussed elsewhere in this bulletin by Dr. Lees of the Iowa Geological Survey and it is sufficient to say here that the three rank in age in the order named. Mine moisture determinations of 36 samples made in this laboratory show mean values of 15.0 per cent, 16.2 per cent and 20.1 per cent for the Cherokee and Mystic and Nodaway coals, respectively. We should therefore expect

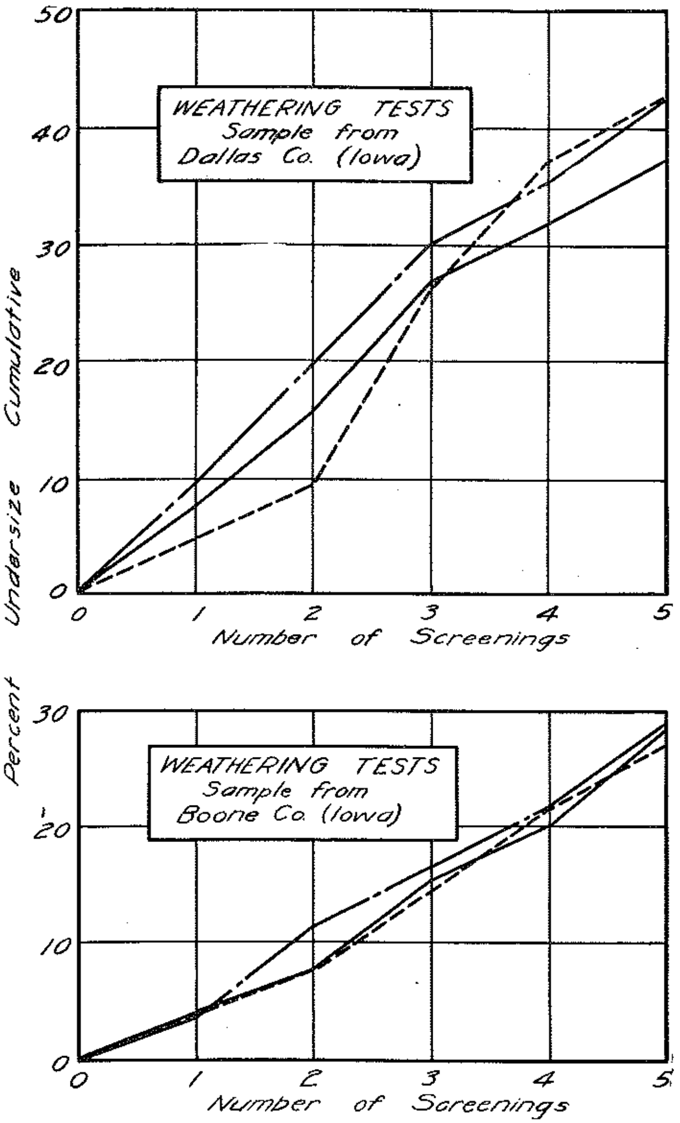

FIG. 4. Curves showing percentages of Dallas and Boone County coals passing screen.

representative samples from these districts to differ in physical properties and the graphs of our results which follow confirm this idea. Figures 2 to 4 for coals from the Lower Cherokee indicate percentages of undersize ranging from 20 to 40, values which we may designate as "weathering coefficients."

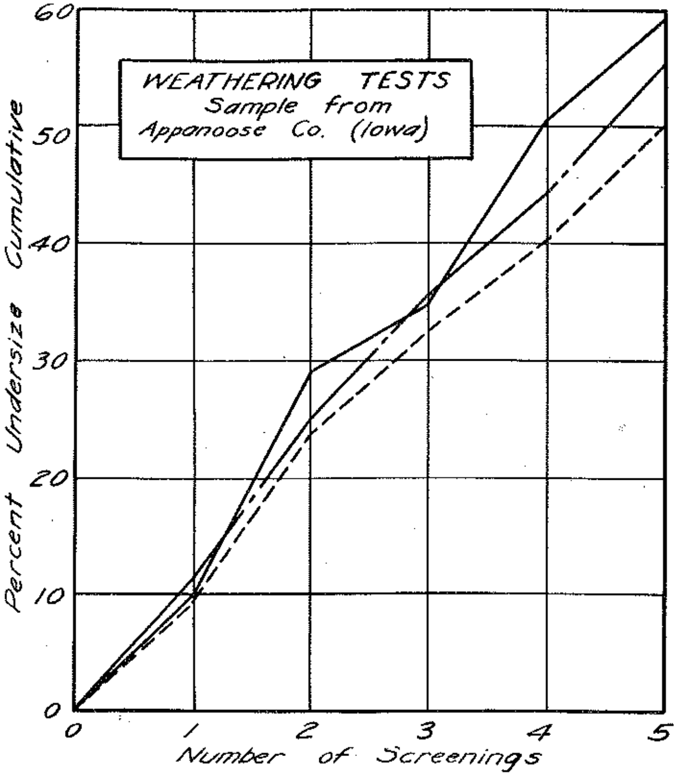

FIG. 5. Curve of Appanoose County coal passing through screen.

Figures 5 and 6 show results of tests of the Mystic seam, one of the most important commercially in the state and one from which a coal of excellent quality is obtained. Its greater friability, which is denoted by a coefficient of 55, has been generally recognized, but apparently it has not greatly diminished its popularity.

The third division, the Nodaway, is represented in this work by the curves shown in Figures 7 and 8. A distinctly higher weathering tendency, expressed by a coefficient of 65, is plainly evident in these coals and special care in handling and shipping probably is necessary to avoid undue proportions of fines. It must not be assumed, however, that they are lacking in merits of their own; cokes of relatively good quality may be made from them, an indication that they should have a ranking much above the subbituminous types of the Western states.

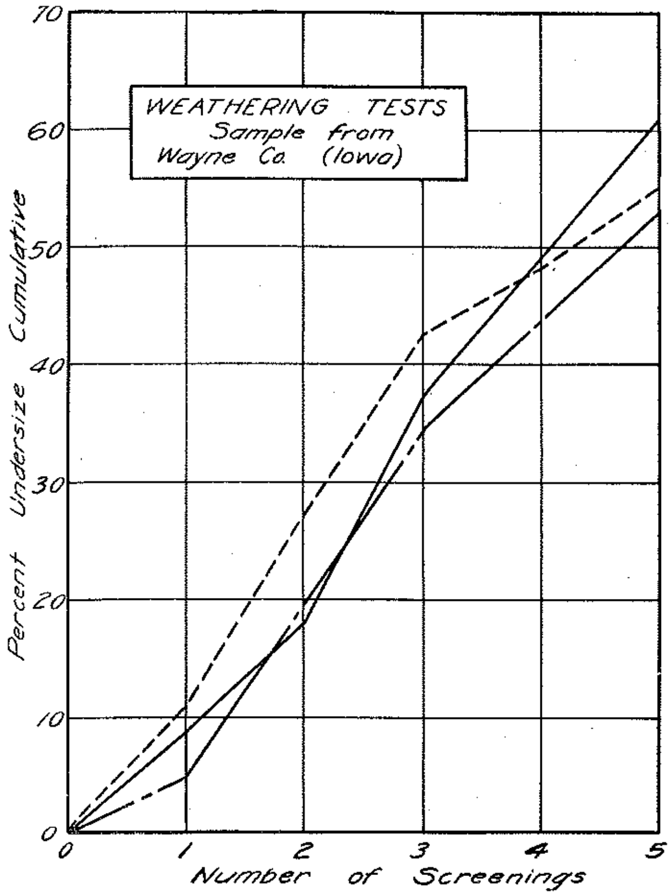

FIG. 6. Curve showing results of weathering tests on Wayne County coal.

It is perhaps unnecessary to emphasize again the fact that these results are produced by severe and highly artificial conditions employed in a method designed to yield comparative data only and that they in no way represent the degree of breakage to be expected in normal handling and storage. The method is quite analogous to the accelerated fading tests which employ strong ultraviolet light to determine the relative stability of dyes or to the abusive treatment given an automobile motor at the proving grounds in order to establish its relative reserve strength. In all such cases absolute results can be obtained only by applying the proper correction factor based on observed results under ordinary conditions.

It is interesting in this connection to examine similar data obtained on three samples of Illinois coals, one from Henry county in the northern part of the state, another from Sangamon county in the central part and two others from Franklin and Saline counties in the extreme south. Casual inspection of the graphs in Figures 9 to 11 will show that except in the case of the Saline county coal, where the crustal movement discussed above has had a profound effect, Iowa coals suffer little indeed in comparison. It must be admitted of course that many more data are needed before general conclusions can be drawn but meanwhile the facts at hand support the authors' contention that much of the popular prejudice against the Iowa product is based upon faulty knowledge of facts.

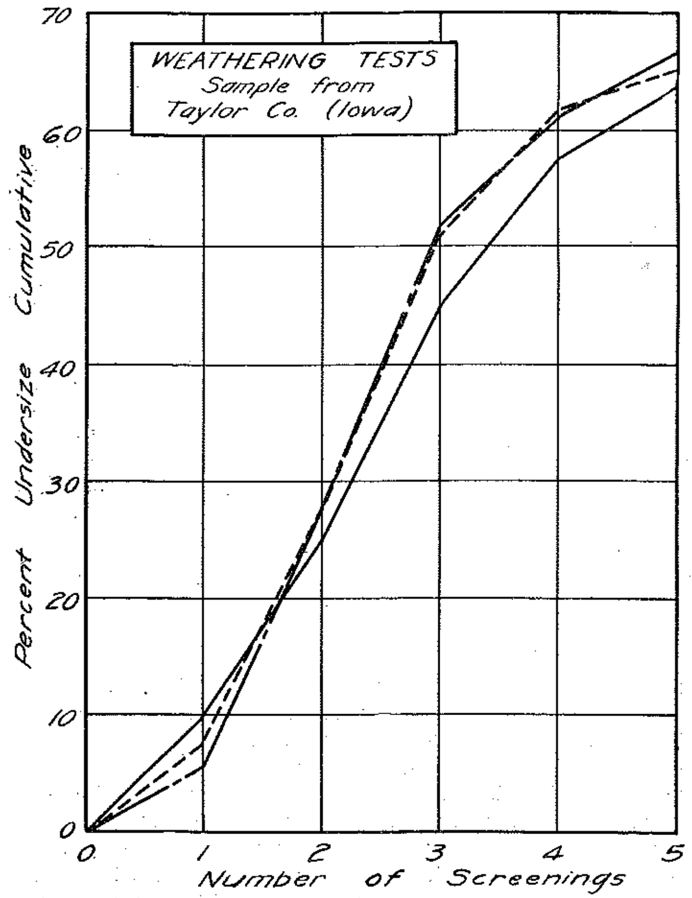

FIG. 7. Curve showing weathering tests on Taylor County coal.

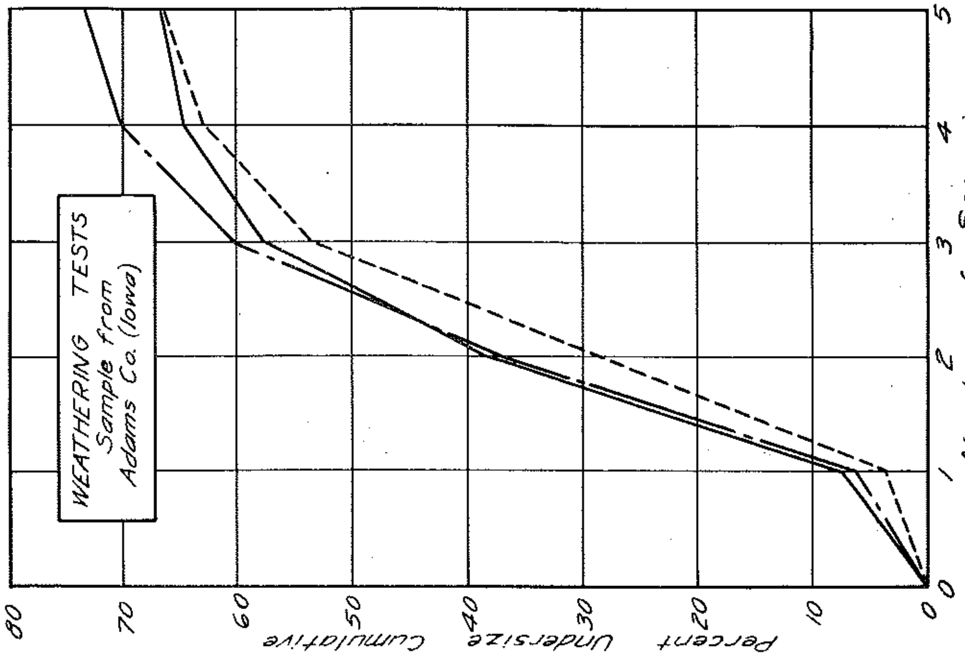

FIG. 8. Weathering of Adams County coal.

