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EFFECTS OF STORAGE UPON THE PROPERTIES OF COAL

BY
S. W. PARR

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UNIVERSITY OF ILLINOIS
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BY
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EFFECTS OF STORAGE UPON THE PROPERTIES OF COAL

I. Introduction

The need of a thorough understanding of the conditions affecting the storage of bituminous coal is becoming more and more apparent. The demand for coal at certain seasons is so great that both mining and transportation facilities are taxed severely in meeting it. Provision has not been made for adequate and proper storage of bituminous coal either at the mines or at the distributing centers, and as a result of this lack there must be maintained throughout the year a sufficient number of operating mines to meet what may be termed the "peak load" which occurs during the winter months. At such times also there is often a shortage of cars, although a smaller number of cars even than is now available would be needed if the work of transportation could be more evenly distributed throughout the year. Mr. C. G. Hall, Secretary of the International Railway Fuel Association, has made an estimate showing that the number of excess mines over and above those which would be normally required to meet the demand, provided their work could be distributed evenly through the year, represents an investment in the United States of $450,000,000. In addition, the extra coal cars, which must be at hand when the demand is heavy but which stand idle accumulating rust for the rest of the year, have cost the railways no less than $105,000,000 more than would be necessary if the same tonnage could be hauled at an even rate. These wastes eventually affect the cost per ton of coal, which every one must pay as a contribution toward the capital investments.

The difficulties attending these conditions are accentuated by occasional abnormal demands such as are created upon the approach of any date for readjusting the wage scale with the accompanying possibility of a strike or lockout. For example, in addition to the normal excess demand during the winter months of 1915-16, a compilation of the published amounts of coal being stored by the various railway systems and larger users only, in view of a possible strike in April, aggregated over 3,000,000 tons.

The industrial disturbances do not include all of the serious considerations, however. If we consider the labor distresses that are accentuated as a result of irregular employment, it at once appears that the problems involved are of great sociological as well as of economic interest.

The work here recorded is a continuation of certain studies, the results of which have been published in bulletin form by the Engineering Experiment Station under the titles of "The Weathering of Coal,"* "The Occluded Gases in Coal,"† and "The Spontaneous Combustion of Coal."‡

The subjects treated in these publications are of fundamental importance, and a thorough understanding of the principles involved under each subject is necessary before any adequate discussion can be undertaken of the problems connected with the storage of coal. The investigations described in Bulletin 38 of the University of Illinois Engineering Experiment Station, on "The Weathering of Coal" were conducted with car-lot samples of coal stored under various conditions. The data obtained covered a period of one year. The investigation was continued for an additional period of five years more, or for a total period of six years. The coal was then turned over to the power plant for steam generation, and boiler tests were made to establish the character of the various samples. These data, together with other facts bearing upon the general subject of coal storage, have accumulated to an extent which warrants their being brought together for record and discussion in this form.

Special acknowledgment is due Mr. J. M. Lindgren, Chemist, and Mr. F. H. Whittum, Assistant Chemist, for the analytical data accumulated beyond the first-year period. Their experience and skill in the matter of sampling and in the use of analytical and calorimetric methods have been especially noteworthy.

II. SUMMARY OF RESULTS

The facts established by this investigation may be briefly summarized as follows:

(1) Freshly mined coal is chemically very active. Certain constituents have a marked affinity for oxygen, with which they enter into combination at ordinary temperatures. While the extent of this reaction depends upon the variety of the coal and

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*S. W. Parr and W. F. Wheeler, Univ. of Ill. Eng. Exp. Sta. Bul. 38, 1909.

†S. W. Parr and Perry Barker, Univ. of Ill. Eng. Exp. Sta. Bul. 32, 1909.

‡S. W. Parr and F. W. Kressman, Univ. of Ill. Eng. Exp. Sta. Bul. 46, 1910.

the amount of these active constituents, a very important factor is the fineness of division or the sum total of the superficial areas of the particles, and accessibility of oxygen to the mass.

(2) The actual loss of heat value resulting from storage is small. It is evident that upon mining out the coal from the bed certain volatile constituents of the marsh gas variety are set free. The heat values represented by such exudations are not great. The tendency to absorb oxygen from the air is also a marked characteristic of freshly mined coal. This is in reality a chemical process, and is accompanied by the generation of a small amount of heat, but these heat losses, compared with the total heat available in the coal, are insignificant. Indeed, it may be fairly questioned whether the heat losses are not more apparent than real since there is an increase of weight due to the absorption of oxygen. Such increase will in itself lower to a corresponding degree the indicated heat value per pound of coal.

(3) There is an increase of "fines" or slack resulting from storage, greater with some coals than with others. This, together with the saturation of the free burning constituent with oxygen, slows up the fire and gives the appearance of being lacking in heat value. However, with an increase of draft and a correct understanding of the combustion conditions to be maintained, a most excellent over-all efficiency can be secured even from coals which have been in storage for long periods.

(4) Bituminous coal can be stocked without appreciable loss of heat values provided the temperature is not allowed to rise above 180 degrees F. Any method of storage, to be successful, must either check or prevent the absorption of oxygen to such an extent that the generation of heat shall not proceed faster than the dissipation and loss of heat due to absorption or radiation.

(5) Underwater storage prevents loss of heat values, and is not accompanied by deterioration in physical properties, such as slacking. The water retained by the coal upon removal is substantially only that held by adhesion or capillarity.

(6) Dry storage is safer and more satisfactory if the fine material is screened out at the storage yard and lump only, preferably sized, is stocked.

It will be seen from this summary that the most serious part of the problem relates to the matter of spontaneous heating, and probably the least serious phase relates to deterioration and actual loss of heat values. It is certain that at the present time a better understanding of these difficulties has been reached, and there is reason for believing that this better understanding of the fundamental principles involved will lead to some practicable and safe procedure for the stocking of bituminous coal.

III. Effects of Storage Upon Coal

HEATING AND SPONTANEOUS COMBUSTION

It is a well established fact that freshly mined coal has a large absorptive capacity for oxygen. In Bulletin 32, "The Occluded Gases in Coal," it is made evident that this avidity for oxygen is most marked in the freshly mined coal, and after exposure to the air for four or five months an approach to the saturation point seems to be reached after which very little oxygen is taken on. A correct interpretation of this phenomenon is essential to an understanding of the spontaneous heating of coal piles. The natural conclusion would be to the effect that the oxygen has been simply absorbed or occluded; that it was a physical rather than a chemical change. The evidence, however, of all the more recent investigations goes to show that it is in fact a chemical combination and that it is accompanied by the generation of a small amount of heat. In Bulletin 46, "The Spontaneous Combustion of Coal,"* it is seen that at a temperature of from 35 to 40 degrees C (95 to 104 degrees F), and with free access of air, the amount of heat generated caused a rise in temperature of from 1 to 1½ degrees C per day. Porter and Ovitz† have measured the quantity of oxygen taken up by a sample of Franklin County coal and found it to be approximately 0.8 per cent of the weight of the coal. Moreover, there is only a very small amount of CO_2 formed. This is explained by the fact that the presence of certain unsaturated compounds allows the oxygen to enter the molecular structure of the coal, with which compounds the oxygen readily combines.

These references are a few of many that might be brought forward showing that at ordinary temperatures freshly mined coal unites

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*Parr and Kressman, Univ. of Ill. Eng. Exp. Station Bul. 46, 1910.

†Journal Industrial and Engineering Chemistry, Vol. 2.

chemically with oxygen and that in the process there is generated a certain amount of heat.

