Preventing Spontaneous Combustion in Stored Coal

Whether a particular coal under given storage conditions will heat from spontaneous combustion to any undesirable extent depends upon many factors. A thorough discussion of the significance of the several factors directly related to heating of the coal pile during storage, satisfactory methods of storage, and methods of measuring and controlling temperatures was presented in a recent paper.[54] The factors include: (1) The tendency of the particular coal to absorb oxygen; (2) the temperature at which the coal is piled; (3) the fineness of any pyrite present; (4) the original size of coal and the dependent surface area; (5) the tendency of the coal to slack; (6) the moisture conditions; (7) the volume of air available to the coal permitted by conditions of ventilation throughout the storage piles; (8) the presence of foreign substances, such as wood, straw, and refuse; (9) the possibilities of dissipating any heat developed; and (10) any added heat from external sources. If these complex factors are evaluated correctly and means are available to carry out proper methods needed in each instance, it is not difficult to store coal satisfactorily. Satisfactory storage methods must be devised primarily with considerations of the type and size of coal, its freedom from foreign materials, and practices that either prevent access of air to the coal entirely or provide for enough air throughout the pile to carry away the heat as rapidly as it develops. Methods of storage considered included: (1) Storing under water; (2) storing in an open pit in the earth; (3) storing slack in layers, either compacted or loose; (4) capping the coal pile with airtight coverings; (5) storing in bins, bunkers, and silos; (6) storing sized coals; and (7) storage in the home.

Storage of Subbituminous Coal

Storage of 10 tons of lump subbituminous coal for 8 months in a tight bin in a typical six-room brick bungalow showed no significant changes in the physical and chemical properties of the coal, and the stored coal gave excellent performance in a hand-fired furnace.[55] The coal was leveled in the bin and covered with wrapping paper to prevent flow of air through the pile. During the storage period the moisture content changed from 23.6 to 21.1 percent, the heating value from 13,270 to 13,060 B.t.u. per pound (dry, ash-free basis), the friability from 21 to 26 percent, and the Bureau of Mines slacking index from 65 to 61 percent. Visual inspection of the coal revealed little degradation. The maximum temperature of 80° F. in the coal was reached after 72 days and then decreased gradually to 65° F. During the 8 months' storage period the outside temperature ranged from 18° to 100° F. Performance of the stored coal in a hand-fired furnace in the same residence during cold weather under normal conditions of use demonstrated that an average of 2.95 pounds of 9,850 B.t.u. coal, or 23,500 net available

[54] Barkley, J. F., Preventing Spontaneous Combustion in Stored Coal: Smoke Prevention Assoc. of America, Inc., Manual of Instructions on Proper Firing Methods, 1943, pp. 1-7a.

[55] Landers, W. S., and Parry, V. F., Domestic Storage of Subbituminous Lump Coal and Its Performance in a Hand-Fired Furnace: Bureau of Mines Rept. of Investigations 3759, 1944, 17 pp.

B.t.u. was required per day per degree day (60° F. base). Fly-ash losses during the test were 2.4 percent of the ash charged in the coal. During the open-draft periods of the test the indicated over-all heating efficiency was about 69 percent. Maximum efficiency obtainable with this coal under practical conditions was 80.9 percent.

Studies of the storage of large quantities of subbituminous slack coal for industrial purposes was continued. The Subbituminous Coal and Lignite Section of the Bureau of Mines at Golden, Colo., in cooperation with the Great Western Sugar Co., Brush, Colo., studied stored coal in an open concrete pit, filled with 13,300 tons of coal from various mines of the Northern Colorado field, during the period from February to May 15, 1944. The coal was placed in 3-foot layers and compacted by a tractor to a bulk density of 58 pounds per cubic foot. The total depth of coal in the bin, after compacting, was about 15 feet. Table 1 give the results of temperature determinations of the coal pile. The data show that practically all oxygen has been eliminated from the gases beneath the surface of the pile and that about one-third of the oxygen of the air was absorbed by the coal and not liberated as products of oxidation. This study and earlier demonstrations prove that subbituminous coal can be stored satisfactorily in open, dry pits.