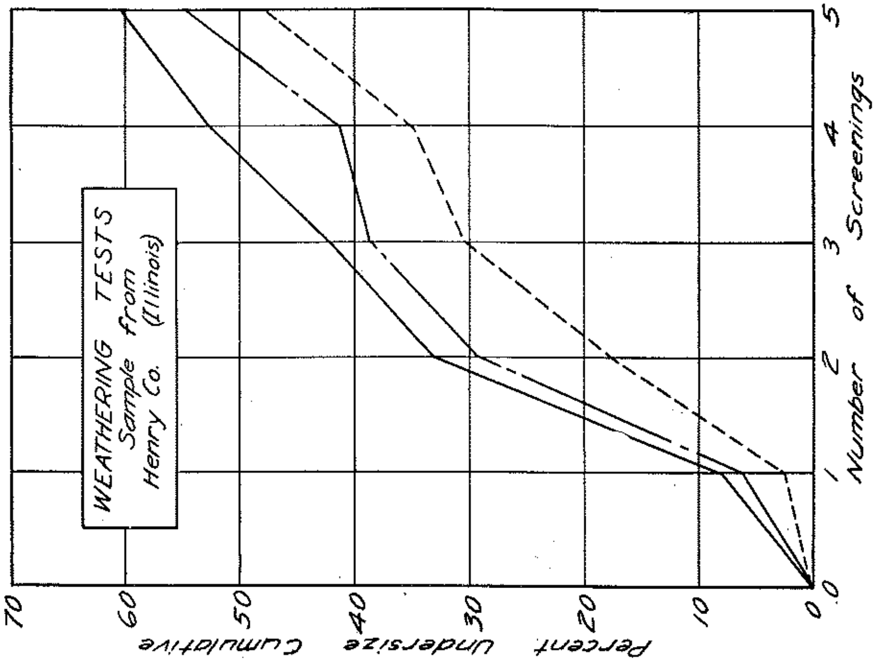

FIG. 9. Weathering of coal from Henry County, Illinois.

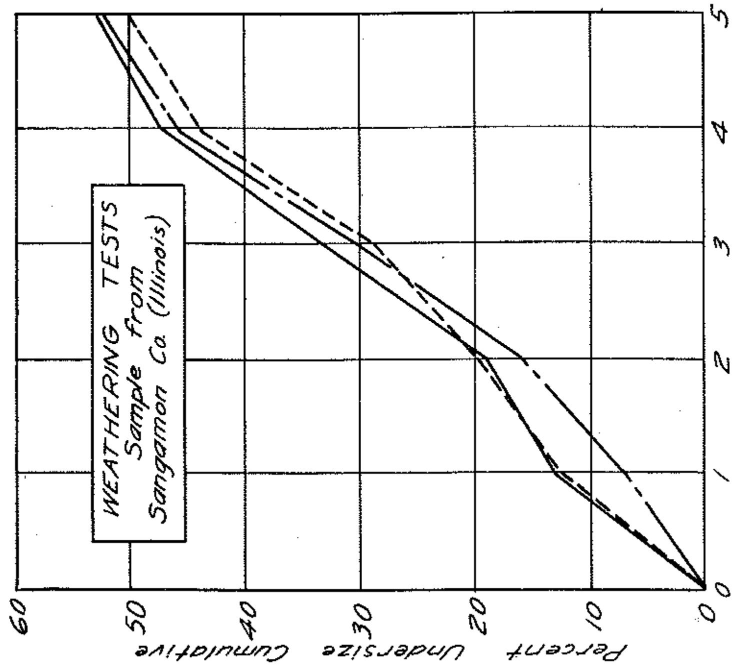

FIG. 10. Weathering of coal from Sangamon County, Illinois.

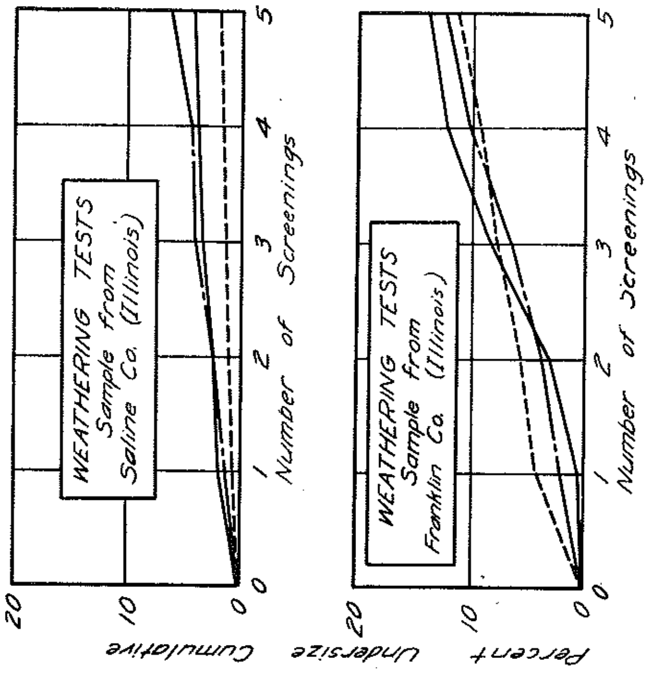

FIG. 11. Weathering of coal from Saline and Franklin Counties, Illinois.

THE WASHING OF IOWA COALS

H. L. OLIN, CLARK BARRETT AND H. D. ALLEN

It is unfortunate but true that Nature in her processes of laying down the organic debris that formed our present coal seams had only indifferent success in maintaining the purity of the mix against gross contamination by wind- and water-borne mineral matter. As a result the ash component of coals from different sources is a variable ranging from less than one per cent on the one extreme to as much as 35 or 40 per cent in exceptional cases on the other.

No extended discussion of the negative virtues of the ash constituents is necessary here. So far as they are present they dilute the combustible components of the mass and reduce its mean thermal value; within certain limits of composition they form low-melting slags or eutectics which promote the formation of clinkers and thus disturb the normal course of combustion; they complicate in many cases the corrosion problems of furnace operation not only through the action of the slags they form but through the gases they generate at high temperatures; at best they are inert wastes that must be transported to the point of consumption and thence to the more or less remote disposal dump.

The removal of much of the mineral matter of coal by various washing methods is commercially possible in general, except when it is intimately disseminated through the mass. If on the other hand it occurs in lumps or bands as pyrite or slate that can be readily broken free from adhering coal satisfactory separation of refuse from combustible may be effected by processes which take advantage of the different settling rates of solid particles of different sizes and densities falling through a liquid medium. Expressed in simple mathematics

$$V_1 = k\,\frac{D_1(S_1-s)}{s}$$

where V_1 is the average velocity of particles of slate or other impurity of mean diameter D_1 and density S_1 in sinking through a solution of density s. If V_2 is the velocity of any pure coal particle of diameter D_2 and density S_2 it follows that the slate and coal will sink with equal velocities only when the inverse ratio

$$\frac{D_1}{D_2} = \frac{S_2-s}{S_1-s}$$

is satisfied. In other words so long as the ratio is less than this value the smallest particle of the heavier substance or slate will attain a final velocity greater than the largest particle of the coal and segregation is therefore possible. It is upon this fundamental principle of physics that the design of the many washers of coal and other minerals is based. The most common type, the jig, employs a plunger to impart an upward surge to the water with the result that the slowly settling coal is floated over a weir while the heavy waste sinks rapidly and is collected below.

Although coal washing as an adjunct to mining operations has been practiced for nearly 80 years the coal industry as a whole has been extremely conservative in taking it up. The first preparation plants were installed not to furnish a better product that should command a higher price but to meet the insistent demands of certain consumers such as the iron smelters for fuels to meet their special requirements. In most cases it seems still to be looked upon as an unnecessary item in production costs and one that should be avoided if possible. In the period covering the last 25 years, of the total coal tonnages an average of 20,400,000 tons or 3.8 per cent only has been washed. Bureau of Mines figures show the following washing activities in the bituminous fields for 1928.

TABLE 1. Bituminous Coal Cleaned at Mines in 1928

State	Coal washed net tons	Cleaned coal net tons	Refuse net tons	Per cent of cleaned coal to total state output
Alabama	14,511,556	13,064,095	1,447,461	74.1
Arkansas	7,581	6,893	688	0.4
Colorado	439,401	386,199	53,202	3.9
Illinois	368,977	315,017	53,960	0.6
Indiana	212,950	193,784	19,166	1.2
Kentucky	597,503	541,975	55,528	0.9
Michigan	129,330	111,469	17,861	18.1
Montana	111,800	101,586	10,214	3.1
Pennsylvania	2,182,820	2,033,908	148,912	1.6
Tennessee	362,665	326,903	35,762	5.8
Virginia	283,435	229,271	54,164	1.9
Washington	1,167,304	892,498	274,806	35.4
West Virginia	3,132,947	2,858,276	274,671	2.1

It appears from the above table that only in Alabama, where sulfur elimination is necessary in order to make the coals available for metallurgical coke, is washing practiced on a large scale. In other regions of the United States its application appears to be limited to the treatment of certain screenings of excessively high ash content and to the production of clean nut and egg sizes for domestic use.

Many factors of course are involved in the economics of washing and a leading authority on the subject has summed up the accumulated experience of the industry in the following general statements:

"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."

Coal Washing in Iowa

So far as records show only one plant has ever carried on washing operations in Iowa, viz. that of the Iowa Coal Washing Company at

Lakonta in Mahaska county. This was opened in 1912 for the special purpose of reducing the ash content of screenings from mines in the vicinity, which ran in some cases as high as 35 per cent, down to a point acceptable to the market. The three jigs employed had a combined capacity of 1000 tons per nine hour day and at that rate used 2400 gallons of water per minute. No figures on total tonnage handled during the five year period are available, but in 1914 the amount washed was 98,587 tons from which 74,595 tons of clean coal were obtained. The plant ceased operations in 1917 on orders from the federal Fuel Administrator.

In a personal letter the former president of the company, Mr. J. M. Timbrell, writes: "We found it possible to reduce the ash to less than 13 per cent but much of the sulfur failed to take the refuse route and went over with the coal. We had no trouble in marketing our product over a wide territory that included Omaha, Sioux City and Cedar Rapids and in competing successfully with the better grades of Illinois and Kansas coals".

Work done on Iowa coals at the Louisiana Purchase Exposition at St. Louis in 1904 has perhaps some historical interest. Carload lots from mines in Wapello, Marion, Polk, Appanoose and Lucas counties were washed in preparation for tests of their coking properties. Average values of ash and sulfur of the raw coals, which were 13.7 per cent and 4.6 per cent respectively, were reduced to 8.7 and 3.7 per cent, but no data on the amount rejected in the washing process are available.

It is evident of course that the whole complex structure of the coal industry has changed since the World War period and that methods and practices that were successful then might be economically obsolete now. But it does not follow on the other hand that clean coal is in less demand at the present time than it was then. Indeed every indication points to a growing reluctance on the part of the consumer to tolerate the nuisance of excess ash and dirt and this change of attitude is being vigorously exploited by salesmen for oil and gas combustion devices. The following advertisement testifying to the demand for clean fuel for domestic use has recently been appearing in a country weekly published in the extreme northwest part of Iowa.

"We have a good supply of Illinois Washed Egg coal for cook stoves. Just the thing for spring and summer use. * * * "

It is rather significant that such a market should exist in a territory whose supply must be shipped over 600 miles from the extreme southern end of a neighboring state, and the possibility of duplicating that supply from sources much nearer home should be worth investigating.

Regardless of the economic conditions that may or may not warrant the operation of commercial washeries in Iowa it seems to us important that the limits of ash and sulfur removal for our coals should be established through scientific laboratory study that will furnish data upon which estimates of commercial separation may be based. Early in

1921 work was begun on this project at the University, the results of which, designated as Series I, were published in the Iowa Geological Survey reports. This covered the intensive laboratory study of six coals from mines in Polk county in which special attention was given to the form in which sulfur appeared in the coal structure.