1. *Oxidation of Pyrites.*—Much consideration has been given by various investigators to the role of iron pyrites in promoting the heating of coal. In the experiments carried out by Dennstedt and Bunz in 1908,* it appears that self-ignition may be brought about in the case of coals having only small amounts of pyritic sulphur. The conclusion is made, therefore, that the presence of iron pyrites is not an essential condition for spontaneous heating. Other investigators working along similar lines have reached the same conclusion. Still others seem to have evidence that pyritic sulphur is an active element in the case. A summary of opinions on this point is given as follows:†

"As to what part sulphur compounds, especially pyrite, play in the spontaneous ignition of coal, opinions differ greatly. Some believe pyrite to be the leading factor, while others believe it plays no part at all, or, if so, ascribe to it a position of minor importance and believe its action to be merely a subsidiary one. The oxidizing action of the air upon pyrite is, however, admitted, and the notion seems to be fairly general and well established that pyritic oxidation tends to raise the temperature of the coal. On the other hand, it is seen from the work of Fayol, Dennstedt and Bunz, Threlfall and others that coals containing pyrite in a quantity too insignificant to be noticed are very apt to ignite spontaneously. The Newcastle coal of New South Wales is also a very good example of this class of coals. Others, however, believe that the only influence of the pyrite is a mechanical one, in which the oxidation of the thin films of pyrite in the coal serves merely to break up the coal."

Investigations of this type, having for their object a study of the processes of oxidation which occur at normal temperatures, are extremely important, especially in that phase of the work which seems to have fully established the fact of oxidation of the organic constituents of the coal. The conclusions are somewhat at fault, however, in assuming that as a consequence the pyritic oxidation is of little importance. It is true that a coal may heat seriously even though pyritic sulphur is absent. This does not constitute proof, however, that the presence of

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*Zeit für Aug. Chemi., Vol. 21, pp. 1821-35, 1908.

†Parr and Kressmann, "The Spontaneous Combustion of Coal," Univ. of Ill. Eng. Exp. Sta. Bul. 46, pp. 83, 1910.

pyritic sulphur in coals may not be equally, or even more largely, responsible for heating than the organic constituents.

This is clearly set forth in Bulletin 46.* On page 52, under "Iron Pyrites," a summarized statement is given as follows:

> "The presence of sulphur in the form of iron pyrites is a positive source of heat due to the reaction between sulphur and oxygen. This may be conveniently referred to as the second stage in the process of oxidation. Here again rapidity of oxidation is directly dependent upon fineness of division. Since coals, as a rule, have a much higher earthy or ash content in the fine duff, and since iron pyrites is a large component of this material, it follows that the presence of dust or duff in all coals of the Illinois type is a positive source of danger."

However, in this summary the authors give first place in time and effect to the oxidation of the organic matter and consider that the activity of the pyrites waits somewhat upon the rise in temperature from such organic oxidation before action with sulphur reaches a serious phase. Special emphasis was laid upon the oxidation of sulphur as a source of heat, but the experiments did not specifically give direct evidence as to the temperature at which pyritic sulphur began to oxidize.

2. *Growth of Sulphates.*—Data on the oxidation of sulphur have recently been developed in connection with the study of variations in the determination of ash values† which have a bearing in this connection. The fact appears that the oxidation of sulphur is active at ordinary temperatures provided (a) that the pyritic iron be finely divided, and (b) that free moisture be present in sufficient amount to satisfy the reactions involved. For example, a certain series of bed samples of coal had been ground to 60-mesh and laboratory samples taken of about 75 grams which were placed in 4-ounce bottles with rubber stoppers. These samples were retained in the laboratory at room temperature from August, 1912, to April, 1913, at which time they were analyzed for sulphur in the sulphate or SO_3 form. For comparison, the original samples ground only to 10-mesh were similarly analyzed. The results are shown in Table 1.

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*Parr and Kressmann, Univ. of Ill. Eng. Exp. Sta. Bul. 46, 1910.

†S. W. Parr, Ill. State Geo. Survey, Co-Op. Bul. 3, 1915.

TABLE 1

GROWTH OF SULPHATE

COMPARISON BETWEEN FINE AND COARSE LABORATORY SAMPLES

Lab. No.	County	H_2O	Total Sulphur	SO_3 60-Mesh Aug., '12	SO_3 60-Mesh April, '13	SO_3 10-Mesh April, '13
5365	Mercer.........	6.33	5.29	0.95	1.46	0.86
5367	Grundy........	8.84	2.27	0.39	0.38	0.18
5370	Mercer.........	4.49	4.92	0.47	0.49	0.25
5372	Mercer.........	4.86	5.46	0.63	1.25	1.12
5376	Grundy........	7.66	2.73	0.61	1.12	0.86
5388	La Salle........	7.93	5.20	1.42	1.79	0.82
5381	La Salle........	8.05	4.83	0.62	1.20	0.81

3. *Effect of Fineness of Division.*—From the results in Table 1 it is evident that oxidation of sulphur has occurred at ordinary temperatures. Five of the seven samples have had from 30 to 40 per cent of the total sulphur thus changed. The second and third samples in this table show no such oxidation. In the second the content of total sulphur is low and of this the actual sulphur in the pyritic form is, of course, still lower. Data on this point were not obtained. In the third sample the water content is lower than that in the other samples of the table. Whether this affords a valid explanation is uncertain. At any rate the point here emphasized is the fact that in the majority of the samples oxidation of the pyritic sulphur occurred in large amounts and at room temperatures. The next point was to determine what conditions were chiefly responsible in this reaction. The last column of the table affords some information. Here it is seen that with one exception the coarse or 10-mesh material had little or no indication of sulphur oxidation. To test further the effect of fineness of division, two of these original samples, about two pounds each, were sized and the sulphate sulphur determined for each size. The results are given in Table 2.

TABLE 2

SULPHATE SULPHUR AS FOUND IN VARIOUS SIZES OF COAL

Lab. No.	10-Mesh	20-Mesh	40-Mesh and Over
5372	0.91	0.89	1.43
5388	0.53	0.60	1.42

It is shown by this table that while substantially no increase in sulphate occurred up to the 20-mesh size, the increase was very marked in the 40-mesh sample, though it should be said that the 40-mesh sample contained also all of the finer material passing through that sieve. This record further emphasizes the fact that oxidation of sulphur increases in activity as the size of particles is decreased and the superficial area in any given mass correspondingly increased.

4. *Effect of Moisture.*—In seeking an explanation for the lack of uniformity in behavior due to sizing alone, it was thought that possibly the amount of free moisture in the sample as well as the percentage of FeS_2 might play an important part. A number of samples were, therefore, selected in which the free moisture was low. In these cases the growth of sulphate in the laboratory sample was small as shown in Table 3.

TABLE 3

EFFECT OF LOW MOISTURE ON THE FORMATION OF SULPHATE

All Values on the Dry Coal Basis

Lab. No.	Moisture	Total Sulphur	Sulphate (SO_3) in Lab. Sample, 60-Mesh 75 Days in Sample Bottle	SO_3 in 3-Lb. Gross Sample. All Sizes up to ¼ Inch after 15 Days in Container	3-Lb. Gross Sample. All Sizes up to ¼ Inch after 75 Days	Sizing of Gross Sample after 75 Days		
						SO_3 in 10-Mesh Size	SO_3 in 20-Mesh Size	SO_3 in 40-Mesh Size
6399	1.74	3.65	.214	.200	.198	.176	.164	.215
6400	2.03	3.19	.218	.230	.228	.199	.195	.257

As affording further evidence on this general proposition, 28 samples of coal were selected from the various districts of the state, and sulphate determinations made on the laboratory samples ground to 60-mesh which had been in storage from the early part of 1912 until June, 1913. Unfortunately, the sulphate factors for the fresh coal are not available, but the table shows that in those samples in which both the water and the sulphur contents were high, there was a greater increase in the percentage of oxidized sulphur than in the case of samples in which water and sulphur contents were low. Note especially Nos. 5359-5389, inclusive, Table 4.