Influence of Storage on Caking and Coking Properties of Coal

The effect of storage or oxidation upon the coke-making properties of coals is of great importance to commercial coke-oven operators who must either store large amounts of coal to insure continuous plant operation or ship coal for long distances which may involve extended storage periods, either at the mine or at the site of the coke ovens. Two representative samples of coal from the Eagle and the Elkhorn No. 3 coal beds have been recently tested and their relative storing qualities determined. Four-hundred-pound samples of these coals, stage-crushed to 0- to 1/4-inch size. were oxidized progressively at 100° C. in air in a rotary, steam-jacketed, oxidation apparatus and then carbonized at 800° C. Values for the "durability of coking power" are given in table 2, and the effects of these accelerated weathering tests on the coke strength indexes are shown graphically in figure 3. For comparative purposes data that have been obtained on two samples of Pittsburgh-bed coal from different mines have been included.

The length of time that a sample of coal can withstand the action of air at 100° C. to cause a 15-percent reduction in its coke-strength index is defined as the "durability of coking power." This value for the Eagle-bed coal is almost as large as that for the sample of Pittsburgh-bed coal from the Warden mine and is double that for the sample of Pittsburgh-bed coal from the Bruceton mine. The coking powers of the Elkhorn No. 3-bed coal are only 46 percent as resistant to storage as those of the sample of Pittsburgh-bed coal from the Bruceton mine.

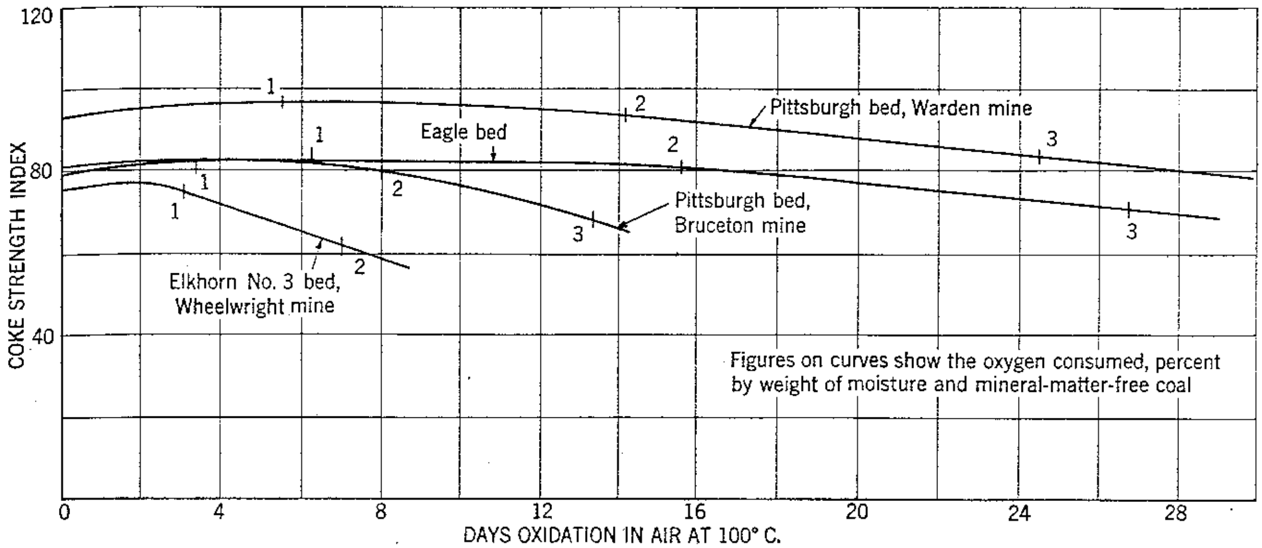

FIGURE 3.- Effects of storage (acceleration) of coal on strength index of coke.