The procedure upon which these and subsequent series were based followed closely that devised by Parr at the University of Illinois and described in Bulletin 125 of the Engineering Experiment Station. The average true specific gravity of the coal was first measured with a pycnometer, using water to fill the voids. A solution of zinc chloride of specific gravity 0.05 higher than that of the coal was made up for use as the floating liquid and this was employed in apparatus similar in construction to that described in the bulletin mentioned, which provides means for making a sharp separation of the two fractions after equilibrium is established.

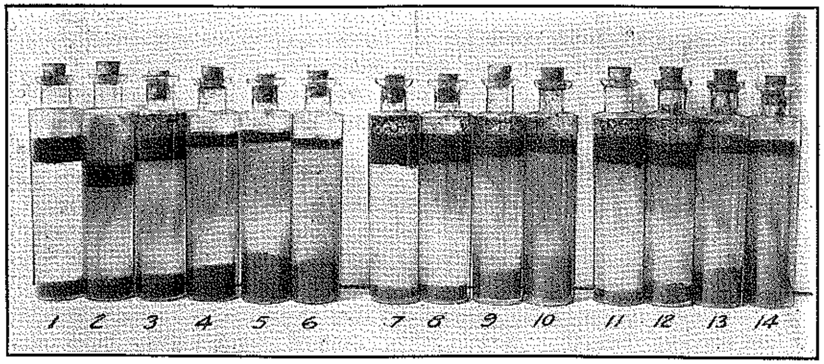

FIG. 1. Separation of coal portions in heavy liquid.

Figure 1 gives an objective illustration of the range of separations possible with the use of solutions of varying densities. Vials 1 to 6 inclusive contain samples of the same coal suspended in solutions of ascending specific gravity while a second and a third sample of other coals are similarly shown in 7 to 10 and 11 to 14. In each group, with each successive solution a purer float fraction is obtained but only at the expense of a larger waste fraction in the sink. Likewise in commercial operation, by proper adjustment of the jig or other machine, any desired ratio of sink and float within limits may be obtained such as may be necessary for a given quality of product. It should be clearly understood of course that in the tables that follow the separations represent single sets of conditions only and that considerable variation is possible by altering solution densities.

In order to assemble the complete results of work on Iowa coal ash done at this laboratory we quote from the earlier publication the figures shown in tables II and III.

Table II. Series I, Sulfur Content of Raw Coals (Polk County)

PERCENTAGES (DRY BASIS)

Sample Number	1	2	3	4	5	6	Mean
Total sulfur ______	5.61	3.02	5.37	5.63	6.33	3.00	4.82
HCl soluble (sulfur as sulfate)	0.17	0.29	0.42	0.55	0.20	0.15	0.29
Pyrite sulfur ______	2.93	2.05	2.96	3.00	3.45	1.60	2.66
Organic sulfur (by difference) __	2.51	.68	1.99	2.08	2.68	1.25	1.86

The special importance of identification of the sulfur forms lies in the fact that only the inorganic pyrite and sulfate sulfur can be removed to any significant extent by washing since the organic sulfur is chemically combined with the coal substance. It is interesting to note in this connection that recent studies at the University of Illinois have shown that the relatively small amount of sulfate present in the coal, usually as calcium sulfate (gypsum), is the cause of much of the corrosion trouble in combustion because of the ease with which it is decomposed into sulfuric acid.

In the following table are shown separation results on the same coals.

Table III. Series I, Distribution of Ash, Iron and Sulfur.

PERCENTAGES (DRY BASIS)

Sample Number	1	2	3	4	5	6	Mean
Moisture in original ______	9.84	6.42	5.56	5.96	2.48	7.56	6.30
Percentage of float _________	72.10	81.80	66.10	73.00	83.50	84.10	76.60
Percentage of sink __________	27.90	18.20	33.90	27.00	17.50	15.90	23.40
Ash							
Original ____	13.61	11.91	12.84	12.22	12.72	9.97	12.21
Float _______	9.40	8.88	19.74	7.90	7.33	6.83	8.35
Sink ________	26.42	35.23	32.45	38.82	46.15	38.90	36.33
Percentage removed ___	54.20	53.80	85.80	85.70	63.50	62.00	67.50
Sulfur							
Original ____	5.61	3.02	5.37	5.63	6.33	3.00	4.83
Float _______	3.50	1.78	3.60	3.53	4.07	1.75	3.04
Sink _______	7.75	6.68	9.13	11.50	14.50	9.02	9.76
Percentage removed ___	38.58	40.30	57.60	55.15	40.10	47.75	46.58
Iron							
Original ____	3.80	2.85	3.42	3.95	3.72	1.75	3.25
Float _______	2.50	1.65	2.25	2.21	1.68	1.02	1.89
Sink _______	7.49	6.10	6.05	8.95	14.80	6.12	8.25
Percentage removed ___	55.00	39.00	59.98	61.20	69.60	55.60	56.73

The figures given in the table above need little comment. Referring to the mean results of the six tests it may be seen that in order to reduce the sulfur content from 4.8 to 3.0 per cent and the ash from 12.2 to 8.3 per cent with elimination of 47.0 and 68.0 per cent respectively of original sulfur and ash, it is necessary to discard 23.4 per cent of the original tonnage. Because of the high waste content of the sink fraction, however, the loss of pure coal is only about 14 per cent of the raw input.

Experimental Work In Series II

Work on the second series of studies on ash and sulfur elimination, undertaken in 1925, was directed especially toward determining differences in ash quality in the float and sink portions in the hope that it might assist in the solution of the problem of preventing clinker formation. To this end quantitative analyses were made of the ash from the various fractions to determine the major constituents of each, viz., the oxides of silicon, calcium, iron and aluminum which, presumably, in their varying proportions influence the behavior of the ash at the temperatures of the furnace.

The samples for this series were selected with a view to providing wide extremes in quality and the analyses as presented do not necessarily represent the average product of the given district or county. Number 1 was a run-of-mine sample from Polk county, No. 2 screenings from Dallas county and No. 3 a hand picked sample from the Mystic seam in Appanoose county. Results are given in Table IV.

Table IV. Series II, Distribution of Mineral Matter in Washed Fractions, Percentages (Dry Basis).

Source and kind of coal	Percentage of original sample	Ash	Volatile	Fixed carbon	Total sulfur	Pyrite sulfur	Organic and sulfate sulfur	Silica (SiO_3) in ash	Lime (CaO) in ash	Iron oxide (Fe_2O_3) in ash	Alumina (Al_2O_3) in ash	Softening point degrees F.
Polk Co. (run-of-mine)	100	12.8	38.7	48.7	6.0	3.9	2.1	15.0	13.5	38.7	7.5	2110
Polk Co. float	84	7.7	37.5	54.7	2.4	1.5	0.8	23.3	2.5	28.8	12.5	1990
Polk Co. sink	16	44.3	30.1	25.5	23.1	19.8	3.3	9.5	18.1	41.7	4.1	2250
Dallas Co. (screenings)	100	24.4	33.8	41.8	7.3	5.8	0.9	30.5	9.4	31.1	19.3	2100
Dallas Co. float	77	15.0	34.1	50.9	3.4	2.5	0.9	26.5	5.0	28.5	9.2	1960
Dallas Co. sink	23	57 2	26.3	16.5	18.5	15.7	2.8	28.3	9.2	30.9	20.5	2090
Appanoose Co. (hand picked)	100	6.2	42.8	50.9	4.0	1.7	2.3	28.7	7.9	34.8	18.1	1960
Appanoose Co. float	89	3.9	42.8	52.7	3.4	1.1	2.3	20.3	......	22.5	6.7	2160
Appanoose Co. sink	11	38.7	28.0	33.3	8.3	6.3	2.0	29.5	16.3	29.2	16.4	2010

The correlation of results of ash analysis with actual fusion point determinations is at best a difficult problem. Fieldner lays down the following general principles:

"The fusibility of the ash depends upon several factors, such as the ratio of silica to bases present, the particular bases present, and the percentage of alumina present. Mixtures extremely high in silica or extremely high in bases are not readily fusible. Ash that is low in iron is usually so highly siliceous that it is not readily fusible. Ash from coals high in pyrite is necessarily high in iron, and the ratio between bases and silica is often such that easily fusible compounds may be formed. As a rule, coals containing considerable sulfur in the form of pyrite are apt to give trouble from clinker formation. Under conditions of the fuel bed, the iron of the pyrite is apt to be converted into ferrous oxide, which with the silica present forms ferrous silicates that fuse at comparatively low temperatures."

From the few data available in the table above it appears impossible to draw any general conclusions on the effect of varying percentages of silica and the basic oxides on melting points of the ash as a whole, or to confirm Fieldner's observations. Neither do they offer any consistent evidence to support the theory that the ash of the float fraction is more refractory than that of the original coal. Indeed it appears in the case of the first sample (Polk county) that the float ash melts at a lower temperature than the original and that the sink has the highest melting ash of all. Only with the Appanoose coal did we note any improvement in this respect, viz., a rise of 200 degrees in the softening temperature of the float. While we cannot therefore expect the washing process to raise the melting point of the float ash it does not follow that clinkering conditions in the furnace will not be improved. Many factors enter into the complicated relationship of the slagging reaction whose bearings have not been clearly determined and nothing short of actual furnace operation would prove definitely whether clinker reduction is possible after the cleaning operation. However, reduction in total ash and especially of iron and sulfur in the pyrite form must yield beneficial results to some degree. Of direct interest are the figures for ash and sulfur reduction in the high ash screenings, which indicate that the most promising possibilities for the application of washing are on the low grade small sizes.

Experimental Work on Series III

Work on the latest series, No. III, was confined to the simple separation of sink and float fractions and the determination of ash and sulfur percentages thereon. The samples covered were those collected and described by Dr. James H. Lees in the Iowa Geological Survey pamphlet "Analyses of Iowa Coals" published in 1929, on which complete analytical results had already been obtained. The methods employed were in general the same as used in the earlier series of washing studies. Results are condensed in Table V.

Table V. Washing Results, Series III, Dry Basis, Percentages.