Doubtless, there are other circumstances connected with the oxidation of sulphur which are of interest, such as the presence of catalyzers, the source of oxygen for satisfying the conditions of the

TABLE 4

SULPHATE IN LABORATORY SAMPLES, STORAGE TIME FROM MARCH, 1912, TO JUNE, 1913, SHOWING CONDITIONS ATTENDING PRESENCE OF MOISTURE AND SULPHUR

Lab. No.	County	Coal Bed	H_2O	Total Sulphur Dry Coal	SO_3 Dry Coal	Remarks
4699	Vermilion	6 N	2.30	2.44	0.18	Sulphate was determined June 2, 1913, on pulverized samples collected February to June, 1912.
4702	Vermilion	6 N	2.08	2.75	0.15	
4706	Vermilion	6 N	2.08	3.48	0.32	
4707	Vermilion	6 N	1.82	4.82	0.35	
4716	Vermilion	7 N	2.31	4.06	0.62	
4724	Vermilion	7 N	1.95	3.77	0.60	
4727	Vermilion	7 N	1.91	3.33	0.37	
4734	Vermilion	7 N	2.24	2.59	0.22	
4744	Vermilion	6 N	4.58	1.94	0.29	
4789	Franklin	6 S	3.88	0.52	0.02	
4811	Franklin	6 S	2.41	1.53	0.22	
4994	Saline	5 S	2.82	2.32	0.54	
5006	Williamson	6 S	3.25	1.11	0.12	
5011	Franklin	6 S	4.14	1.53	0.18	
5024	Saline	5 S	5.87	3.78	0.80	
5121	Williamson	6 S	3.73	1.42	0.11	
5122	Williamson	6 S	6.25	1.46	0.12	
5134	Williamson	6 S	6.25	1.24	0.10	
5224	Franklin	6 S	5.87	1.12	0.06	
5339	Mercer	1 N	3.21	5.66	0.98	
5359	Rock Island	1 N	4.84	6.56	2.14	
5361	Rock Island	1 N	5.74	4.56	1.08	
5362	Rock Island	1 N	4.96	5.26	1.15	
5364	Mercer	1 N	6.34	4.94	1.69	
5368	Grundy	2 N	7.08	3.04	0.59	
5369	Grundy	2 N	6.98	2.53	0.44	
5377	Grundy	2 N	7.83	4.00	1.34	
5389	La Salle	2 N	7.71	3.57	0.83	

reaction, the mercasite or pyrite form of the sulphide crystals, the method of distribution, whether in microscopic or massive aggregates, the character and influence of the associated material, and the segregation of sulphate crystals towards the finer materials. Indeed, the more thorough understanding of some of these points might contribute in a very practical way to our knowledge of the conditions which promote the heating of coal. Definite information along these lines depends upon further study. However, for purposes of this discussion it is of importance to note that at least two conditions, if existing, namely, fineness of division, and presence of moisture, will result in oxidation of the sulphur. Supplementary to this should be recalled the fact already developed in Bulletin 46 that the oxidation of 0.5 per cent of sulphur, or approximately less than ⅕ of the amount present in the average Illinois coal, would produce sufficient heat to raise the temperature of the mass, not allowing for radiation losses, about 125 degrees F. If the initial temperature were 50 degrees F, an increase to 175 degrees would approach the danger point. At about 180 degrees the activity reaches a stage owing to the greater rapidity of oxidation at that temperature, at which the chemical reaction quickly proceeds to the point where it becomes autogenous.*

In the discussion concerning the generation of heat from sulphur oxidation it is not intended to minimize the effect of oxidation of the organic matter as an initial source of heat, independent of the activity of the sulphur. In bituminous coals the two, doubtless, proceed independently, but where both activities exist together there is an acceleration of the reaction due to the rapid rise of temperature. In this manner there is a greater quantity of heat produced in a given period of time, and hence the coal mass comes more quickly and more positively to the autogenous or danger stage.

5. *Summary on Oxidation.*—Oxidation of the organic materials in freshly mined coal is active in all coals of the bituminous or lignitic type. The conditions which accelerate the action are increase of temperature and fineness of division.

Oxidation of the sulphur of iron pyrites is active provided the sulphide of iron is finely divided and there is sufficient moisture present to satisfy the reaction. The quantity of finely divided pyritic material will of course be greater in screenings than in lump, and since the ash content in screenings is from one to two times as great as in the lump, the quantity of pyritic sulphur is correspondingly greater.

The conditions to be observed in stocking coal so far as oxidation is concerned, are thus fairly well outlined. The enumeration of these conditions will be taken up later.

DETERIORATION

Experiments on the weathering of coal are described in Bulletin 38.† Car lots were stored in open and in covered bins and smaller lots of 100 to 200 pounds under water. The samples for determination of heat values were taken on the day of mining the coal, and thereafter at seven days, two months, six months and one year.

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*Note the abrupt change in the direction of the curves at 80 degrees C, showing temperature rise, as in "Spontaneous Combustion of Coal," Univ. of Ill. Eng. Exp. Sta. Bul. 46, p. 28.

†Parr and Wheeler, "The Weathering of Coal," Univ. of Ill. Eng. Exp. Sta. Bul. 38, 1909.

All of the samples with the exception of the submerged samples, were continued in storage beyond the period covered by the results presented in Bulletin 38, for a total period of six years. Two additional sets of laboratory samples were taken; one after a total period of three years, and another at the end of six years. After the storage in the original bins for four years, both the covered and open lots were moved to a new location. After a period of six years, final laboratory samples were taken in connection with the cleaning up of the various lots and the making of boiler tests. Five standard boiler tests were made at the close of the period.

For greater convenience all of the analytical results for the entire period are presented in Tables 5 to 10, inclusive.

TABLE 5
VERMILION COUNTY NUT COAL

Lab. No.	Sample Taken after Mining	Dry Coal			B. t. u. Referred to Actual or Unit Coal	Decrease	
		Ash	Sulphur	B. t. u.		B. t. u.	Per Cent
	STORED IN EXPOSED BINS						
1031	Same day..............	10.55	4.25	12991	14814	...	....
1081	7 days................	13.98	2.65	12412	14716	98	0.66
1240	2 months..............	14.21	2.47	12265	14577	237	1.60
1656	6 months..............	13.53	2.10	12396	14575	239	1.61
2088	1 year................	13.62	2.82	12282	14498	316	2.13
4105	3 years...............	13.22	1.75	12018	14075	739	4.98
7298	6 years...............	13.06	1.58	11984	14000	814	5.49
	STORED IN COVERED BINS						
1031	Same day..............	10.55	4.25	12991	14814	...	....
1081	7 days................	13.98	2.65	12412	14716	98	0.66
1249	2 months..............	13.08	2.13	12475	14604	210	1.42
1662	6 months..............	11.76	2.14	12571	14472	342	2.31
2094	1 year................	13.52	2.72	12220	14403	411	2.77
4101	3 years...............	14.26	2.29	11691	13890	924	6.23
7372	6 years...............	9.84	1.57	1202	13867	947	6.39
	STORED UNDER WATER						
1031	Same day..............	10.55	4.25	12891	14814	...	....
1081	Same day as submerged	13.98	2.65	12412	14716	98	0.66
1647	6 months..............	15.37	3.34	12013	14524	290	1.96
2100	1 year................	13.85	3.81	12231	14517	297	2.00

NOTE: For Unit Coal formula, see footnote to Table 12.

TABLE 6

WILLIAMSON COUNTY NUT COAL

Lab. No.	Sample Taken after Mining	Dry Coal			B. t. u. Referred to Actual or Unit Coal	Decrease	
		Ash	Sulphur	B. t. u.		B. t. u.	Per Cent
			STORED IN EXPOSED BINS				
1090 1091	Same day.............	13.98	3.73	12499	14859	...	....
1098	7 days................	14.90	3.02	12341	14821	38	0.26
1246	2 months.............	14.32	4.12	12409	14835	24	0.16
1657	6 months.............	13.81	3.45	12455	14765	95	0.64
2090	1 year.................	11.88	2.73	12759	14734	125	0.84
4103	3 years................	12.52	2.60	12503	14548	311	2.09
7374	6 years................	12.86	2.20	12339	14406	453	3.04
			STORED IN COVERED BINS				
1090 1091	Same day.............	13.98	3.73	12499	14859	...	....
1098	7 days................	14.90	3.02	12341	14821	38	0.26
1247	2 months.............	14.08	3.84	12378	14739	120	0.81
1663	6 months.............	13.06	3.60	12469	14644	215	1.45
2096	1 year.................	13.24	3.20	12428	14616	243	1.64
4100	3 years................	13.93	2.93	12085	14323	536	3.60
7299	6 years................	13.96	2.16	12103	14324	535	3.60
			STORED UNDER WATER				
1090 1091	Same day.............	13.98	3.73	12499	14859	...	....
1098	Same day as submerged	14.90	3.02	12341	14821	38	0.26
1648	6 months.............	15.65	3.12	12097	14673	186	1.25
2102	1 year.................	14.87	3.42	12251	14721	138	0.93