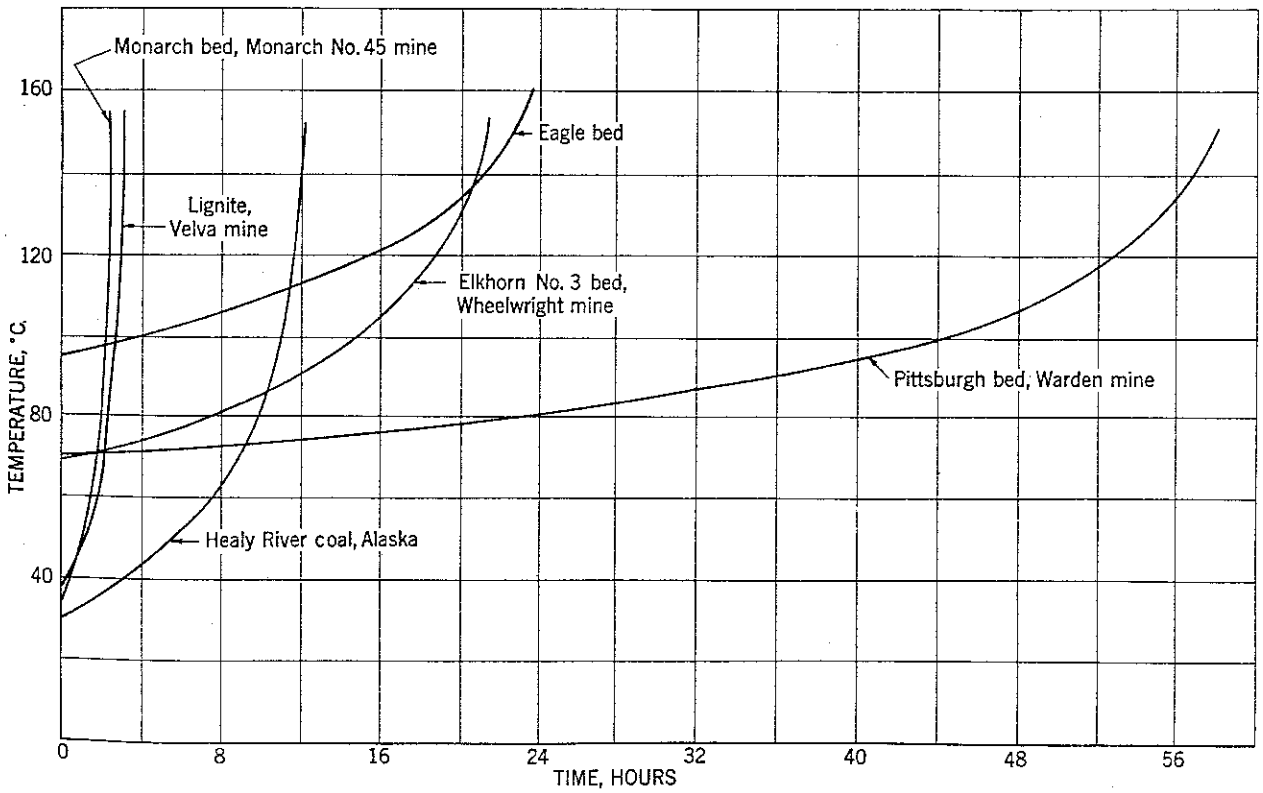

FIGURE 4.- Self-heating of dry, 0 to $\frac{1}{4}$-inch coal in an atmosphere of 85- percent oxygen.

TABLE 1. - Observed temperature and composition of gas in subbituminous coal stored in open pit at Brush, Colo., June 27, 1944[1]/

Station number	Temperatures in the coal °F. 3 feet	6 feet	9 feet	Composition of gases at 4 feet, percent CO_2	O_2	CO	N_2	Oxygen absorbed[2]/
1	130	98	85	13.5	0.3	0.0	86.2	32
2	132	108	92					
3	140	110	90	12.0	.2	.0	87.8	40
4	135	108	92					
5	132	110	95	12.1	.3	.0	87.6	40
6	125	100	82					
7	137	108	90	12.1	2.5	.5	84.9	25
8	125	105	82					
9	122	97	78	7.7	4.3	.0	88.0	42
10	125	105	85					
11	133	105	87	6.9	10.2	.1	82.8	12
12	130	105	85					
13	128	103	87	12.4	.2	.0	87.4	39
14	135	110	90					
15	128	105	85	12.4	.8	.3	86.5	34
16	140	110	87					
17	132	108	85	11.3	.4	.0	88.3	44
18	135	112	82					
19	137	110	85	14.1	.2	.0	85.7	30
20	132	100	83					
Average	132	106	86	11.5	1.9	.1	86.4	33

Average entire pit, 108° F.

1/ Observations made at 20 stations, 30 feet from walls of pit and 40 feet apart. Length of pit is 423 feet, width 100 feet, and coal depth about 15 feet. The pit contains about 13,300 tons of coal placed in approximately 3-foot compacted layers during the period from February to May 15, 1944. Top surface of pit is level and compacted to give total average bulk density of 58 pounds per cubic foot.