No.	County of source	Percentage of sink	Percentage of float	Sulfur in original coal	Sulfur in sink	Sulfur in float	Percentage of original sulfur removed	Ash in original coal	Melting point of ash, deg. F.	Ash in sink	Ash in float	Percentage of original ash removed	No.
1	Polk	31.50	68.50	6.3	8.28	3.32	41.4	10.4	2063	17.70	7.35	53.6	1
2	Polk	26.70	73.30	7.0	9.65	3.45	36.8	17.4	1981	30.10	12.98	46.2	2
3	Polk	25.70	74.30	5.9	12.02	2.91	52.3	11.0	1940	27.93	6.10	65.4	3
4	Polk	29.30	70.70	6.5	13.00	3.62	58.6	19.6	2035	47.74	8.22	71.3	4
5	Polk	32.20	67.80	6.1	7.68	3.71	40.5	15.3	1935	23.71	8.28	50.2	5
6	Polk	33.10	66.90	4.6	7.70	2.24	55.4	18.6	2063	37.15	9.95	66.0	6
7	Dallas	15.85	84.15	4.6	11.58	2.10	39.9	14.8	1947	48.12	7.52	51.5	7
8	Polk	19.45	80.50	4.3	7.73	2.05	34.9	7.5	2033	16.95	5.14	44.0	8
9	Warren	21.10	78.90	7.3	14.35	4.05	41.4	16.8	2025	42.54	10.41	53.4	9
10	Warren	19.35	80.65	5.2	11.40	3.12	42.4	15.1	2193	39.71	9.48	50.8	10
11	Polk	24.60	75.40	6.0	12.17	3.52	49.8	16.9	2177	42.62	8.91	62.0	11
12	Dallas	28.50	71.50	3.7	7.51	1.84	57.8	14.8	2192	36.42	6.42	70.1	12
13	Boone	31.65	78.35	4.1	9.22	1.97	48.7	12.1	1960	34.51	6.12	81.6	13
14	Boone	22.40	77.60	4.8	10.96	2.12	51.2	14.7	2353	39.83	7.72	60.2	14
15	Dallas	25.55	74.45	4.6	9.47	2.24	52.7	16.7	2005	41.74	8.33	63.5	15
16	Boone	29.61	70.39	5.1	8.22	2.30	47.7	10.8	2037	21.82	6.33	59.9	16
17	Boone	32.70	67.70	6.0	8.91	3.43	48.4	11.6	1889	20.91	7.21	59.1	17
18	Appanoose	16.45	83.55	4.5	----	---	---	10.5	1980	29.44	7.01	45.9	18
19	Appanoose	15.33	84.67	3.3	6.58	1.89	30.6	7.9	2023	19.54	5.91	37.9	19
20	Monroe	28.30	71.70	2.5	4.23	1.74	47.8	11.5	2168	21.52	7.81	52.9	20
21	Marion	22.10	77.90	4.2	8.04	2.82	42.3	11.3	1937	27.11	7.12	52.8	21
22	Appanoose	25.30	74.70	5.5	11.67	3.22	53.6	13.3	1930	34.60	6.23	65.9	22
23	Appanoose	34.00	66.00	4.7	8.08	2.57	58.4	14.4	2000	29.91	6.85	70.5	23
24	Appanoose	20.70	79.30	5.6	11.57	3.05	43.4	11.9	1930	31.96	6.84	55.4	24
25	Appanoose	31.10	68.90	4.0	5.82	2.15	45.2	11.5	1998	21.65	7.17	58.5	25
26	Wayne	17.30	82.70	4.7	10.88	2.75	40.1	9.9	1945	28.92	6.05	50.5	26
27	Lucas	27.75	72.35	6.3	13.63	4.26	60.1	16.6	1946	43.12	6.72	71.9	27
28	Lucas	36.10	63.90	2.5	4.35	1.71	63.4	15.9	2055	33.92	5.98	77.0	28
29	Marion	33.90	86.10	3.1	5.17	2.18	56.5	12.8	2000	25.95	6.44	68.9	29
30	Marion	28.10	71.90	3.2	4.54	2.24	39.9	11.3	1957	20.32	7.89	50.4	30
31	Appanoose	14.86	85.14	4.0	11.70	2.84	43.4	13.0	2148	50.01	8.92	57.2	31
32	Page	36.20	63.80	4.2	7.71	2.82	66.4	16.7	2253	36.42	6.10	78.9	32
33	Taylor	24.30	73.70	7.0	14.65	4.35	50.8	16.7	2237	42.73	8.56	62.2	33
34	Adams	32.60	67.20	4.5	6.68	3.01	48.7	12.5	2238	22.88	7.67	59.8	34
35	Adams	28.90	71.10	3.9	6.87	2.17	50.8	15.5	1985	33.70	8.49	62.8	35
36	Mahaska	18.45	81.55	2.4	4.52	1.86	34.7	12.2	2040	29.12	8.55	43.9	36
Mean		25.86	74.14	4.8	9.04	2.73	47.8	13.6	2044	32.01	7.85	58.6	Mean

The figures presented in the table show clearly the qualitative difference that exists in the ash constituents of the coals studied and in the way they are attached to the pure coal. For example samples 1 and 18 with practically equal percentages of ash (10.5 per cent) yield float products with substantially the same ash contents (7.35 and 7.01 per cent respectively). But the percentage of total sample rejected in the sink is in the first case nearly twice that of the second, an indication of marked difference in cleanness of separation, which must be a determining factor in the economics of washing processes. While a general comparative study of this kind is indicative of what may be expected of industrial scale operation and while it serves to show the relative ease or difficulty of separating refuse matter from the clean fuel, much more intensive laboratory work should of course be done on any given coal before a question involving commercial operation is decided.

An interesting trend in the heating of both private dwellings and public buildings is the growing popularity of the small automatic stoker for burning bituminous screenings. Some of these are so designed as to demand a coal with ash of relatively high melting point to facilitate its removal from the ash zone of the furnace in the form of a solid clinker. Reference to the melting point column in Table V shows that the fusion temperatures for our Iowa coal ashes are low as compared with values around 2500°F. for some of the eastern coals. In our opinion the necessity for designing a machine to suit the fuels of the region in which the machine is to be used is a problem that must be solved by the manufacturer. At any rate stokers are made that have proved highly successful with Iowa coals and doubtless they will increase in popularity because of their greater flexibility. While we have shown that washing probably does not raise the melting point of the float ash nevertheless the material reduction in ash quantity that it effects should be highly advantageous in operating the furnace of whatever kind. Further work on this general problem will be concentrated upon the study of screenings and other small sizes to determine the extent to which they can be improved to fit them for domestic consumption. These projected investigations will include small unit washer runs designed to furnish sufficient washed material for practical demonstrations and tests.

THE COKING OF IOWA COALS

H. L. Olin, F. V. Johnson, Jr., and R. C. Kinne

Probably no other phase of coal technology has been more intensively studied in the last two decades than that pertaining to carbonization or coking, particularly in the so-called low temperature ranges as distinguished from the high temperature processes designed for the production of metallurgical coke. Not only in the United States but in Great Britain and the Continent research work in this field has been vigorously carried on and its literature at the present time is of enormous volume. In a recent bibliography on low-temperature coking alone, references to 413 journal articles are cited and even this list is probably far from being complete.

The intense activity in this phase of coal research bears eloquent testimony to the public interest in the problems of fuel improvement, especially those that have a bearing on the elimination of the smoke and soot nuisance. Indeed the major purpose in most of the work that has been done has been to produce a free burning but smokeless fuel from bituminous coals by subjecting them to partial distillation at moderately low temperatures thereby breaking down and removing the heavy hydrocarbons that produce the smudge in raw coal combustion. Unfortunately out of this great mass of effort has come little if any commercial success, not because of failure of the technologist to control his process and to produce a prepared fuel of the desired quality but because present economic conditions in the fuel industries preclude the profitable marketing of such a material. From the standpoint of domestic heating the best examples of the low or medium temperature cokes that have been made on the experimental scale have proved to be admirable fuels. In general they possess the advantage of metallurgical or gas cokes in being clean and smokeless, but in addition they are usually reactive to a high degree and kindle readily at moderate temperatures. Without question the general adoption of such fuels would effectively solve the smoke problem of our cities through complete elimination of the conditions that bring it about, but until the general public becomes less complaisant with air pollution both within and out of doors the use of specially processed coals will doubtless increase slowly indeed.

From the theoretical standpoint, however, it is highly desirable to study the coking possibilities of a coal along with its other properties, not only to meet the possibility of future coking developments but to provide data for its scientific classification. Iowa coals have long been considered as noncoking in character, largely perhaps because experimental tests on 5 coals from as many different counties in Iowa made at the St. Louis Exposition in 1904 were negative in character. It must be noted, however, that the methods used were those suitable only for low volatile eastern coals and that when applied to those of entirely different character good results should not have been expected.

With a view to establishing the true coking properties of the coals of the state so nearly as possible studies along this line have been made since 1924, the results of which are still incomplete. They do indicate, however, that when treated under the proper conditions Iowa coals yield coke products that are fairly hard and coherent and that show much promise of possible use. These studies are included in two series in which different methods were used and in which different results were obtained.

Coking Series I

The earlier method was relatively simple in character. It involved the use of an electrically heated cast iron retort holding about 8 pounds of coal, connected with a condensing and purifying train for separating the tar and otherwise cleaning the gas. Temperatures were maintained strictly within the low range and in no instance did they exceed 470°C (878°F) in the middle of the charge. The crushed sample was put directly into the retort without preliminary heating and the distillation proceeded for periods ranging from 6 to 12 hours.

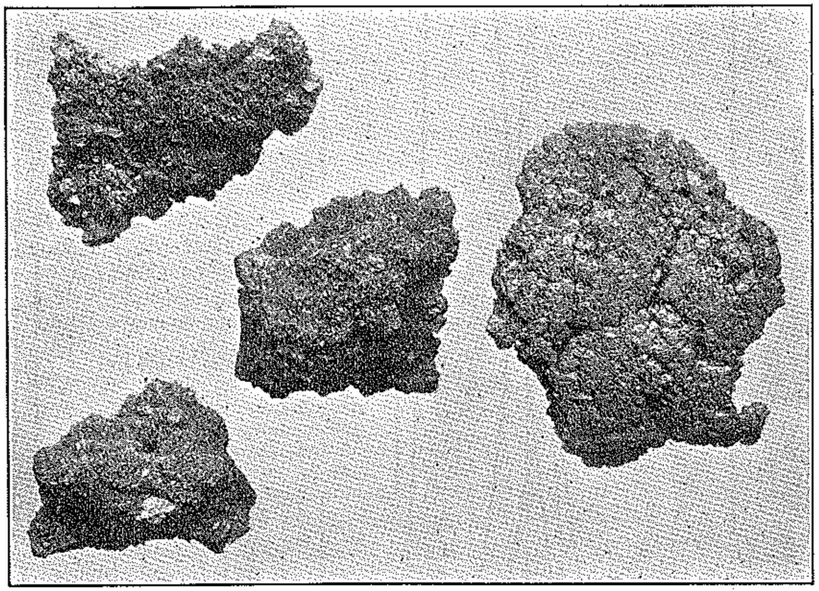

FIG. 1. Low temperature coke from Marion County coal, Series I.

In brief, the results of experiments carried out under these conditions were unsatisfactory, in all probability because the temperatures were too low and because the preliminary treatment of the coal was faulty. Yields of gas and tar were small, but more especially the coke residue barely fused together and had little coherence. The sample shown in Figure 1, the product of a Marion county coal, was perhaps superior to any of the others but at best it left much to be desired and the tests as a whole indicated the necessity for improving the method.

Series II

Unquestionably the most important and scientifically sound of the many processes for the low or medium temperature coking of coal is that developed by Parr at the University of Illinois. Without entering into a

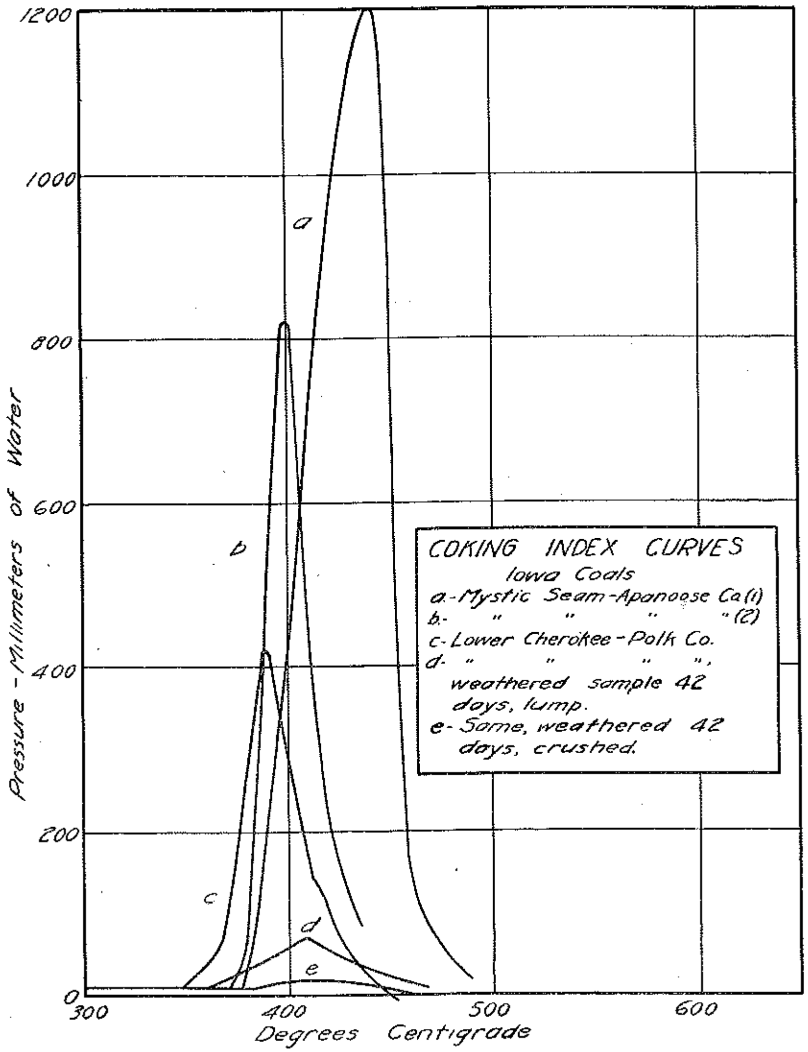

FIG. 2. Curves showing coking tendencies of Iowa coals.

highly technical discussion of the method, which is particularly applicable to the high oxygen coals of the Middle West, we may say that it involves a preliminary heating of the crushed coal in a rotary drum to a temperature just short of its fusing point. From this it is immediately dumped to the retort proper which has previously been heated to the maximum coking temperature. In this retort the actual fusion and coking takes

place, assisted to a considerable extent by the heat produced exothermically, i. e., generated by chemical reactions within the coal substance itself. As a result of this combined external and internal heating the reaction moves rapidly to the center of the charge and complete carbonization is effected in a relatively short time.