FIG. 1. OPEN STORAGE BINS

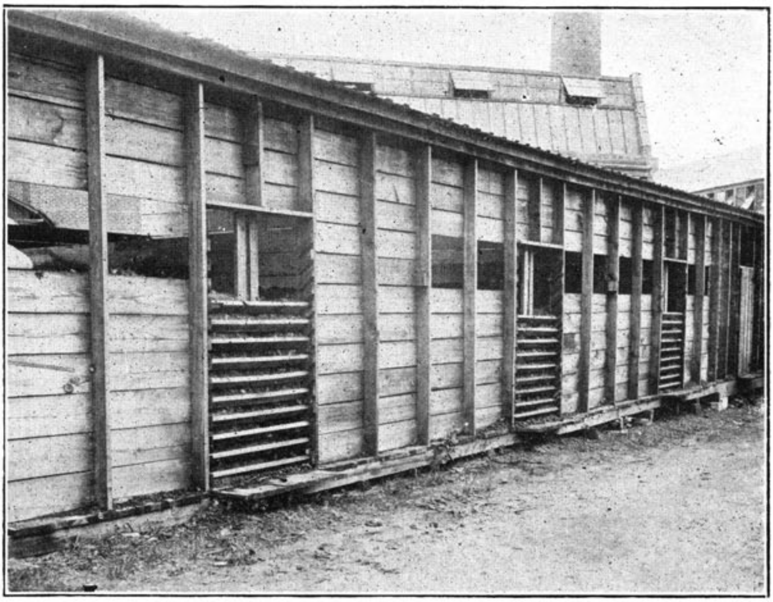

FIG. 2. COVERED STORAGE BINS

TABLE 7

SANGAMON COUNTY NUT COAL

Lab. No.	Sample Taken after Mining	Dry Coal			B. t. u. Referred to Actual or Unit Coal	Decrease	
		Ash	Sulphur	B. t. u.		B. t. u.	Per Cent
			STORED IN EXPOSED BINS				
1078	Same day	17.87	5.75	11741	14773	...	...
1084	7 days	16.63	5.10	11800	14571	202	1.37
1248	2 months	17.45	4.66	11626	14497	276	1.87
1658	6 months	16.03	4.91	11798	14444	329	2.23
2086	1 year	14.97	4.68	11860	14307	466	3.15
4107	3 years	15.55	4.13	11621	14102	671	4.54
7277	6 years	14.10	3.76	11180	13813	960	6.49
			STORED IN COVERED BINS				
1078	Same day	17.87	5.75	11741	14773	...	...
1084	7 days	16.63	5.10	11800	14571	202	1.37
1250A	2 months	16.08	5.03	11912	14600	173	1.17
1250B	2 months	17.57	5.01	11626	14535	238	1.61
1664	6 months	16.30	4.52	11682	14336	437	2.96
2092	1 year	15.99	4.65	11589	14165	608	4.12
4098	3 years	17.34	4.78	10681	13278	1495	10.11
7370	6 years	11.83	1.45	11971	13767	1006	6.81
			STORED UNDER WATER				
1078	Same day	17.87	5.75	11741	14773	...	...
1084	Same day as submerged	16.63	5.10	11800	14571	202	1.37
1649	6 months	15.90	4.21	11854	14461	322	2.18
2098	1 year	15.95	5.11	11851	14503	270	1.83

TABLE 8

VERMILION COUNTY SCREENINGS

Lab. No.	Sample Taken after Mining	Dry Coal			B. t. u. Referred to Actual or Unit Coal	Decrease	
		Ash	Sulphur	B. t. u.		B. t. u.	Per Cent
	STORED IN EXPOSED BINS						
1032	Same day	17.88	2.35	11937	14888	...	...
1080	7 days	13.98	2.87	12414	14726	162	1.09
1082	7 days	13.69	2.29	12507	14759	129	0.87
1238	2 months	15.73	2.53	11958	14497	391	2.63
1239	2 months	14.69	2.90	12178	14578	310	2.08
1653	6 months	15.63	2.44	11969	14487	401	2.69
2089	1 year	14.46	2.24	12006	14304	584	3.92
4108	3 years	15.95	1.98	11229	13625	1263	8.48
7369	6 years	13.79	3.85	11210	13275	1613	10.83
	STORED IN COVERED BINS						
1032	Same day	17.88	2.35	11937	14888	...	....
1080	7 days	13.98	2.87	12414	14726	162	1.09
1082	7 days	13.69	2.29	12507	14759	129	0.87
1241	2 months	15.26	2.51	12124	14608	280	1.88
1659	6 months	14.51	2.25	12071	14391	497	3.34
2095	1 year	15.36	2.42	11797	14225	663	4.46
4102	3 years	14.43	2.26	11199	13329	1559	10.47
	STORED UNDER WATER						
1032	Same day	17.88	2.35	11937	14888	...	....
1080	Same day as submerged	13.98	2.87	12414	14726	162	1.09
1082	Same day as submerged	13.69	2.29	12507	14759	129	1.87
1644	6 months	13.87	2.32	12270	14514	374	2.51
2101	1 year	13.55	2.71	12283	14483	405	2.72

TABLE 9

WILLIAMSON COUNTY SCREENINGS

Lab. No.	Sample Taken after Mining	Dry Coal			B. t. u. Referred to Actual or Unit Coal	Decrease	
		Ash	Sulphur	B. t. u.		B. t. u.	Per Cent
STORED IN EXPOSED BINS							
1089	Same day.............	14.13	3.17	12426	14782	...	....
1099	7 days................	14.37	3.34	12287	14666	116	0.78
1244	2 months.............	15.66	2.67	12133	14701	81	0.55
1654	6 months.............	13.76	2.84	12342	14597	185	1.25
2091	1 year................	13.77	2.75	12328	14579	203	1.37
4106	3 years...............	13.25	2.26	13335	14470	312	2.11
7371	6 years...............	13.42	2.23	12077	14196	586	3.96
STORED IN COVERED BINS							
1089	Same day.............	14.13	3.17	12426	14782	...	....
1099	7 days................	14.37	3.34	12287	14666	116	0.78
1245	2 months.............	12.62	2.98	12608	14705	77	0.52
1660	6 months.............	13.60	3.03	12372	14610	172	1.16
2097	1 year................	13.43	2.72	12385	14582	200	1.35
4099	3 years...............	13.07	2.66	12146	14230	552	3.73
7281	6 years...............	12.64	2.19	12153	14144	638	4.31
STORED UNDER WATER							
1089	Same day.............	14.13	3.17	12426	14782	...	....
1099	Same day as submerged	14.37	3.34	12287	14666	116	0.78
1645	6 months.............	14.38	3.54	12262	14645	137	0.93
2103	1 year................	13.60	2.97	12447	14698	84	0.57

TABLE 10

SANGAMON COUNTY SCREENINGS

Lab. No.	Sample Taken after Mining	Dry Coal			B. t. u. Referred to Actual or Unit Coal	Decrease	
		Ash	Sulphur	B. t. u.		B. t. u.	Per Cent
STORED IN EXPOSED BINS							
1079	Same day.............	17.13	4.92	11752	14604	...	....
1085	7 days................	17.04	4.47	11684	14481	123	0.84
1242	2 months..............	17.22	5.00	11645	14488	116	0.79
1655	6 months.............	17.02	4.54	11526	14281	323	2.21
2087	1 year.................	17.25	4.54	11153	13853	751	5.14
4104	3 years................	15.94	4.03	11131	13565	1039	7.11
7373	6 years................	14.95	3.32	11326	13604	1000	6.85
STORED IN COVERED BINS							
1079	Same day.............	17.13	4.92	11752	14604	...	....
1085	7 days................	17.04	4.47	11684	14481	123	0.84
1243	2 months..............	18.33	4.70	11414	14404	200	1.37
1661	6 months.............	17.30	4.67	11466	14263	341	2.33
2093	1 year.................	17.06	4.73	11248	13944	660	4.52
4097	3 years................	18.71	4.86	10325	13072	1532	10.48
7279	6 years................	17.39	3.81	10497	13025	1579	10.81
STORED UNDER WATER							
1079	Same day.............	17.13	4.92	11752	14604	...	....
1085	Same day as submerged	17.04	4.47	11684	14481	123	0.84
1646	6 months.............	19.86	5.60	11127	14372	232	1.59
2099	1 year.................	18.27	4.81	11479	14478	126	0.86

6. *Indicated Heat Losses.*—An inspection of the tables shows that the heating value decreases most rapidly during the first week after mining and continues to decrease more and more slowly for an indefinite time. One per cent is about the average loss for the first week, and an additional loss of two or three per cent may occur by the end of the first year. At the end of the six-year period the indicated losses in some cases equal nearly eleven per cent.