2/ Oxygen absorbed,

$$\text{percent} = 100 \times \frac{\frac{N_2}{0.809} - \left(N_2 + CO_2 + O_2 + \frac{CO}{2}\right)}{\frac{N_2}{0.809} - N_2},$$

Based on ultimate CO_2 = 19.1 percent.

TABLE 2. - Sources, rank, and durability of coking power of the coals tested

Coal and Source	Rank	Durability of coking power, T_{15} days	Ratio to Pittsburgh bed, Bruceton mine
Pittsburgh bed, Warden mine, Allegheny County, Pa.	High-volatile A	28.5	2.11
Pittsburgh bed, Bruceton mine, Allegheny County, Pa.	do	13.5	1.00
Eagle bed, (prospect hole), Kanawha County, W. Va.	do	27.8	2.06
Elkhorn No. 3 bed, Wheelwright mine, Floyd County, Ky.	do	6.2	.46

The small figures on the curves of figure 3 show how much oxygen the coal has consumed during the corresponding time of accelerated weathering as shown on the (abscissa). Examination of these curves indicates that the Eagle-bed coal oxidizes at a slower rate than any of the other three coals while the Elkhorn No. 3-bed coal consumes oxygen faster than any of the other coals shown.

Spontaneous Heating of Stored Coal

The relative tendencies of a number of coals to heat spontaneously in storage have been measured in the Bureau of Mines laboratory by two different methods. In the first procedure, the characteristic oxidation rate of a 0-1/4-inch sample of the coal at 100° C. in air is measured through the use of a 50-pound, rotary, steam-jacketed equipment similar in operation to the 400-pound equipment described earlier.56/ The second procedure involves the drying of a sample of 0- to 1/4-inch coal at 100° C. in an inert atmosphere and then placing the dried coal in an adiabatic type calorimeter of 110 pounds capacity, heating to the temperature at which it is desirable to start the test, and then passing oxygen up through the apparatus at such a rate that an atmosphere containing 85 percent or more oxygen is maintained in contact with the coal. The rise in temperature of the coal is a measure of the tendency of the coal to heat spontaneously in storage.

Table 3 gives the results that have been obtained for several of the coals tested by the two methods. The agreement between the two types of tests is good for the high-volatile A coals and seems fairly satisfactory for the subbituminous coals and lignite. These latter coals are much more apt to cause trouble through spontaneous heating during storage than the high-volatile A coals, and because of their high reaction rates, it is difficult to measure accurately their tendencies to heat.

Figure 4 gives the experimental self-heating curves that were obtained from the adiabatic calorimeter tests. To compare the tendencies of these coals to heat, it is necessary to calculate the heating rates at some definite temperature, such as 100° C. Thus, although the curve for the Eagle coal starts at slightly less than 100° C. and the Pittsburgh bed between 70° and 80° C., their self-heating tendencies can be compared by a comparison of their rates of temperature rise at 100° C. The self-heating curves show that the Monarch coal and the lignite samples are the most likely to heat in storage; the Healy River coal is somewhat less likely to cause trouble; the Elkhorn No. 3 bed coal is much less likely to heat than the lower-rank coals, but it is about twice as liable to cause trouble as the Pittsburgh-bed and Eagle-bed samples. The average numerical values of the relative tendencies for these coals to heat spontaneously are given in the last column of Table 3.

56/ Schmidt, L. D., and Elder, J. L., Atmospheric Oxidation of Coal at Moderate Temperatures - Rates of the Oxidation Reaction for Representative Coking Coals: Ind. Eng. Chem. (Ind. Ed.), vol. 32, February 1940, pp. 249-256.

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TABLE 3. - Comparison of the tendencies of various coals to heat spontaneously during storage

Coal and source	Rank	Characteristic oxidation rate at 100° C. R_a (X=1)1/	Ratio to Pittsburgh-bed coal	Self-heating rate at 100° C., °C. per hr.	Ratio to Pittsburgh-bed coal	Average ratio to Pittsburgh-bed coal
Pittsburgh bed, Warden mine, Allegheny County, Pa.	High-volatile A	0.13	1	1.83	1	1
Eagle bed (prospect hole), Kanawha County, W. Va.	do	.12	.9	1.12	.6	.8
Elkhorn No. 3 bed, Wheelwright mine, Floyd County, Ky.	do	.27	2.1	4.0	2.2	2.2
Monarch bed, Sheridan County, Wyo.	Subbituminous B	3.32/	453/	143	78	62
Healy River coal, Alaska	Subbituminous C	.572/	7.73/	22.5	12.3	10
Velva mine lignite, Ward County, N. Dak.	Lignite	13.12/	177 3/	93	51	144

1/ Characteristic oxidation rate, the percentage of oxygen consumed per day at 100° C. in air after the coal has consumed 1 percent of its dry, mineral-matter-free weight of oxygen.