The choice of the Parr process for the experimental runs of the second series made it necessary first to undertake a study of typical coals of the state to determine the temperatures at which the organic matter melts to a plastic mass inasmuch as temperature control up to this point is mandatory in the preliminary heating stage. The apparatus used in this work was a modification of that devised by Layng and Hathorne. The principle underlying its operation involves the heating of a carefully graded sample in a glass tube while an inert gas such as pure nitrogen under constant head is being forced through it in a steady stream. Until softening takes place the granular material offers free passage to the gas and the manometer indicates minimum pressure. When, however, the temperature reaches the point of incipient fusion the flow resistance mounts and reaches a maximum at the stage of greatest plasticity of the coal. From this time on the coal decomposes in the process of carbonization and the formation of the porous coke structure again affords the gas a relatively free path. By plotting pressures as read from the manometer against temperatures indicated by a thermocouple inserted in the tube, graphs of the peculiar type shown in Figure 2 are obtained. Inspection of these curves shows readily the points at which fusion begins and those at which decomposition is complete and thus the limits of the critical range are easily fixed.

Inasmuch as a coal must fuse or melt freely in order to produce the cementing action required in the making of a good coke it follows that the height of the fusion curve is in general a criterion of the coking value of a coal. So great, however, is the avidity of fresh coal for oxygen that moderate exposure of the sample to air soon brings about an oxidation of the coking constituents which completely changes its chemical nature. The new substance does not melt and while it loses its volatile matter on being heated the residue is a granular powder in no sense a coke. The graph cited shows clearly in curves (d) and (e) the destructive effect of oxidation and indicates the necessity for selecting fresh raw material for coking operations, at least where the fusion tendencies are initially rather weak.

Table I gives results of fusion tests on a number of coals for which data are available at present. Included in this table are data on the age of the sample from the time it was taken from the mine, which as indicated above must be considered in interpreting the other data. Temperatures of initial fusion and temperature and pressure at the crest are self-explanatory while by "minimum coking temperature" is meant that at which the pressure again becomes normal.

Table I. Coal Fusion Tests

No.	County	Age of sample days	Minimum fusion temp. Deg. C.	Temp. at crest, Deg. C.	Pressure at crest, mm. water	Minimum coking temp., Deg. C.
1	Polk	43	346	392	218	432
2	Polk	50	363	---	---	---
3	Polk	35	347	392	82*	445
4	Polk	56	347	386	82*	436
5	Polk	6	347	392	419	452
6	Polk	14	362	404	204	456
7	Dallas	10	362	406	438	457
8	Polk	5	360	400	400	460
9	Warren	17	362	403	234	462
10	Warren	5	356	402	350	460
11	Polk	3	360	403	306	470
12	Dallas	3	360	420	449	486
13	Boone	4	360	408	200	470
14	Boone	4	360	401	600	470
15	Dallas	6	360	403	584	480
16	Appanoose	3	370	408	788	473
17	Appanoose	7	366	406	818	---
18	Wayne	11	370	422	1208	495
19	Marion	13	372	413	480	470
20	Marion	19	372	410	73	470

*Possibly taken from a partly weathered face.

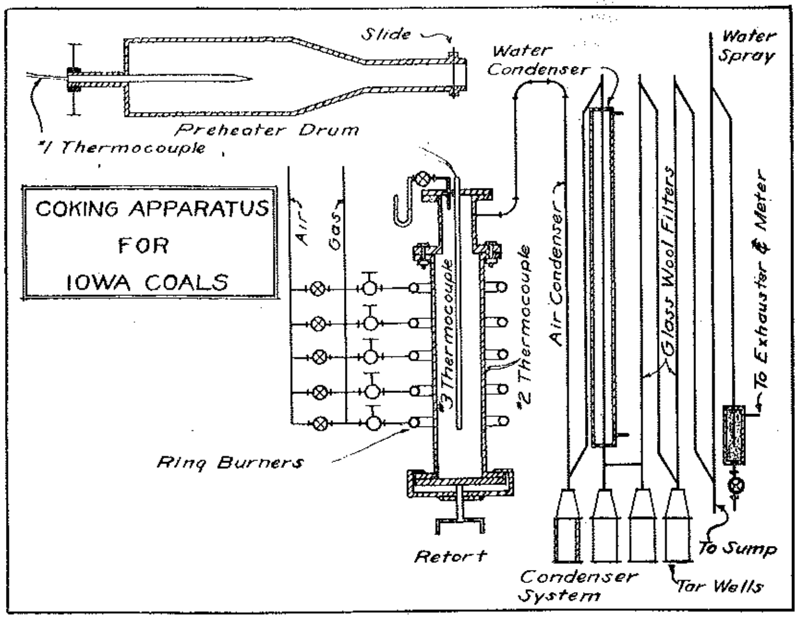

FIG. 3. Diagram of apparatus used in coking Iowa coals.

It may be seen from the table above, which is still incomplete, that the coals from the southern counties are measurably superior to the others in coking tendency as indicated by crest temperatures and that we should expect some of the best results from samples from that district. The validity of this prediction is being confirmed in a striking manner and we shall doubtless produce the best cokes from the Mystic Seam coal.

The apparatus used in the coking tests proper and shown in diagram in Figure 3 embraces three functional units, the preheater drum, the gas fired retort and the purifying train, all of which are graphically described. All temperatures were measured by means of Chromel P—alumel thermocouples of 8 gauge wire with the cold junction at constant temperature in a bath of ice water. All these couples develop the same potential at 600°C within 0.05 m. v., the limit of the meter.

PROCEDURE

The coals used in this series were collected at the mines, sealed in air-tight carbide drums of about 50 pounds capacity and shipped immediately to our laboratory where they were processed as soon as possible, usually within a week. After being crushed to a maximum of one-half inch the charge was placed in the revolving preheater in batches of 40 pounds or more and heated to a point well below fusion temperature, in most cases about 300° C.

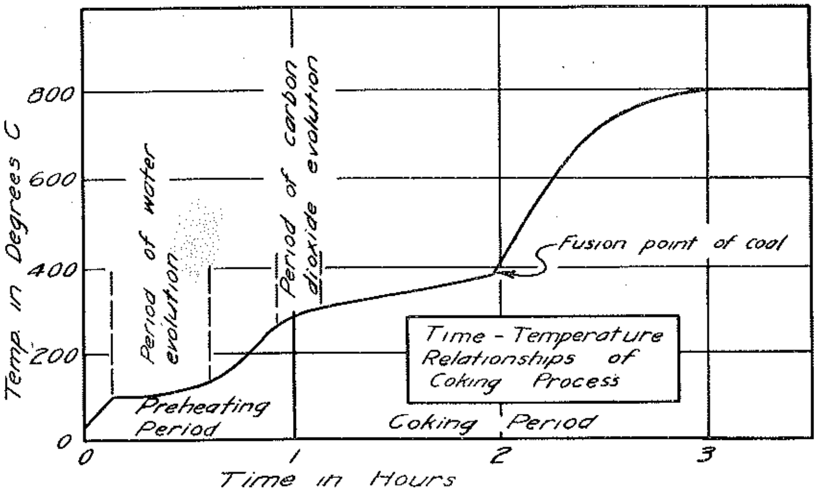

FIG. 4. Chart showing temperatures in coking Iowa coals.

After being held at the 300° temperature for about 10 minutes to complete a one hour preliminary period the drum was tilted and the charge dropped into the retort previously heated to 800° C. The condensing and cleaning train to purify the gas consists of 2 two-inch water-cooled pipes, 2 pipes packed with glass wool to act as a filter and finally a pipe in which a spray of water was kept in play. In general the charge was completely processed in 3 hours from the beginning of the preheating period.

Figure 4 shows graphically the time-temperature relationships of the process and indicates the stages that lead progressively to fusion and decomposition of the coal substance. While the graph shown is a type curve only it probably represents quite accurately the conditions that hold for all the Iowa coals studied. It was found as predicted that the coals showing the highest peaks in the fusion point determinations produced in general the firmest and best cokes and promised the most interesting possibilities for further study.

In the following table we have assembled some data on a number of runs of this series. These results, however, are incomplete and are presented as only roughly indicative of what may be expected. No work has been done on the tars and gases and little or none on the physical properties of the cokes.

Table II. Coke and Tar Yields—Iowa Coal Carbonization.

Source of coal	Amount coke per ton of coal, pounds	Tar, gallons per ton	Ave. temperature for last hour, Deg. C.
Polk Co.—Economy Coal Co.	1,068	----	----
Wayne Co.—Violet Valley Coal Co.	900	13.2	----
Appanoose Co.—Center Coal Co.	1,000	17.9	769
Boone Co.—Scandia Coal Co.	975	23.8	776
Dallas Co.—Shuler Coal Co.	1,040	24.0	807
Mahaska Co.—Oskaloosa Coal & Mining Co.	1,050	21.5	777
Adams Co.—Ruth Coal Co.	880	18.4	806
Marion Co.—Pershing Coal Co.	965	20.2	820
Boone Co.—Boone Coal Co.	905	12.5	802
Polk Co.—Gibson Coal Co.	850	21.2	800

The general appearance and characteristics of the cokes produced may be judged from the cuts shown in Figures 5 to 14. Data on crushing strength and chemical compositions, resistance to handling and kindling temperatures are not yet available but will be given in a forthcoming bulletin. Briefly, these cokes are fairly coherent, far superior in this respect to any produced by the old methods, and after screening could probably be handled without excessive breakage. They burn of course without smoke inasmuch as they retain a maximum of five per cent of volatile matter. Moreover they kindle extremely readily, being in this respect much more active than gas house or metallurgical coke.

Aside from the bearing that the coking properties of these coals may have on the possibility of establishing a carbonization industry which, although now remote, may be of importance in the future, this coking tendency is of direct interest to the domestic consumer. It is a matter of common knowledge that the most satisfactory furnace coals are those that form in combustion an easily controlled coke structure rather than a loose

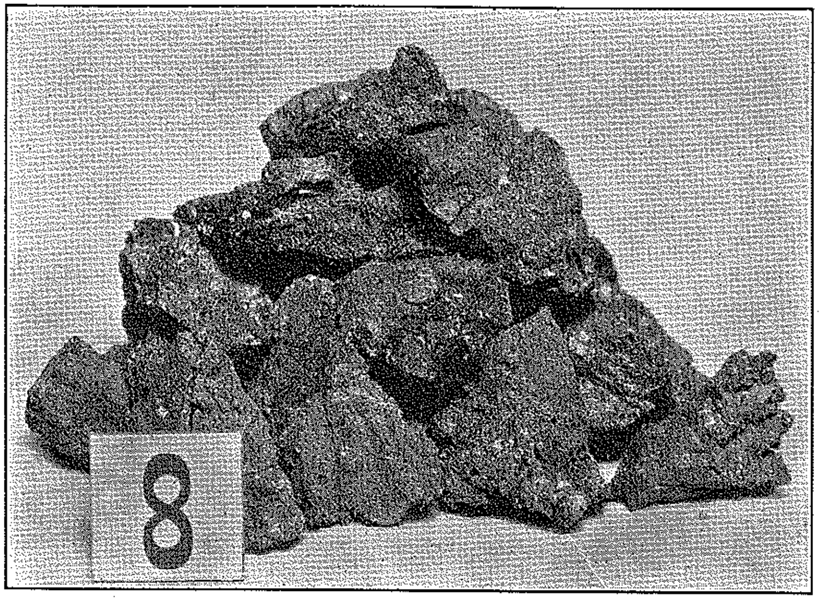

FIG. 5. Coke from Wayne County coal. Violet Valley Coal Co.