These losses may be ascribed to three distinct causes:

(a) The escape of combustible gases.
(b) The absorption of oxygen.
(c) The increase in weight of the organic or combustible portion of the coal.

7. *Escape of Combustible Gases.*—From certain experiments given in a former bulletin* there is positive evidence that combustible gases exude from freshly mined coal. The extent of this loss, however, is very small. Porter and Ovitz† have carried out a quantitative measurement of such escaping gases and estimate in the case of a coal from Benton, Franklin County, Illinois, the total loss of heat values in a period of seventeen months to be 0.16 per cent. As this was an extreme case for this variety of coal it is evident that the heat loss due to the exudation of combustible gases is practically negligible.

8. *Absorption of Oxygen.*—In Bulletin 32‡ on the occluded gases in coal it is shown that freshly mined coal has a marked avidity for oxygen. It has been shown¶ that the union of oxygen with the coal is a chemical combination and not a simple absorption. While we should expect such chemical action to be accompanied by the generation of heat and consequently by a reduction in the heat value of the coal, there is little information available as to the extent of such loss.

Porter and Ralston§ show the positive formation of heat from oxygen combination but do not present any data as to the amount of this loss. Lamplaugh and Hill** have attempted to measure the amount of heat, and their results show an average for English coals of 3.3 calories for each cubic centimeter of oxygen absorbed. Winmill and Graham†† have carried the same line of experimentation further and have modified slightly the factor for the heat generated, their result showing 2.1 calories per cubic centimeter of oxygen absorbed. The difference is, for the purpose of the present discussion, not material since the desired result is the approximate heat loss due to the oxygen combinations at ordinary temperatures. The maximum absorption under the most favorable circumstances ranges from 7 to 8 cc. oxygen per gram of coal as recorded in the experiments by Lamplaugh and

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*Parr and Wheeler, "The Deterioration of Coal Samples," Univ. of Ill. Eng. Exp. Sta. Bul. 17, p. 33.

†U. S. Bureau of Mines, Technical Paper No. 2, 1910.

‡Parr and Barker, "The Occluded Gases in Coal," Univ. of Ill. Eng. Exp. Sta. Bul. 32.

¶Parr and Hadley, "The Analysis of Coal with Phenol as a Solvent," Univ. of Ill. Eng. Exp. Sta. Bul. 76.

§U. S. Bureau of Mines Tech. Paper 65, p. 8, 1914.

**Trans. Inst. Mining Engrs., Vol. 45, p. 629, 1913.

††Winmill and Graham, "The Absorption of Oxygen by Coal," Colliery Guardian, Sept. 11-18, 1915.

Hill and also by Winmill and Graham. Porter and Ralston found in the case of a Franklin county, Illinois, coal exposed for five months at ordinary temperatures to pure oxygen, an absorption at the rate of 5.3 cc. per gram of coal. This is approximately 10 calories per kilo of coal or about 0.12 per cent of the heat value of the coal. The loss of heat thus represented is so small that it is negligible as a factor effecting deterioration in the quality of the coal. It may, however, possess significance in the matter of spontaneous heating. This phase of the subject will be hereinafter discussed.

9. *Increase in Weight.*—It is evident that, if in the processes which attend the weathering of coal there is an increase in weight of the coal substance, the indicated heat losses are more apparent than real. For example, if at the beginning of the storage period a pound of the unit coal substance shows a value of 14,700 B.t.u., and at the end of the period the original pound has increased in weight by absorption or additions, say 5 per cent, then the heat value per pound of the resulting material will be 14,000 B.t.u., thus indicating an apparent loss of 4.76 per cent. Evidence from many sources has accumulated to show that coal exposed to air or oxygen increases in weight. In the experiments described by Parr and Hadley* it is shown that under certain conditions in the residue insoluble in phenol, which is regarded as the degradation product of the cellulose constituent, there is as much as 3 per cent increase in weight due to the taking up of oxygen. This work further shows that such additional oxygen is chemically combined and not merely absorbed. Other experimenters have presented evidence to the effect that coal increases in weight. Somermeier† has shown an increase due to oxidation for an Illinois coal 2.47 per cent. Porter and Ralston ‡ show also a measurable increase in weight due to oxygen absorption. In their experiments on oxidation at various temperatures they note that Illinois and Pittsburgh coals "show increases of weight up to 260 degrees in spite of the loss of carbon and hydrogen in CO_2, CO and H_2O." Study of some of the values presented in Table 11 seems to give

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*"The Analysis of Coal with Phenol as a Solvent," Univ. of Ill. Eng. Exp. Sta. Bul. 76.

†Professor Somermeier was doubtless the first to suggest that the indicated decrease in heat values was in reality the result of an increase in weight. N. W. Lord and E. E. Somermeier, U. S. Geol. Surv. Bul. 323, p. 22.

‡U. S. Bureau of Mines, Tech. Paper 65, p. 20-22, 1914.

further evidence of an increase in weight of the organic or combustible part of the coal. Some of these data with a discussion of their bearing on this point are presented under the following topic.

10. *Decrease of Ash Percentages.*—A study of the relative ash values corresponding to the various stages of indicated heat losses reveals a consistent lowering of the percentages of ash. This result obviously is normal since the actual increase in the organic constituents of coal during storage with the corresponding increase in the weight of any given sample must result in a relatively lower amount of ash, or an apparent decrease in ash.

Of course, the exact duplication of these theoretical conditions was impossible in these experiments. The oxidation of the sulphur varied and the leaching out of the soluble sulphates would alter the ash values in a corresponding degree. Other variables might enter, such as irregularities in sampling or the possible accumulation of foreign or earthy matter. Notwithstanding all these possibilities of inaccuracy there is a striking consistency of results with reference to the decrease of indicated ash percentages as the process of weathering proceeded. The ash values of the several masses taken at the beginning and at the close of the six-year period are presented in Table 11.

TABLE 11

INDICATED ASH AT THE BEGINNING AND AT THE END OF SIX YEARS IN STORAGE IN OPEN BINS

No.	Coal and County	Average Ash Values as Determined by Analysis of 3 Samples (1) at the Mine (2) at Unloading of Car (3) after 2 Months	Average Ash Values after 6 Years as Shown by Analysis of 2 Samples (1) from Open Bins (2) from Covered Bins	Indicated Decrease in Ash
1	Nut—Sangamon........	17.01	12.96	4.05
2	Nut—Vermilion........	12.95	11.45	1.50
3	Nut—Williamson.......	14.32	13.41	0.91
4	Screenings—Sangamon..	17.43	16.17	1.26
5	Screenings—Vermilion ..	15.20	13.79	1.41
6	Screenings—Williamson.	14.19	13.03	1.16

Inspection of the ash values presented in Tables 5 to 10, inclusive, further emphasizes the results shown by Table 11. The factors for the submerged coal have not been included in Table 11. Although these samples were under test for only a year, they show a constancy in the ash values and an absence of change, which is in keeping with the uniformity of heat values credited to the unit coal substance.