2/ The rate of oxidation, percentage of oxygen consumed per day at 100° C. in air after the coal has consumed 5 percent of its dry, mineral-matter-free weight of oxygen. For Pittsburgh bed, Warden mine, this value is 0.074 percent per day.

3/ Ratio of the oxidation rates after the coal has consumed 5 percent of its dry, mineral-matter-free weight of oxygen compared to Pittsburgh bed, Warden mine.

UTILIZATION OF COAL

Combustion

Fuel-Engineering Service

The Fuel-Engineering Service is a consulting service furnished by Bureau engineers to other Federal agencies with respect to the selection and use of fuels and equipment for burning fuels. Special surveys were made at the request of the Navy Department, the Department of Agriculture, the Veterans Administration, the Procurement Division, and a number of Government heating plants in the Washington (D. C.) area. A survey of the new power plant at Patuxent River Naval Station provided information for selecting the proper coal for use in this plant. Operation difficulties caused by the corrosion of tubes in two boilers at the Washington Navy Yard were investigated, and various changes were recommended as temporary measures to insure continued operation. Acceptance tests on new dust collectors and induced-draft fans at the Horticulture Station of the Department of Agriculture at Beltsville, Md., were completed. At the request of the Veterans Administration, efficiency calculations were made for proposed new boiler equipment at Lyons, N. J., and plants at Sheridan, Wyo., and Bowney, Ill., were studied to determine suitable types of stokers. Two heating plants of the Housing Administration in the vicinity of Arlington, Va., were examined to establish the best types of coal, changes in equipment, and operating routine and resulting recommendations were made to the Procurement Division. Proper routine operating practices were recommended at the heating plant of the Columbia Institute for the Deaf. Studies and resulting recommendations were made on equipment changes at the Capitol Power Plant and at the new power plant at St. Elizabeths Hospital. Investigations of stoker operations, burning of anthracite-bituminous coal mixtures, and possible carry-over of oil into the boiler were conducted at the District Building. Tests were made on a new incinerator in the Government Printing Office. An acceptance test was made of a new boiler feed-water heater at the Glen Dale Sanitarium, and necessary changes in operation were recommended. Consulting service was rendered various Government agencies on the analyses of bids and awards for the purchase of fuel and on related matters involving fuel purchases, as affected by war conditions.

Boiler Feed-Water Conditioning

Analyses and resulting recommendations were made for 18,685 samples of water submitted by Federal agencies during the fiscal year. This number was almost triple that of the previous year. A large part of the increase - 17,894 samples in all - was to insure adequate supplies of suitable waters for the War Department. Reports were made on analyses of 7 boiler compounds and 45 boiler scales, sludges, or deposits. Three hundred and ninety-nine special Bureau of Mines field boiler-water test kits, 11,361 bottles of chemical reagents, and 10,712 test-kit replacement items were distributed, mostly to Army posts in this country and overseas. A simple test kit was developed for determining the causticity of boiler water for boilers being operated overseas by the Army. An investigation was made for the War

Department on the causes of corrosion in return feed lines at Chanute Field in Illinois. A special research study of this problem is being continued at that field with the cooperation of the War Department. Plant surveys were conducted at the request of Gallinger Hospital, St. Elizabeths Hospital, the Home for Aged and Infirm, the Southwest Health Center, and the Garbage Reduction Plant to solve certain water problems. At the request of the Federal Public Housing Authority, an address on boiler feed-water conditioning was given in New York City before a called meeting of superintendents of various housing projects. Personal instruction in testing boiler water was given to operators at the National Training School for Boys, the Capitol Power Plant, and the District Building. At the request of the Procurement Division specifications for polyphosphates were formulated for use in the General Schedule of Supplies. Several new types of polyphosphates were investigated for possible use in Government plants. Consulting service on various other problems was given to 34 different Government establishments in Washington, D. C., and in 7 States.