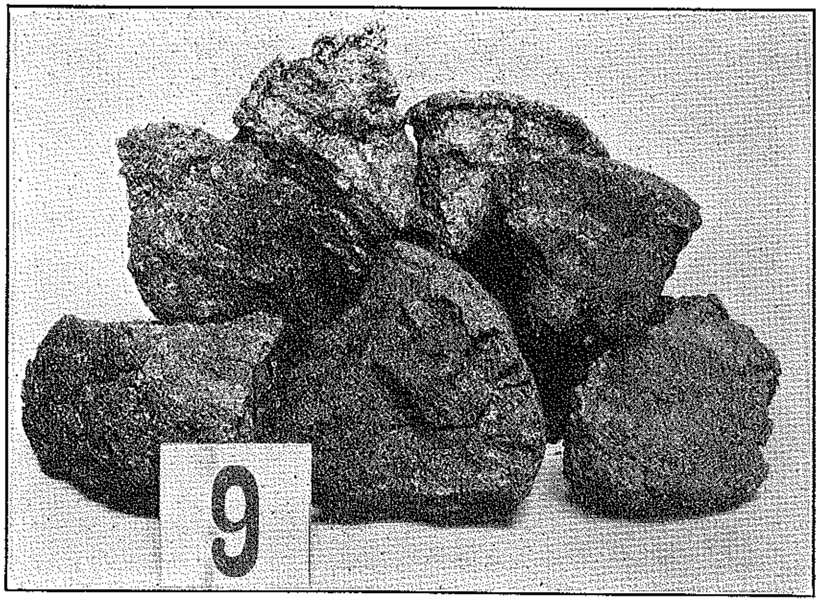

FIG. 6. Coke from Appanoose County coal. Center Coal Co.

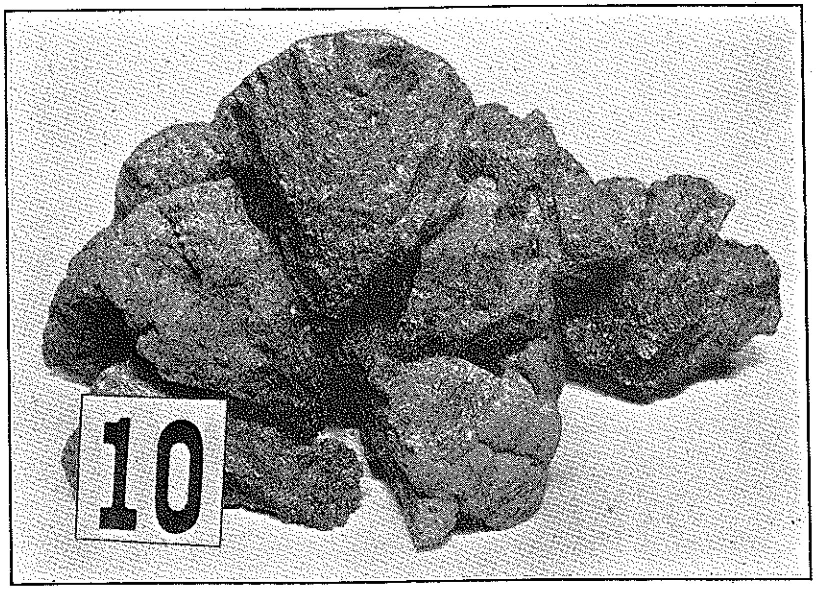

FIG. 7. Coke from Boone County coal. Scandia Coal Co.

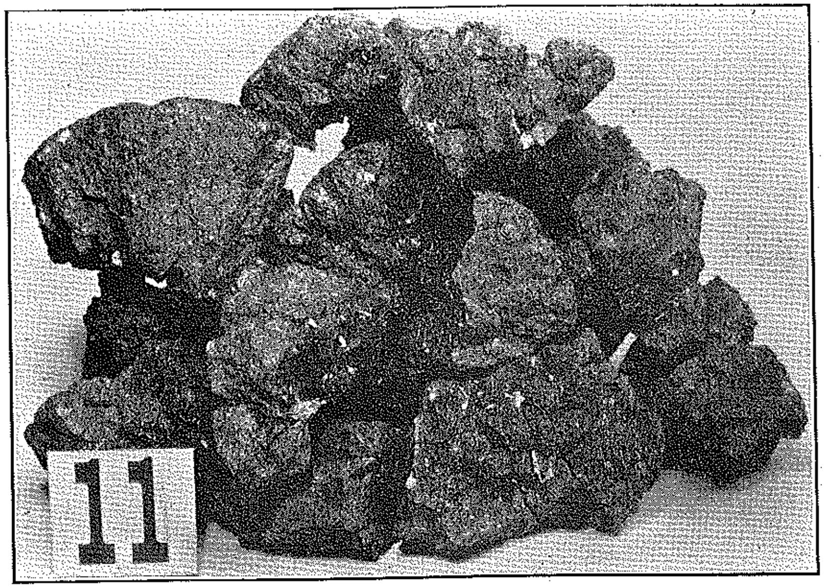

FIG. 8. Coke from Dallas County coal. Shuler Coal Co.

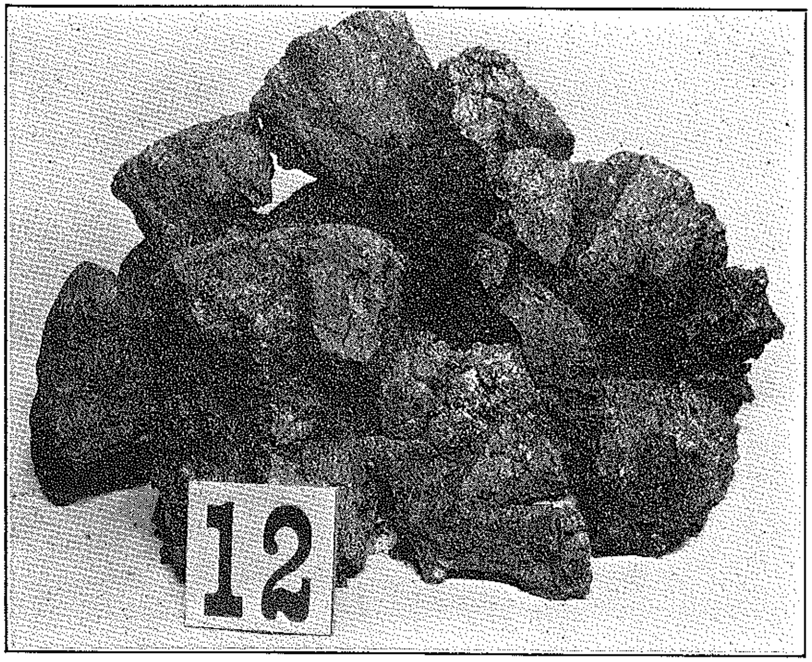

FIG. 9. Coke from Mahaska County coal. Oskaloosa Coal & Mining Co.

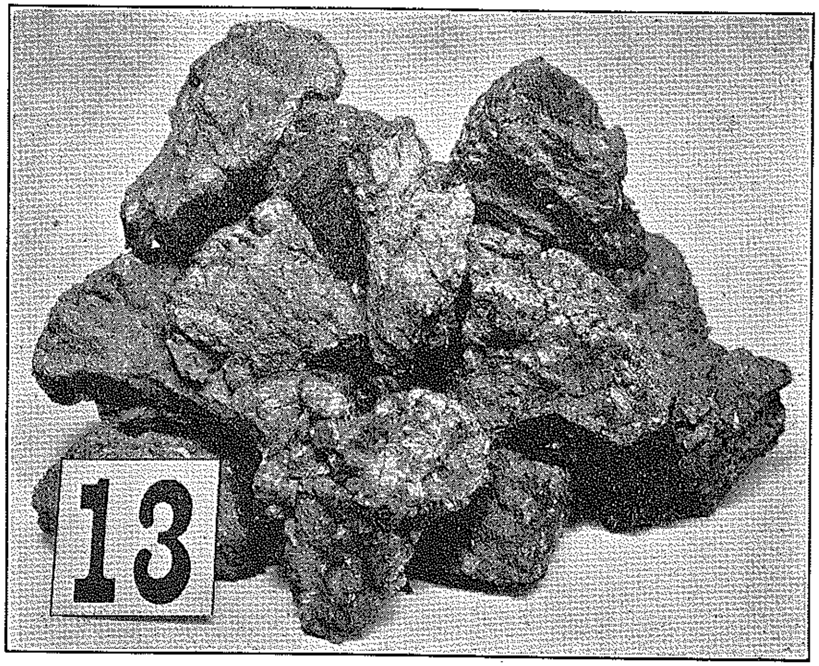

FIG. 10. Coke from Adams County coal. Ruth Coal Co.

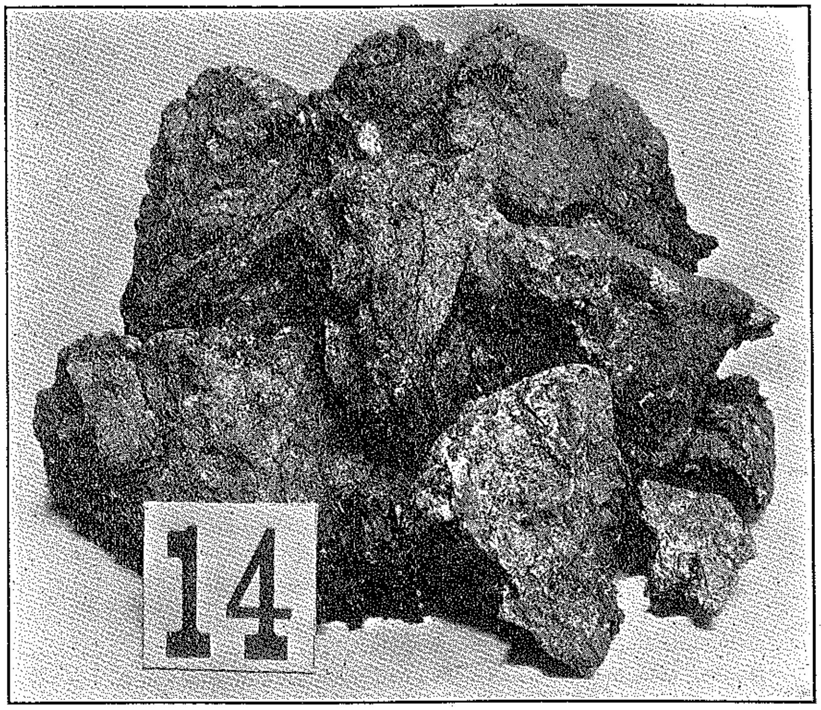

FIG. 11. Coke from Taylor County coal. New Market Coal Co.

FIG. 12. Coke from Marion County coal. Pershing Coal Co.

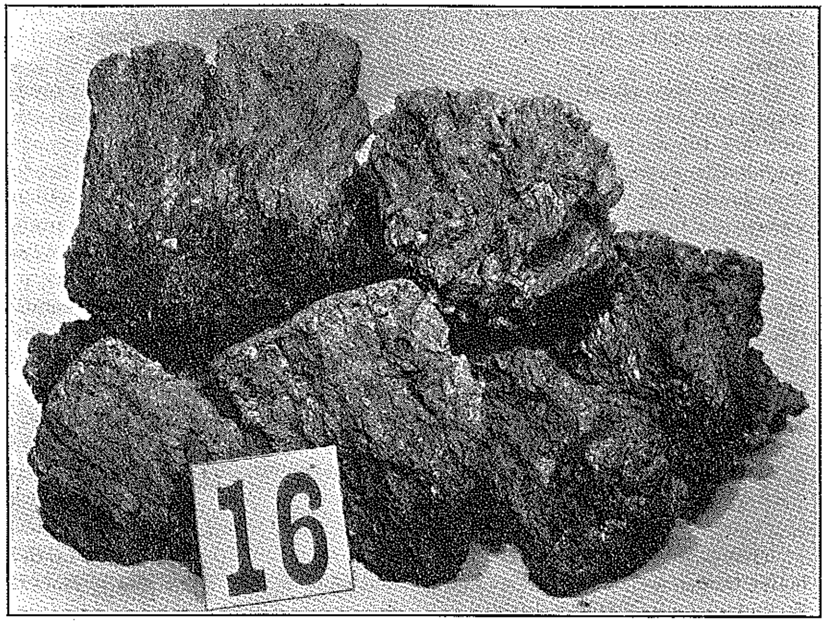

FIG. 13. Coke from Boone County coal. Boone Coal Co.