The increase in weight of the coal in storage by addition to the organic constituents is further illustrated by the values presented in Table 12. The values presented in Column 1 represent the heat value for the unit coal when fresh, as found by averaging the unit coal values for three samples taken at the mine, at the time of unloading, and after two months in storage. The calorific values of the dry coal in open storage at the end of six years are shown in Column 2. The accompanying ash and sulphur values are shown in Columns 3 and 4. Column 5 shows the percentages of ash or inert material which must be present in order that the fresh unit coal

TABLE 12

INCREASES IN WEIGHT OF COAL DURING STORAGE, IN RELATION TO THE INDICATED DECREASE IN HEAT VALUE

No.	Coal and County	B. t. u. per Lb. of Fresh Coal Average of 3 Samples Taken (1) at Mine (2) at Unloading of Car (3) after 2 Mos. Storage	B. t. u. per Lb. after 6 Years Open Storage, Dry Coal Basis	Ash as Weighed Dry Coal Basis, with Heat Values as in Col. 2	Sulphur in Dry Coal after 6 Years Open Storage	Ash Plus Additive Material Acquired in 6 Years Open Storage	Ash as in Col. 3 but Corrected for Sulphur as in Formula for Unit Coal	Showing Amount of Additive Material by Difference
		1	2	3	4	5	6	7
1	Nut—Sangamon.......	14,614	11,180	14.10	3.76	23.5	17.3	6.2
2	Nut—Vermilion........	14,700	11,984	13.06	1.58	18.5	14.9	3.5
3	Nut—Williamson.......	14,838	12,339	12.86	2.20	16.9	15.1	1.8
4	Screenings—Sangamon.......	14,524	11,326	14.95	3.32	21.9	17.9	4.0
5	Screenings—Vermilion........	14,717	11,210	13.79	3.85	23.8	17.0	5.2
6	Screenings—Williamson......	14,716	12,077	13.42	2.23	17.2	15.7	1.5

For discussion of Unit Coal and Corrected Ash see Univ. of Ill. Eng. Exp. Sta., Bul. 37, p. 33.

$$\text{Unit B. t. u.} = \frac{\text{Indicated (dry) B. t. u.} - 5000 \text{ sulphur}}{1.00 - (1.08) + 22/40 \text{ sulphur}}$$

Corrected (dry) ash = ash as weighed × 1.08 + 22/40 sulphur.

values of Column 1 may after six years drop to the values shown in 3. These percentages are derived by the formula,

$$100 - \frac{\text{B.t.u. per pound after storage}}{\text{B.t.u. per pound of fresh coal}}$$

The values in Column 6 are the corrected ash values for the coal after six years in open storage.*

The difference between the apparent corrected ash values of Column 6 and the required ash for producing the values shown in Column 2 is a measure of the additive material which is assumed to have been taken up by the organic constituents as absorbed oxygen or hydroxyl additions. These additions bear a certain general relation to the indicated decrease of ash shown in Table 11 and, of course, thus bear a more direct relation to the indicated deterioration percentages (see Tables 5 to 10).

These facts taken together, therefore, seem to afford added basis for the statement that the actual losses of heat values in stored coal are apparent rather than real, and that the true heat losses are those due to escaping combustible gases and to the heat generated by direct combination of oxygen both of which have been shown to be practically negligible.

IV. MOISTURE VALUES FOR WEATHERED COAL

The moisture values for the stored coal at the end of the six-year period are presented in Table 13. Some recent work on the Properties of the Water in Coal† by Porter and Ralston suggests a relation between the type of coal and the amount of "inherent" or hygroscopic moisture retained by the coal upon air-drying. It might be argued, therefore, that if the coals here considered during storage altered in type, possibly by a reversion toward the lignitic form, then a correspondingly high percentage of the moisture should be retained on air drying. The values shown in the table are without significance as far as this theory is concerned. However, the data should be

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*Corrected Ash (dry) = ash × 1.08 + $\frac{22}{40}$ × sulphur (see formula for Unit Coal, footnote to Table 12).

†H. C. Porter and O. C. Ralston, U. S. Bureau of Mines, Technical Paper 113, 1916.

presented for other reasons. For example, the high percentage of total moisture is in a general way characteristic of the several kinds of coal in that it is affected by the degree of subdivision or disintegration which has taken place. As may be seen by reference to the discussion concerning the slacking of these coals, the coals which have undergone the greatest disintegration have the highest percentage of total moisture present. This result, however, is to be expected and is due to physical rather than to chemical action.

V. Summary of Chemical Studies

The results presented in the foregoing tables and the data analyzed in the discussions may be summarized as follows:

(1) After a period of one year, the indicated loss of heat values is relatively low, averaging about 3 or 3½ per cent.

(2) Different coals vary in indicated heat losses, those from the southern Illinois districts showing less change than those from the central part of the state. Exposure beyond a period of one year accentuates this difference between coals from different localities. The denser coals, such as those from Williamson county, undergo but little additional change, while the coals from the northern parts of the state show a decrease in the indicated heat values. The difference, however, does not exceed about 10 per cent.

(3) Deterioration is consistently greater in the case of screenings than in that of screened nut.

(4) Since the heat values are referred to the unit coal basis, that is, the moisture, corrected ash, and sulphur free material, and since an actual loss of heat values by ordinary processes of oxidation would result in the formation of CO_2 and H_2O, both volatile under the conditions, it follows that the heat losses are largely relative, since they must result from a relative increase in weight of the organic substance of the coal. For example, any increase in weight, as by the addition of oxygen to the chemical structure of the organic material, would result in a lower indicated heat value per pound of the unit substance as compared with the heat value per pound before such addition had occurred. Similarly, changes in the sulphur combination due to oxidation would increase the weight of the

coal in a manner not taken into consideration in deriving the "corrected" ash values. Thus, where FeS_2 becomes $2FeSO_4 + 7H_2O$, the relative weights for sulphur are in the ratio of 1:7; that is, the content of sulphur compounds as the result of the new combinations has increased in weight seven times.

(5) Storage in *open bins* shows quite consistently a *lower* percentage of loss of heat value per pound than *is the case with storage under cover.* This is easily understood when it is considered that the additional material formed, due to the oxidation of the sulphur, is soluble and tends to leach out under the long continued application of water resulting from exposure to the elements. For this reason, therefore, the increase in weight is greater in the case of the coal under cover than in that of the coal exposed in open bins. The resulting unit coal values should, therefore, be higher for the coal stored in open bins, or the leached coal, than for the coal stored under cover or the unleached coal. Comparisons as to the relative values in covered and uncovered bins should, however, be made only up to and including the three-year period. The removal to new locations of the bins and piles shortly before the three-year old samples were taken resulted in the reconstruction of the covered bins with flat and leaky roofs through which the water had more or less free access to the coal.

(6) The extent of oxidation or increase in weight is a function of the character of the coal. The coal in which the cellulose residuum seems to predominate has the greater avidity for oxygen, and the coal in which the resinic residuum predominates is less affected. The tabulation of the samples, therefore, is in the order of such activity, namely, Sangamon, Vermilion, and Williamson counties. This feature is consistent with the studies in the absorptive capacities for oxygen of various coals as carried on by Porter and Ralston and is especially of interest in connection with the studies of Dr. Hadley on the relative avidity for oxygen of the cellulose residuum as compared with the absorptive capacity of the resinic bodies, separation into these two type components being affected by means of phenol.*

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*"The Analysis of Coal with Phenol as a Solvent," Univ. of Ill. Eng. Exp. Sta. Bul. 76, p. 21, 1914.

According to the results derived by Dr. Hadley, the cellulose residue had a far greater avidity for combination with oxygen than the resinic material.

TABLE 13

PERCENTAGE OF MOISTURE IN WEATHERED COAL, LOSS DUE TO AIR-DRYING, AND THE AMOUNT RETAINED BY THE AIR-DRIED SAMPLES

Table No.	Lab. No.	Coal, County and Condition	Total Moisture	Loss Due to Air-Drying	Moisture Retained in the Air-Dried Sample
1	7369	Screenings Vermilion Exposed Bin	17.70	14.15	4.14
2	7370	Nut Sangamon Covered Bin	19.95	16.54	4.09
3	7371	Screenings Williamson Exposed Bin	12.01	8.59	3.74
4	7372	Nut Vermilion Covered Bin	17.79	14.50	3.85
5	7373	Screenings Sangamon Exposed Bin	19.26	15.79	4.12
6	7374	Nut Williamson Exposed Bin	9.77	7.05	2.93
7	7277	Nut Sangamon Exposed Bin	20.35	17.01	4.03
8	7279	Screenings Sangamon Covered Bin	22.04	19.36	3.33
9	7298	Nut Vermilion Covered Bin	20.02	16.01	4.77
10	7299	Nut Williamson Covered Bin	12.54	9.45	3.30

VI. CHANGES IN PHYSICAL PROPERTIES

11. *Sizing Test.*—The extent of the disintegration or "slacking" which takes place in connection with the storing of coal is a matter of considerable importance because of the effect upon combustion on the grates where a large amount of finely divided material is present In order to determine the effect of storage upon slacking the sizing tests were continued to cover the entire period of six years. The

tests were made with a revolving screen with round perforations, as shown in Fig. 3.

