Suggestions included a gate instead of a removable cap on the baffled settling chamber for dumping the ash from the hopper and a side plate on the device to provide easy access to the interior.

Smoke Abatement

Work was continued by the Model Smoke Law Committee of the American Society of Mechanical Engineers on the preparation of a model smoke law. A summary to provide a basis for establishing dust-load limitations was made of test data on the amount of "dust" emitted in the products of combustion by different types of fuel-burning equipment at various loads and on the dust-catching efficiency of present-day dust collectors. Two meetings of the committee were held at New York City and one at Pittsburgh. A semifinal draft of all sections and comments covering about 5 years' work was completed; it is planned this coming year to complete the work now assigned to this committee. Consulting service on various problems connected with smoke abatement was given to city officials in Los Angeles, Calif., Washington, D. C., and Tacoma, Wash.

National Fuel Efficiency Program

Work was continued on establishing and maintaining a network of active volunteer coal-conservation workers. The chief objectives of the program centered around a Nation-wide effort to conserve all fuels through their more efficient utilization. The program was under the general guidance of the National Fuel Efficiency Council, composed of fuel engineers of national reputation. The council held two general meetings during the year and carried out many individual assignments. Some 190 coordinators directed the program on fuel conservation in their individual areas. About 830 engineers and industrialists of outstanding reputation locally served on advisory committees of the various coordinators. Some 5,000 volunteer engineers made plant surveys and obtained the cooperation of more than 13,000 plant owners and organizations, who then appointed employees as "waste chasers" in individual plants to direct the engineering work of saving fuel. In addition to the personnel of the Washington, D. C., central office, district engineers, with offices at Chicago, Ill., Indianapolis, Ind., and Kansas City, Mo., and two other district engineers visited the coordinators and their committees as aides in establishing and maintaining the program in all of the areas.

Various general meetings were held in different cities, and talks were made before both national and local societies and groups. Appropriate literature was prepared to acquaint operating personnel with the best methods of operating power and heating plant equipment to effect maximum fuel conservation. Twenty-nine new waste chasers' quiz sheets were issued during the fiscal year. Upon requests, a total of 1,244,804 copies of these 29 and 16 other earlier-published quiz sheets were distributed; a total of 363,798 copies of single-sheet explanatory memoranda accompanied 10 of the quiz sheets. Three new quiz sheets are in press, and 5 are in preparation. Check sheets numbering 16,275 copies on industrial furnaces, 17,443 on heating plants, and 49,301 on industrial boiler plants were distributed to the waste chasers. A total of 1,150 copies of Recommended Procedure for Coordinators and 54,223 copies of the Brief of Regional Engineer's Procedure[61] were distributed. Publicity on the National Fuel Efficiency Program was furnished gratuitously by many companies. This publicity was in the form of 4 colored posters, 67 articles in industrial and technical publications and house organs, advertising space in magazines, and a broadcast over a national radio hook-up; posters distributed by request numbered 54,223. Three hundred copies of 3 publicity press releases were distributed to all new coordinators for publication in local newspapers. Nine press releases covering the development of the program were distributed to the general press through the Office of War Information.

As an example of how the campaign to save fuel operates, the field survey work in plants in one district of the Pittsburgh, Pa., area will be summarized briefly. Seventy-five man-days were spent in the field inspecting 146 heating plants. The territory covered was predominantly residential; 77 of the visits were made to apartment houses burning an average of 185 tons of coal each per year. Other plants, such as hospitals, schools, central heating plants, and commercial establishments, had higher average consumption; the total annual tonnage burned in all plants inspected was 74,600. No relationship could be detected between the size of the plant and the efficiency of operation or the physical condition of the equipment. The fuel savings possible, therefore, appear to be nearly independent of the size of plant in the range of 50 to 15,000 tons annual consumption of coal. Based on estimated savings possible, approximately 6,500 tons of coal could be conserved in this one Pittsburgh district or 87 tons of coal saved per man-day of inspection time if the recommendations of the regional engineers were followed.