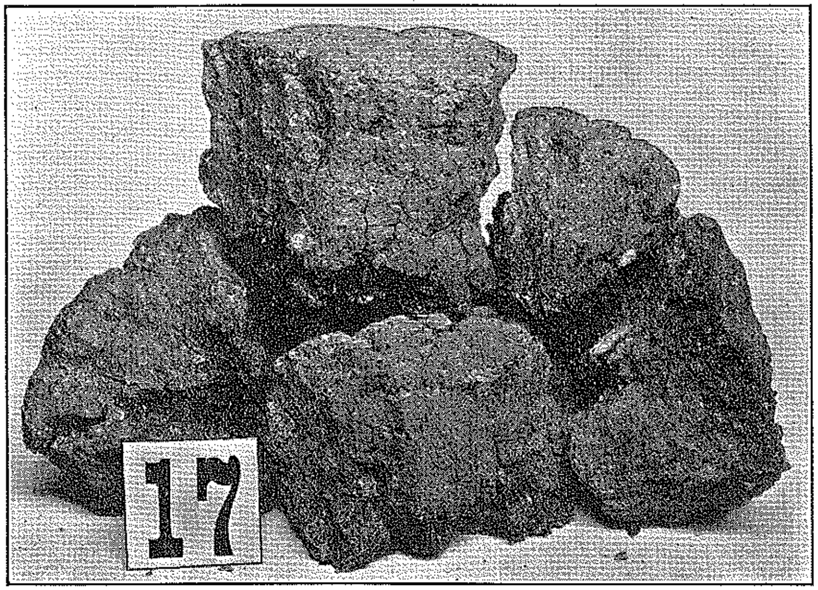

FIG. 14. Coke from Polk County coal. Gibson Coal Co.

and powdery mass that cannot hold the fire. It follows therefore that even a moderate tendency in this direction is not without some significance.

As we have repeatedly pointed out this presentation is merely a progress report since most of the work along these lines lies ahead of us. In addition to carrying out a thorough study of the cokes already made we confidently expect to improve our process so as to produce cokes much superior to any yet obtained. For example some of our Iowa coals which possess an excessive amount of the fusible coking constituents will probably yield an improved coke through blending with other coals or with noncoking types. At any rate we have gone sufficiently far already to show that Iowa coals can produce promising cokes under the proper conditions and that the contrary idea which has prevailed so long in the popular mind is as erroneous as many other impressions concerning our native fuels.

THE GEOLOGY OF IOWA COALS

JAMES H. LEES

This paper is added to those by Doctor Olin and his associates in the belief that some knowledge of the method of coal formation will be useful in understanding its character.

Time-scale. A generalized time-scale to show those periods which are of special interest in this study may well be given here and is as follows:

Cenozoic
  Present
  Pleistocene—Glacial period
  Pliocene
  Miocene—Some coal in California
  Oligocene
  Eocene—Coal and lignite in Gulf states and Washington
Mesozoic
  Cretaceous—Coal and lignite in Rocky Mountain region and North Dakota
  Jurassic
  Triassic—Some coal in Virginia and North Carolina
Paleozoic
  Permian
  Pennsylvanian—Coal from Pennsylvania to Texas and Alabama
  Mississippian—Some coal in Appalachians and Arkansas
  Devonian
  Silurian
  Ordovician
  Cambrian
Proterozoic
Archeozoic

Factors Affecting Character of Coal. The Iowa coal fields, as the table shows, belong to the Pennsylvanian system of strata. Theoretically there is no direct relation between the geologic age of a coal bed and the character of the coal therein, but practically it is true that under normal conditions the older coals are of higher grade than are those of more recent age. This is illustrated in the gradation from the high grade bituminous coals of Pennsylvanian age in the eastern and central interior states through the softer bituminous and sub-bituminous coals of the Rocky Mountain Cretaceous to the Eocene lignites of the southern states and the far west.

Then too the thickness of cover is an important factor in the hardness and general character of coals. For example the Pennsylvanian system of western Pennsylvania—the bituminous field—has a maximum thickness in the southwestern counties of 2,600 feet and the upper division, which is the least productive but which furnishes the heaviest cover, is 800 feet thick above its one merchantable coal bed. The Pennsylvanian strata of the Illinois fields have a maximum thickness of 2,000 feet, although the basal barren sandstones are in places 700 feet thick. Coal No. 6, the Herrin bed, the famous Franklin county coal, is reached in Franklin county at depths ranging from 200 to 700 feet. The Des Moines series, the productive coal measures of central and southeastern Iowa, are usually assigned a maximum thickness of 750 feet, but in most places the depth to the coal beds is much less than this, and few mines exceed 300 feet in depth. All of these beds may have been thinned by erosion in the immense period of time since they were uplifted from the ocean level.

Another factor which affects the hardness of coal beds is the movements of the earth's crust. The best illustration of this is the anthracite coal of eastern Pennsylvania and the high grade bituminous coals of West Virginia. These occur in regions that have been folded into mountain ranges, within which the coals have been squeezed and heated until they are hard and firm. If it were not for these disturbances these coals probably would be no better than those farther west and south.

The combination of a progressively thinning cover and of gradually diminished earth movements and the accompanying changes in the rocks from the Appalachian mountain region toward the Mississippi valley and the Great Plains forms an important if not a dominating factor in the progressive softening of the coals from the anthracites of eastern Pennsylvania to the bituminous coals of Iowa and Texas. There is no basic difference between the coals of different provinces. They were formed from similar materials and under approximately similar conditions.

Conditions of Coal Formation. At the opening of Pennsylvanian time the land surface of the east-central part of the United States, say from Nova Scotia and southern New England westward to eastern Kansas, was low-lying but very irregular. Some interesting evidence of the irregularity of the surface of the Mississippian strata has been revealed by drillings in Polk county. At Mitchellville the Mississippian limestones were reached about 760 feet above sea level, on the southeast edge of Des Moines 600 feet, in the western part of Des Moines 374 feet, and at Commerce, west of the city, 300 feet above sea level. Another instance which recently came to my attention is shown in the Chicago, Burlington and Quincy railroad well at Tracy, southeast of Des Moines. On the east bank of the Des Moines river, two miles east of the village, the sandy limestones of St. Louis (upper Mississippian) age rise several feet above water level. In the well, which was drilled in the bottoms, only a few feet above river level, the Pennsylvanian shales were penetrated ninety-two feet before the St. Louis limestones were reached. There is here a difference in elevation of a hundred feet within two miles. Very similar conditions prevailed throughout the general region in which the coal beds were later to be formed.

Climatic conditions at the beginning of Pennsylvanian time became more favorable than ever before for the development of a very extensive and abundant vegetation. This was not a sudden development, for coal beds in Mississippian strata of the eastern states show the presence of similar conditions, although these were but the beginnings of the exceptionally favorable situation of the Pennsylvanian. It does not seem necessary to assume, as was formerly done, the presence of a hot dense moist atmosphere through which the sun's rays had never penetrated and whose heavy gases were absorbed by the vegetation of the period. On the contrary the evidence points rather to possible aridity as well as to lower temperatures than were formerly assumed.

Under these general conditions then, the Pennsylvanian period began with the continental sea advancing from the southwest up a great trough or syncline which occupied the western interior from Iowa to Texas, just as the sea was advancing over other land areas farther east. On the low-lying marginal reaches between uplands and ocean a series of great coastal swamps was forming, similar to the Great Dismal swamp and the coastal marshes of Virginia and the Carolinas. Similar bogs or marshes no doubt developed over poorly drained areas remote from the sea, just as is true today, and so fresh water, brackish water, and salt water swamps existed simultaneously, each with its appropriate vegetation. This vegetation consisted of giant tree-ferns, horsetails and other plants, whose stems are now so often seen in coal and the associated rocks, and of an undergrowth containing smaller ferns and other lowly phases of plant life. The flowering plants and the modern types of trees had not yet appeared on the earth. Probably there was a growth of vegetation over the drier land areas, but as is the case with similar growths today such vegetation would normally leave no record of its existence. The plants, however, which lived in the swamps, as they died fell into the waters from which they had sprung and were there partly preserved. During the process of decay in the open air the carbon and hydrogen of wood unite with the oxygen of the air or of the wood and so form carbon dioxide and water and pass from our notice. But under water atmospheric oxygen is largely excluded, and the reactions are chiefly among the elements of the wood itself. Under these conditions marsh gas (CH_4) is formed, with some carbon dioxide (CO_2) and water (H_2O). All of these processes would use up the carbon less rapidly than the other elements and so would result in the increase of carbon in the residue. Bacterial action also is important.

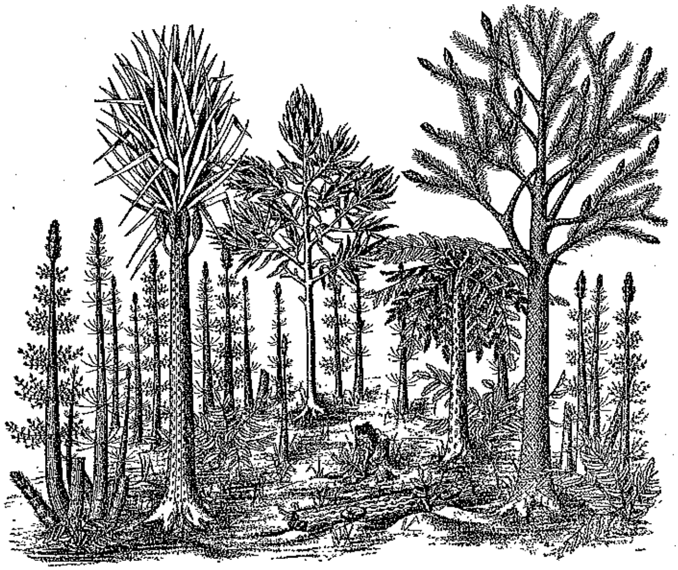

FIG. 1. A view showing the kinds of trees that grew in the forests and swamps of Pennsylvanian time. These were the trees of which Iowa coal was made and whose impressions are so often found in the coal and in the strata associated with it.

As generation after generation of the ancient plants lived, died, and fell to the floor of the swamp there was gradually accumulated an increasing layer of vegetable material which was constantly undergoing progressive changes which carried it further and further from its original state and into peaty and possibly lignitic stages. How fast this vegetal material accumulated is very difficult and perhaps impossible to estimate with any degree of accuracy. The abundance of vegetation and its rate of growth, the percentage which would be preserved, the prevailing climatic conditions and doubtless other factors would affect the problem. The estimate has been made that under conditions as we know them nearly 10,000 years would be required for the formation and preservation of a foot of vegetal material having a specific gravity of 1.4, about that of average coal.

Forming of Iowa Coal Beds. In the course of time the interior sea reached Iowa. The marsh and bog types of vegetation grew and accumulated here as we have described the processes above and Iowa's coal resources began their formation. The statement has already been made that the surface over which the Pennsylvanian sea advanced was very irregular. Because of this fact the earliest deposits on a slowly sinking land area would be in the valleys and depressions and the burial of the hills and uplands would come later, perhaps much later. Some of the coal swamps which were formed in these depressions were limited by walls of limestone, and miners of the present day find these walls barring their further advance and marking the limits of the coal bed they are working.

Most of the basins and depressions in which the Iowa coal swamps formed were rather limited in extent, and so the accumulations of vegetable matter which later became consolidated into coal are not very large, most of them being only a few hundred or at most a few thousand acres in size. These beds are mostly lenticular in vertical section, being much thicker near the center than on the margins, where they usually feather out and finally disappear. A noteworthy exception to this rule, however, is the bed known as the Centerville or Mystic seam. This bed, although it has an average thickness of only about two and a half feet, and has a rather wide vertical range, still is very uniform in its character and appearance, as well as in its thickness, and is estimated to underlie in workable condition about 1,500 square miles in Appanoose and Wayne counties in Iowa and several neighboring counties of Missouri.