Corrosion of steam-heating systems is due primarily to carbon dioxide, which acidifies the condensate. One method of preventing corrosion is to introduce enough amine into the steam to neutralize the acidity. The use of cyclohexylamine for this purpose has been studied both in the laboratory and in an operating system.[57] This amine is quite volatile and leaves the boiler with the steam relatively quickly after it enters with the feedwater. To maintain an alkaline condition continuously in the condensate at traps and heaters, frequent and preferably continuous additions of amine should be made to the system. Losses of the amine occur at vents in the system, quantities of the chemical being found in the vented vapors from the de-aerating heater. In a system that is amine-treated all of the carbon dioxide in the steam tends to be fixed in the condensate.

Cyclohexylamine treatment has helped to reduce the return-condensate corrosion in steam-heating systems. The amine probably can inhibit corrosion in the manner peculiar to the nitrogenous bases to which it is related. although this disadvantage is not unsurmountable, all of the defects in the use of cyclohexylamine in steam systems are due to its excessive volatility.

Smoke Abatement

Work was continued by a committee of the American Society of Mechanical Engineers on the formulation of a model smoke law. Agreements on various sections of the law were reached and assignments made for new work. A joint meeting was held with a subcommittee of the American Society for Testing Materials to coordinate certain features of the work. Consulting service was given representatives of Alexandria, Va., and of Salt Lade City, Utah, in connection with their smoke problems and development of proper methods of control.

57/ Berk, A. A., Observations on the Use of Cyclohexylamine in Steam-Heating Systems: Bureau of Mines Rept. of Investigations 3754, 1944, 42 pp.; abs. Combustion, vol. 16, August 1944, p. 51.

How to Save Fuel

Widespread demand for practical information that everyone can use in an effective manner to save fuel was met by additional publications[58] of a report which appeared in several other places during the fiscal year 1943.[59]

National Fuel Efficiency Program

Current requirements, estimated production, and distribution of fuels justify a thorough analysis of all factors involved in efficient fuel utilization or of the energy derived from it. Increasing difficulties resulting from the shortage of labor in the production, transportation, and distribution of fuel and from frequent break-downs of overloaded and worn-out equipment have focused direct attention on any and all means that may be used to conserve fuels and to improve their utilization. The National Fuel Efficiency Program was established to meet these objectives. Twelve leading fuel engineers were selected to serve as the National Fuel Efficiency Council. Plans were devised to carry out a fuel-conservation program by volunteer effort on the part of fuel users. These plans included dividing the United States into various areas, each of which is supervised by a volunteer coordinator. As of June 30, 1944, 111 coordinators - outstanding men in their respective communities - had been appointed. These coordinators appoint their own individual advisory councils, under whom are 5,000 volunteer "regional engineers." These engineers visit individual fuel-burning plants, obtain pledges of the management to cooperate in the program and to appoint one of their employees as a "waste chaser," and with the waste chaser inspect the plant to determine possible savings. The engineers also supply the plants with "quiz sheets." These short, thought-provoking questions-and-answer sheets were prepared by committees representing the best engineering thought of various industries of all phases of fuel burning and utilization of heat and energy. Subject items, including bibliographies for 20 quiz sheets, have been completed. Paid personnel in district offices at Chicago, Ill., and Indianapolis, Ind., assist the voluntary coordinators in an assigned district to further the general program. Interest in the National Fuel Efficiency Program is being evidenced by requests for talks before various national and local societies and groups in the larger cities. Free publicity on this program has been furnished by two-page advertisements in leading technical publications, as well as by write-ups in popular magazines, industrial "house organs," and press releases. Excerpts from addresses by Bureau of Mines personnel outlining the aims and progress of the National Fuel Efficiency Program were published.[60] The immense value of this broad program for conserving and

58/ Barkley, J. F., Prevent Fuel Waste For War: Factory Management and Maintenance, vol. 101, July 1943, p. 164; Pilbrico Firebox, July-August 1943, p. 11.

59/ Fieldner, A. C., Beltz, J. C., and Fisher, P. L., Annual Report of Research and Technologic Work on Coal Fiscal Year 1943: Bureau of Mines Inf. Circ. 7272, 1944, 58 pp.

60/ Fuel Efficiency Program: Smoke (Official Bull., Smoke Prevention Assoc. America, Inc.), vol. 11, No. 6, June 1944, 2 pp.