Three sizing tests were made: one at the time the coal was placed in storage, one after a period of eighteen months, and one at the end of six years. It should be recalled that approximately three years before the last screening tests the storage piles were removed by wagon to a new location involving a double handling. Since the

TABLE 14

RESULTS OF SIZING TESTS ON NUT COAL STORED IN OPEN BINS

Round-Hole Screen		Original Sizes		In Storage for 1½ Years		In Storage for 6 Years	
Through Inches	Over Inches	Per Cent	Cumulative Per Cent	Per Cent	Cumulative Per Cent	Per Cent	Cumulative Per Cent
			SANGAMON COUNTY				
3	1	89.4	....	64.3	....	30.9	....
1	¾	4.1	93.5	6.9	71.2	9.6	40.5
¾	½	3.5	97.0	8.4	79.6	15.9	56.4
½	⅜	1.2	98.2	3.2	82.8	8.5	64.9
⅜	¼	0.6	98.8	4.0	86.8	3.2	68.1
¼	⅛	0.6	99.4	7.4	94.2	17.0	85.1
⅛	0	0.6	100.0	5.8	100.0	14.9	100.0
Total...............		100.0		100.0		100.0	
Average Diameter ...			1.854 inches		1.442 inches		.889 inches
			VERMILION COUNTY				
3	1	66.2	....	42.5	....	25.0	....
1	¾	5.0	71.2	8.0	50.5	6.3	31.3
¾	½	7.2	78.4	11.8	62.3	12.5	43.8
½	⅜	4.0	82.4	6.9	69.2	8.7	52.5
⅜	¼	4.0	86.4	6.8	76.0	12.5	65.0
¼	⅛	5.0	91.4	10.9	86.9	16.3	81.3
⅛	0	8.6	100.0	13.1	100.0	18.7	100.0
Total...............		100.0		100.0		100.0	
Average Diameter....			1.458 inches		1.074 inches		.753 inches
			WILLIAMSON COUNTY				
3	1	94.0	....	70.2	....	60.6	....
1	¾	1.6	95.6	5.7	75.9	9.1	69.7
¾	½	1.8	97.4	6.6	82.5	8.3	78.0
½	⅜	0.7	98.1	3.1	85.6	2.7	80.7
⅜	¼	0.5	98.6	3.2	88.8	3.7	84.4
¼	⅛	0.5	99.1	4.6	93.4	5.5	89.9
⅛	0	0.9	100.0	6.6	100.0	10.1	100.0
Total...............		100.0		100.0		100.0	
Average Diameter ...			1.910 inches		1.532 inches		1.383 inches

extent of disintegration was not materially different for the coals stored in the exposed bins and for those stored in the covered bins, and since during the last years of storage the covered bins were almost as much exposed to rain and weather conditions as the uncovered bins, the results of sizing tests on coals stored in covered bins are omitted. Those for the coals stored in open bins are presented in Tables 14 and 15.

TABLE 15

RESULTS OF SIZING TESTS ON SCREENINGS IN OPEN BINS

Round-Hole Screen		Original Sizes		In Storage for 1½ Years		In Storage for 6 Years	
Through Inches	Over 1 Inch	Per Cent	Cumulative Per Cent	Per Cent	Cumulative Per Cent	Per Cent	Cumulative Per Cent
			SANGAMON COUNTY				
1¾	1.0	38.8	....	15.1	....	10.0	....
1.0	¾	7.9	46.7	9.3	24.4	8.2	18.2
¾	½	13.2	59.9	15.6	40.0	14.5	38.7
½	⅜	6.6	66.5	7.7	47.7	10.9	43.6
⅜	¼	7.2	73.7	9.4	57.1	15.4	59.0
¼	⅛	11.2	84.9	17.2	74.3	24.5	83.5
⅛	0	15.1	100.0	25.7	100.0	16.5	100.0
Total...............		100.0		100.0		100.0	
Average Diameter ..			.768 inches		.498 inches		.452 inches
			VERMILION COUNTY				
1¾	1	19.0	....	11.3	....	8.8	....
1.0	¾	8.9	27.9	6.3	17.6	6.3	15.1
¾	½	14.8	42.7	12.9	30.5	12.1	27.2
½	⅜	8.5	51.2	9.3	39.8	9.3	36.5
⅜	¼	11.1	62.3	11.8	51.6	13.9	50.4
¼	⅛	16.4	78.7	21.0	72.6	29.0	79.4
⅛	0	21.3	100.0	27.4	100.0	20.6	100.0
Total...............		100.0		100.0		100.0	
Average Diameter ..			.548 inches		.425 inches		.403 inches
			WILLIAMSON COUNTY				
1¾	1	18.9	....	19.0	....	6.0	....
1.0	¾	9.0	27.9	9.2	28.2	5.5	18.2
¾	½	14.4	42.3	15.4	43.6	11.5	32.7
½	⅜	8.5	50.8	9.5	53.1	9.3	43.6
⅜	¼	10.4	61.2	10.6	63.7	14.4	59.0
¼	⅛	15.4	76.6	17.0	80.7	32.2	83.5
⅛	0	23.4	100.0	19.3	100.0	21.1	100.0
Total...............		100.0		100.0		100.0	
Average Diameter ..			.542 inches		.557 inches		.255 inches

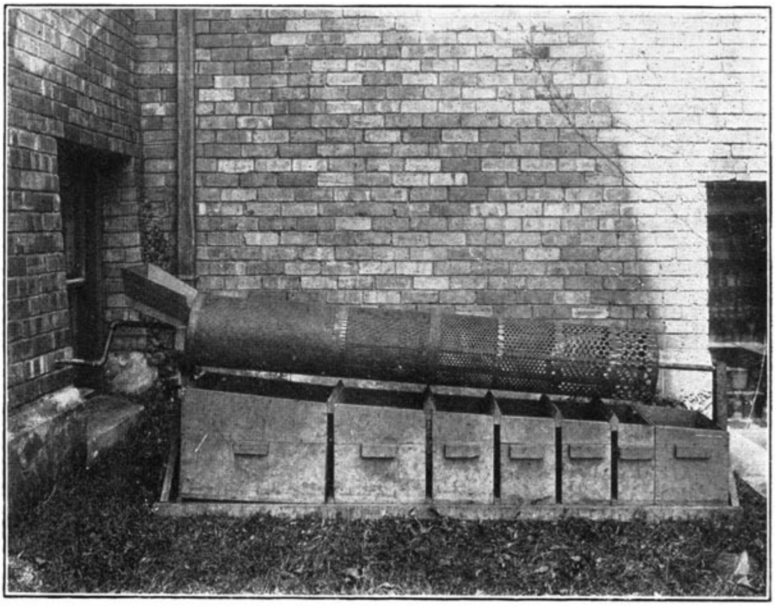

FIG. 3. REVOLVING SCREENS USED IN SIZING TESTS
(Reproduced from Univ. of Ill. Eng. Exp. Sta. Bul. 78, 1909)

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A condensed summary of the detailed results presented in Tables 14 and 15 is given in Table 16. The total dust passing through a ¼-inch screen is taken as the factor indicating the increase of fine material, and percentages of increase for the two periods are based on the total amount of material in the original coal over ¼-inch in size. Moreover, the samples taken from this table vary with reference to the method of storage, three being from exposed and three from covered bins. These particular samples are used in the table for the reason that the same storage lots were selected for making the standard boiler tests which are hereinafter discussed.