There were many slow changes in the level of the land during Pennsylvanian time and some of these would gradually carry the coal swamps under the level of the sea. At such times the swamps would be covered by layers of sand or mud or perhaps limy ooze, depending on local conditions. These materials in due time were consolidated into sandstone or shale or limestone and also by their weight compressed the underlying bed of vegetal matter until it assumed the characters of lignite or the various grades of bituminous coal. The thickness of each deposit depended, of course, on the length of time it was accumulating, the rate at which material was contributed, the amount of condensation caused by compression or drying or chemical changes and doubtless by other factors. The estimate has been made that a vigorous growth of vegetation would yield annually about a ton of dried matter per acre. If the annual yield for a thousand years were all preserved, except for the natural loss by escaping gases, and were duly compressed it would yield less than an inch and a half of coal. In spite of this slow growth some Iowa coal beds are known to have thicknesses of eight to ten feet, and one bed with a measured thickness of thirteen and one-half feet and a reported thickness at another point of sixteen feet has been found in Marion county. Most of the beds which are worked, however, are four to five feet thick on an average. From these thicknesses they range down to mere films between layers of shale or other rock.

The coal beds form only a small percentage of the total thickness of the Iowa coal measures, as is true in other states. The purity of the coal would depend on the amount of waste matter—mud and sand—which was washed in from surrounding uplands or brought in by streams. If such material were nearly or entirely absent the deposit might become a high grade coal while conversely a large amount of this waste material would cause the deposit to be bony coal or perhaps only a carbonaceous shale.

Des Moines Series. The rock makers of the Pennsylvanian—conglomerates, sandstones, shales and limestones—form much the greater bulk of the strata, even though they are not quite so important economically. The source of these materials has been mentioned above, and it may be said in addition that the conglomerates would accumulate close to the land, where the streams and the currents would first begin to drop their loads, while the sands and clays would be carried and dropped progressively farther off shore, where the waters were quieter and the currents had less and less carrying power. The limestones would form in still, clear, though not necessarily very deep waters, but nevertheless under more typically marine conditions. With a knowledge of these varying conditions under which different strata form we are able to recreate to some extent a picture of the circumstances under which the earlier beds of the Pennsylvanian system of Iowa strata were laid down. These beds are known as the Des Moines series, and at present they cover southwestern Iowa and extend as far north as Onawa and Humboldt while their eastern margin may be defined roughly as along a line drawn between Iowa Falls and Keokuk. Undoubtedly the Des Moines seas had a much wider extent as outliers of their deposits are known at many places as far north and east as Iowa City and Maquoketa, and a large mass with workable coal beds is present between Muscatine and Davenport. Probably at their widest extent the Iowa and Illinois arms of the interior sea were united over eastern Iowa and western Illinois. Most of these outliers, however, contain no coal beds or only very thin ones, indicating that conditions in those localities or at those times were not favorable to the

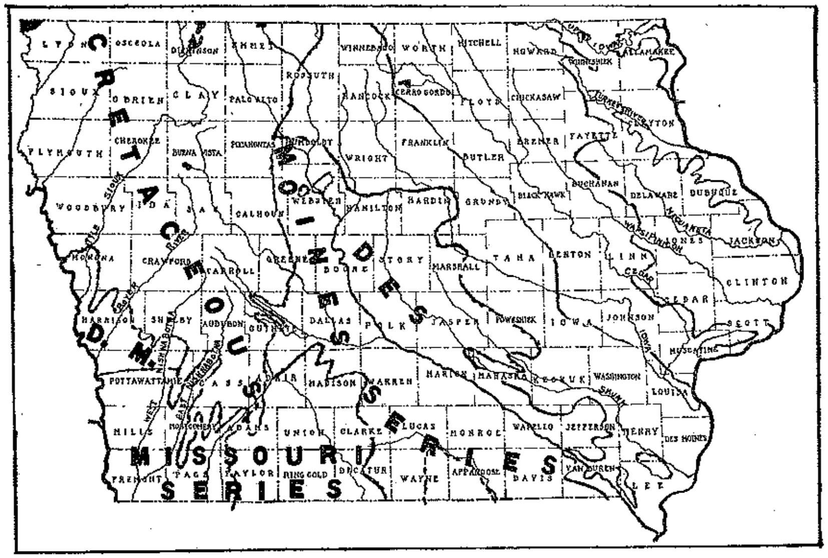

FIG. 2. Sketch map showing distribution of the Iowa strata which contain coal (Des Moines and Missouri series) and lignite (Cretaceous). Rocks of the Des Moines series underlie those of the Missouri series and the Cretaceous system. All are more or less covered by glacial drift. The broken line in Appanoose and Wayne counties incloses the area in Iowa underlain by the Mystic coal; the broken line across Taylor and Adams counties represents the eastern limit of the Nodaway coal. The Cherokee coals are distributed throughout the Des Moines series. See the text. The irregular northwest-southeast lines across eastern Iowa represent the eastern margins of older systems of rocks.

accumulation of coal. It is a peculiar fact and one of large economic interest that very little coal has been found in these strata west of Guthrie Center and Jefferson—or in other words, west of the eastern margin of the overlying strata. A few evidences of the presence of coal have been found, as at Missouri Valley and Denison, but here again conditions for extensive coal formation do not seem to have been present. Most coals of the Des Moines series belong in the Lower Cherokee beds, the lowest part of the series, but the Mystic seam is in the Upper Cherokee and the thin coals of Guthrie and nearby counties belong in the Henrietta beds, which are younger than the Cherokee beds and overlie them.

Missouri Series. In southwestern Iowa the Des Moines series is overlain by a group of beds known as the Missouri series. This consists of many alternating beds of limestones and shales of marine origin together with two beds of coal, which resemble the Mystic bed in their uniformity of thickness and character and their rather wide distribution. The upper or Nyman coal is too thin to be of economic importance, as it is not more than a foot thick. The lower bed, the Nodaway coal, is about eighteen inches thick and has been mined in Montgomery and Page and western Adams and Taylor counties. It comes to the surface in the latter two counties but is known from borings as far west as Nebraska City.

Cretaceous System. Overlying all the older formations of northwestern and west-central Iowa are the sandstones and limestones and shales of the Cretaceous system. The Cretaceous of northwestern Iowa carries some lignite, but the beds are too thin and of too poor quality to be of economic value. The sandstones extend as far east as Jefferson and Guthrie Center and as far south as Cass and Adams counties, with outliers beyond, but their chief importance lies in the fact that they cover up the Missouri and Des Moines beds and so render these formations more difficult of access.

Amount of Coal. In connection with this study I have made these computations regarding the amount of Iowa coal. The area of Iowa underlain by beds of Des Moines age is 24,250 square miles. I suppose that all of this area may be considered as legitimate prey for the promoter if not for the prospector. The area of Des Moines beds which are not covered by Missouri or Cretaceous strata is about 11,250 square miles, or 7,200,000 acres. If now we consider all of this area to be coal-bearing, which probably is an exaggeration, and if we assume an average thickness of workable coal of four feet, which probably is a sufficiently liberal allowance and which will give a content of 4000 tons per acre, we shall have a total original volume of 28,800,000,000 tons. The total possible area underlain by the Nodaway coal of southwestern Iowa is about 1500 square miles or 960,000 acres, according to recent studies of that region. The maximum thickness which we may assign to this coal is 1.5 feet, which would give a yield of 1,440,000,000 tons. The total coal supplies from the two series of strata, then, would be 30,240,000,000 tons. Now on the one hand future explorations may extend the known areas of workable coal and we may have to use thinner and deeper beds than those now being mined. These factors if realized will increase the available supply. On the other hand it is practically certain that hundreds of square miles within the productive territory are absolutely barren and that other hundreds contain only beds that are too thin to be of great service under any economic conditions. Then too there are bodies of coal of workable extent and thickness which have too poor roof or too much water to be used. These factors will decrease the available supply by an unknown amount, but by one which will, I fear, at least counterbalance the favorable factors.

Depth of Mining. With regard to the possible depth of mining in Iowa it may safely be said that there is no danger of the economical limit being reached for the simple reason that coal absolutely does not exist in Iowa at the great depths which are entirely feasible with modern mining and hoisting machinery. The deepest mines in the state are in Dallas county near Waukee and are 373 feet and 417 feet deep. The Des Moines and Missouri strata are thickest in the southwestern part of the state, and here the records of wells at Clarinda and Bedford place the base of the Des Moines series—the lowest possible horizon for finding coal—at 1610 feet and 1340 feet respectively below curb, probably the greatest depths these strata reach anywhere in the state. In 1913 the Assumption Coal Co. was hoisting coal in Christian county, Illinois, from a depth of 1004 feet. A good many shafts in the anthracite field of Pennsylvania are more than 1000 feet deep. An English colliery is hoisting coal from a two- to six-foot bed at a depth of 3900 feet, and another is mining a two-foot bed 2460 feet below the surface. These figures indicate the possibilities in future Iowa mines if necessity arises.

Coal Production. Up to the end of 1929 Iowa coal mines had produced 279,786,000 tons, of which practically 115,000,000 tons had been mined since 1910. If we assume, as is usually done, that half a ton was left in the mine for each ton that was removed, that means a total exhaustion of 419,679,000 tons or about 1.4 per cent of the total supply. If we estimate the annual exhaustion as 10,000,000 tons, the average for the past twenty years, we shall see that the supply is still good for nearly 3000 years. Even if it seems best to reduce the estimate by fifty per cent, the supply is sufficient to remove worry to the distant future—as human life goes. The Nodaway field, at the present rate of exhaustion, about 35,000 tons a year, should last for 40,000 years.

The earliest recorded production of coal in Iowa was given in the U. S. Census for 1840 as 400 tons. In 1848 the production reached 10,000 tons; in 1876 the ouput was 1,250,000, and by 1899 it had reached 5,000,000. The largest production was 8,965,000 tons in 1918, although the greatest spot value was reached in 1920, when the output was valued at $30,800,000. Since 1920 the production has been less than during most of the earlier years of the present century, reaching a low level of 2,950,000 tons in 1927. In 1929 output had grown to 4,241,000 tons, valued at $11,948,000.

Mining Methods. The Nodaway coal is mined by the longwall system, by which the coal is undercut and breaks down by its own weight and that of the overlying strata. Powder is not used to a great extent, and hence the coal is not shot to pieces so badly as by other methods. A few machines have been used for undercutting, but most of the work is done with picks. Similar methods are used in the Centerville (Mystic) bed of Appanoose and Wayne counties, except that a number of machines are used in the former county. In most of the other Iowa mines, the shortwall or room and pillar method is used, and the coal is "shot from the solid." That is, it is drilled and blasted with powder or other explosive, after a cut has been made along the side of the room. This method produces a great deal of small coal which must be sold as steam coal, but it seems to be preferred by the miners. However, machine mining and the longwall system are used in some mines. Over a hundred mining machines are in use in the state. Shortwall mining necessitates leaving about one-third of the coal in the ground, while longwall methods permit nearly complete extraction.

Lamination. Because of their thinner cover and the other conditions mentioned earlier in this paper the Iowa coals have not been compressed into so hard layers as have the eastern coals. All coals show more or less alternating bright and dull laminae, of which the latter are somewhat softer than the former and contain more mother coal or mineral charcoal. This mother coal is softer than the brighter coal, and a coal which contains much of it will not have the hardness and the ability to stand up under rough handling and other treatment that brighter more solid and uniform coals possess. Doctor Savage of the Illinois Geological Survey has suggested that the mother coal and the dull laminae were formed when the water level of the swamp was a little lower than usual and decay of the vegetation went on for a time in the air. When the water level rose the layers formed under water would make the bright bands. Iowa coals contain a good deal of mother coal and dull laminae. So do Illinois coals, but the eastern coals are more uniformly bright.

Summary. In summary we may state that: Coal was formed in swamps, many of which were of great extent. The thicker the cover the harder the coal.

Crustal movements and changes of the rocks help to make harder coal. Iowa coal is of Pennsylvanian age, as are the eastern coals.

The coal beds alternate with other strata owing to changes in level of sea and land and changes in deposition.

The known productive coal areas of Iowa amount to about 12,750 square miles, of which 11,250 square miles are in the Des Moines series of strata and 1,500 miles in the Missouri series. The possible tonnage of this area is 30,240,000,000.

No coals exist in Iowa beyond the economical limit of mining.

Only a little more than one per cent of the possible supply has been used so far. At this rate there is coal enough to last about 3,000 years.

The Centerville and Nodaway coals are mined longwall, without shooting. Most other coal is shot and is mined shortwall.

Because of thinner cover and less alteration Iowa coals are softer than eastern coals. Also they contain more alternations of softer dull laminae and harder bright laminae, which adds to their softness.