TABLE 16

INCREASE IN FINE MATERIAL AFTER ONE AND ONE-HALF AND SIX YEARS (BASIS OF REFERENCE, THE TOTAL COARSE MATERIAL IN THE ORIGINAL COAL PASSING OVER ¼-INCH SCREEN)

Table No.	Coal and County	How Stored	Initial Storage	After 1½ Years		After 6 Years	
			Dust Passing ¼-Inch Screen	Dust Passing ¼-Inch Screen	Percentage Increase of Fine Material Referred to Original Coal over ¼-Inch	Dust Passing ¼-Inch Screen	Percentage Increase of Fine Material Referred to Original Coal over ¼-Inch
1	Nut—Sangamon.....	Open	1.2	13.2	12.1	31.9	31.0
2	Nut—Vermilion......	Open	13.6	24.0	12.0	35.0	24.7
3	Nut—Williamson....	Covered	1.4	11.0	11.1	13.9	12.6
4	Screenings—Sangamon.....	Covered	26.3	38.5	16.5	45.1	25.5
5	Screenings—Vermilion......	Open	37.7	48.4	17.1	49.6	19.1
6	Screenings—Williamson....	Covered	38.8	45.4	10.7	50.6	19.2

An examination of Table 16 shows that the rate of disintegration is consistent with the variety of coal as already discussed in connection with the absorptive capacity for oxygen, and suggests that the process of oxidation of the organic material may be quite as largely responsible for this breaking down of the particles as the oxidation of the finely divided pyrite sulphur. The latter may or may not be distributed throughout the texture of the coal; this characteristic, for Illinois coal at least, has not been determined.

VII. BOILER TESTS ON WEATHERED COAL

Upon the completion of the storage experiments at the end of the six-year period, it was decided to conduct if possible a series of boiler tests under standard conditions and to compare the results of tests with stored coal with those of similar tests in which fresh coal is used. Such an opportunity presented itself in connection with a series of boiler tests being conducted at that time by Mr. A. P. Kratz, who was making a general study of boiler losses.*

The coal which Mr. Kratz was using as standard material consisted of screenings from the Mission Field, Vermilion county, Illinois. Nineteen tests were conducted with this coal. Five additional tests were made on samples of the weathered coal, one sample each of nut coal being selected from the lots from Sangamon, Vermilion and Williamson counties, and one sample each of screenings from the Sangamon and the Williamson county lots. With reference to the ash content and the percentage of finely divided material, the properties of the stored coals did not differ greatly from those of the fresh coals. An excellent basis was, therefore, provided for comparing the efficiency of the stored and fresh coals. As might be expected, some experience had to be acquired as to the best method of handling and firing the weathered coals, and although the first test was unsatisfactory, subsequent experiments yielded results which proved trustworthy and useful as a basis of comparison.

"On the first test the coal banked slightly at the water-back, and the whole amount on the grate became clinkered. It immediately became evident that in order to run at all, the coal had to be kept away from the water-back. After the clinker had been removed a fresh start was made, and care was taken to keep the fuel bed from four to six inches away from the water-back. When this was done no further trouble was experienced."†

With reference to the relative drafts required for a given rate of combustion with the fresh and the weathered coal, the tests showed that a stronger draft is required for the weathered coal. Moreover, by comparing draft requirements for those lots which were in close agreement as to their dust content, it seems evident that the higher draft requirement is not necessarily due to a higher dust factor. The

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*A. P. Kratz, "Study of Boiler Losses," Univ. of Ill. Eng. Exp. Sta. Bul. 78, 1915.

†Univ. of Ill. Eng. Exp. Sta. Bul. 78, p. 50, 1915.

explanation for this is simple if we recall the discussion already presented concerning the avidity for oxygen of freshly mined coal. This avidity for oxygen seems to be directly related to the free burning character of the coal. Pillar coal and coal that has been long in storage does not burn so freely as fresh coal. On account of this characteristic such coal is thought to have lost a large part of its heat, when as a matter of fact it may have the same number of heat units but a very different rate of combustion. Another factor, and probably a minor one, is the loss of combustible gases. Mention has been made of the fact that part of the deterioration which occurs in the first few days or weeks after mining is due to the escape of certain light volatile or gaseous fuel constituents. It is evident, therefore, that either on account of the avidity of the fresh unsaturated coal for oxygen or the presence of light fuel constituent, or because of both conditions combined, the fresh unweathered coal burns freely and gives up its heat units readily, whereas the opposite is true with weathered coal. This difference, therefore, must be offset by a stronger draft or by some combination of conditions which will effect a speeding up of the burning or oxidation process. If by this means the rate of combustion can be made to approach that of the fresh coal, a corresponding degree of efficiency should result. The correctness of this theory is borne out by the results shown in Table 17. It is to be noted that the over-all efficiency of

TABLE 17

RESULTS OF BOILER TESTS WITH MISSION FIELD FRESH COAL AND WITH WEATHERED COAL AFTER SIX YEARS IN STORAGE

Mission Field			Weathered Coal				
Test No.	Boiler H. P. Developed	Efficiency of Boiler, Furnace, and Grate Per Cent	Test No.	No.	Coal and County (Tables 5 to 10)	Boiler H. P. Developed	Efficiency of Boiler, Furnace, and Grate Per Cent
10	554.0	63.96	20	1	Nut—Sangamon.......	568.5	64.50
11	569.6	61.21	21	4	Screenings—Sangamon.......	557.2	63.05
12	572.7	60.67	22	3	Nut—Williamson......	727.1	65.98
13	589.0	69.87	23	6	Screenings—Williamson......	509.6	60.04
14	555.9	64.75	24	2	Nut—Vermilion........	655.0	64.20
15	506.6	65.50					
16	644.0	60.84					

the weathered coal averages quite as high as that of the fresh screenings.

The general summary covering the behavior of the coal in steam generation after six years of storage, as set forth in Bulletin 78 of the University of Illinois Engineering Experiment Station, is as follows:

> "1. Burning weathered coal is largely a question of correct handling and ignition. Under these circumstances it gives as good results as fresh screenings.
>
> "2. Weathered coal requires a little thinner fire and more draft than fresh screenings.
>
> "3. When using weathered coal the fuel bed should not approach any nearer to the water-back than from 4 to 6 in., otherwise trouble with clinker is experienced.
>
> "4. Practically as high capacity was obtained with weathered coal as with the other coals used, and, if anything, the fuel bed requires less attention."

In this reference, attention is called further to the fact that the results obtained and the conclusions presented are based on the heat values in the coal as fired and do not take into account the matter of deterioration. But it has already been shown in the previous discussion that the deterioration is largely apparent in a physical change and that the actual loss of heat value is small. Hence, the efficiency factors developed in the tests may be accepted as fairly representing results obtainable on weathered coal in which the heat loss resulting from weathering is practically negligible.

VIII. CONCLUSIONS

The facts presented in the preceding sections of this bulletin justify the following conclusions:

> (1) Bituminous coal can be stocked without appreciable loss of heat values provided the temperature is not allowed to rise above 180 degrees F. In fact, there is no appreciable evolution of CO_2 at temperatures below 260 degrees F.
>
> (2) The indicated heat loss per pound of coal is due more largely to an increase in weight of a unit mass of coal resulting from the absorption of oxygen than to an actual deterioration or loss of heat units.

(3) Freshly mined coal has a large capacity for absorbing oxygen which combines chemically with both the organic combustible and the iron pyrites present.

(4) The combination of oxygen with coal at ordinary temperatures generates a small increment of heat.

(5) The rapidity with which oxygen is absorbed depends upon the temperature of the mass and the extent of the superficial area exposed, that is, the fineness of division of the coal.

(6) If heat is generated by this slow process of oxidation more rapidly than it is lost by radiation, the acceleration of the reaction causes a rise in temperature which quickly brings the mass up to the danger point. A temperature of 180 degrees F. is named as the danger point because, if the coal reaches that temperature, practically all of the free moisture is vaporized and the further rise in temperature will be very rapid.

(7) Any method of storage to be successful must either check or prevent the absorption of oxygen to such an extent that the generation of heat shall not proceed so rapidly as to exceed natural heat losses due to radiation.

(8) Underwater storage prevents loss of heat values, and is not accompanied by deterioration in physical properties, such as slacking.

(9) Dry storage is far more safely undertaken if the fine material is screened out at the storage yard and the lump only, preferably sized, is stocked.

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