Among the many articles describing the work of the National Fuel Efficiency Program, the following may be mentioned as representative.[62]

Properties of Coal Ash as Related to Clinkering and Slagging

Excessive accumulations of slag on the heat-absorbing surfaces of large central-station boiler furnaces often cause difficulties in operation and interfere seriously with the expected transfer of heat from the furnace through the boiler tube to produce steam. As a result, not only may the circulation

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61/ Brief of Regional Engineer's Procedure: Nat. Eng., vol. 49, March 1945, pp. 196-198.

62/ Cheasley, T. C., Work of the National Fuel Efficiency Program: Min. Cong. Jour., vol. 30, December 1944, pp. 26-28; Proc. Illinois Mining Inst., Oct. 27, 1944, pp. 24-29; discussion, pp. 29-31; Smoke (Official Bull. Smoke Prevention Assoc. America, Inc.), vol. 11, June 1944, 2 pp.
Barkley, J. F., Fuel Conservation: Manual of Instructions on Proper Firing Methods (Official Pub., Smoke Prevention Assoc. America, Inc.), 1945, pp. 1-12.
The National Fuel Efficiency Program: Solid Fuel Eng., vol. 3, August 1944, pp. 8-10; Nat. Eng., vol. 48, September 1944, pp. 588-604; October 1944, pp. 641-656, 673; vol. 49, April 1945, pp. 278, 280; Heating, Piping, and Air Conditioning, vol. 16, November 1944, pp. 65, 66, 621, 628, and 640; The Rochester Engineer, vol. 23, January 1945, p. 93.

of water and steam within the boiler be affected, with possible damage to some tubes, but superheat control is difficult, and oftentimes the output of the boiler must be decreased to permit operation within safe temperature limits. Cleaning of these badly fouled surfaces during operation usually requires excessive labor; if the deposits occur in inaccessible locations, it is often necessary to shut down the boiler, with resultant loss of steaming capacity of the power plant. Studies over the past several years of the physical properties of coal-ash slags at high temperatures have furnished much needed fundamental information from which it has been possible to analyze the factors controlling the thickness of these slag deposits.[63] Such factors are divided into two classes, one fixed by the properties of the slag and the other dependent upon furnace conditions. For the slag, not only is the viscosity of the liquid portion important, but also the "temperature of critical viscosity" at which the slag changes from a fluid to a plastic state on slow cooling. Since both the viscosity and the temperature of critical viscosity are related to composition, it is possible to predice the relative thickness of slag deposits for different slags of known composition under idealized furnace conditions. Figure 16 shows the relative thickness of slag deposits of a wide range of compositions in terms of the total iron content computed as Fe_2O_3, the amount of CaO present, and the ferric percentage, which is a measure of the state of oxidation of the iron forms. Although computed for the case where the furnace side of the deposit is at a temperature of 2,800° F. and the cold side in contact with the tube is at 1,200° F., similar plots can be made for other furnace conditions. In general, for fixed furnace conditions, increased temperature of critical viscosity and increased viscosity of the slag cause approximately equal increases in the thickness of the slag deposit. However, as the temperature of critical viscosity approaches that of the furnace side of the slag deposit, there is a large increase in thickness, independent of the viscosity. Increase in the iron content of the slag, as well as increase in the fraction of the iron in the ferrous state, decreases the thickness of the deposit. The relative thickness is also decreased by increase in the CaO content, the effect being greatest with slags containing less than 20 percent equivalent Fe_2O_3.

Thermal Conductivity of Coal-Ash Slags

To obtain data on the rate at which heat is transferred through deposits of coal-ash slags, and to furnish information on slag characteristics to better understand the action of slag in large industrial furnaces, a study is being conducted in cooperation with the Special Research Committee on Furnace Performance Factors of the American Society of Mechanical Engineers. Design and construction of the experimental apparatus is now 95 percent complete. Methods of measuring the thermal conductivity of liquids are more difficult than with solid materials, and problems resulting from measuring temperatures as high as 2,700° F. further complicate the design of equipment. The principle used is to confine the molten slag in the annular space between two concentric platinum alloy cylinders; thermocouples attached to the cylinders

[63] Reid, W. T., and Cohen, P., Factors Affecting the Thickness of Coal-Ash Slag on Furnace-Wall Tubes: Trans. Am. Soc. Mech. Eng., vol. 66, 1944, pp. 685-690; abs. Combustion, vol. 16, July 1944, pp. 42, 44.

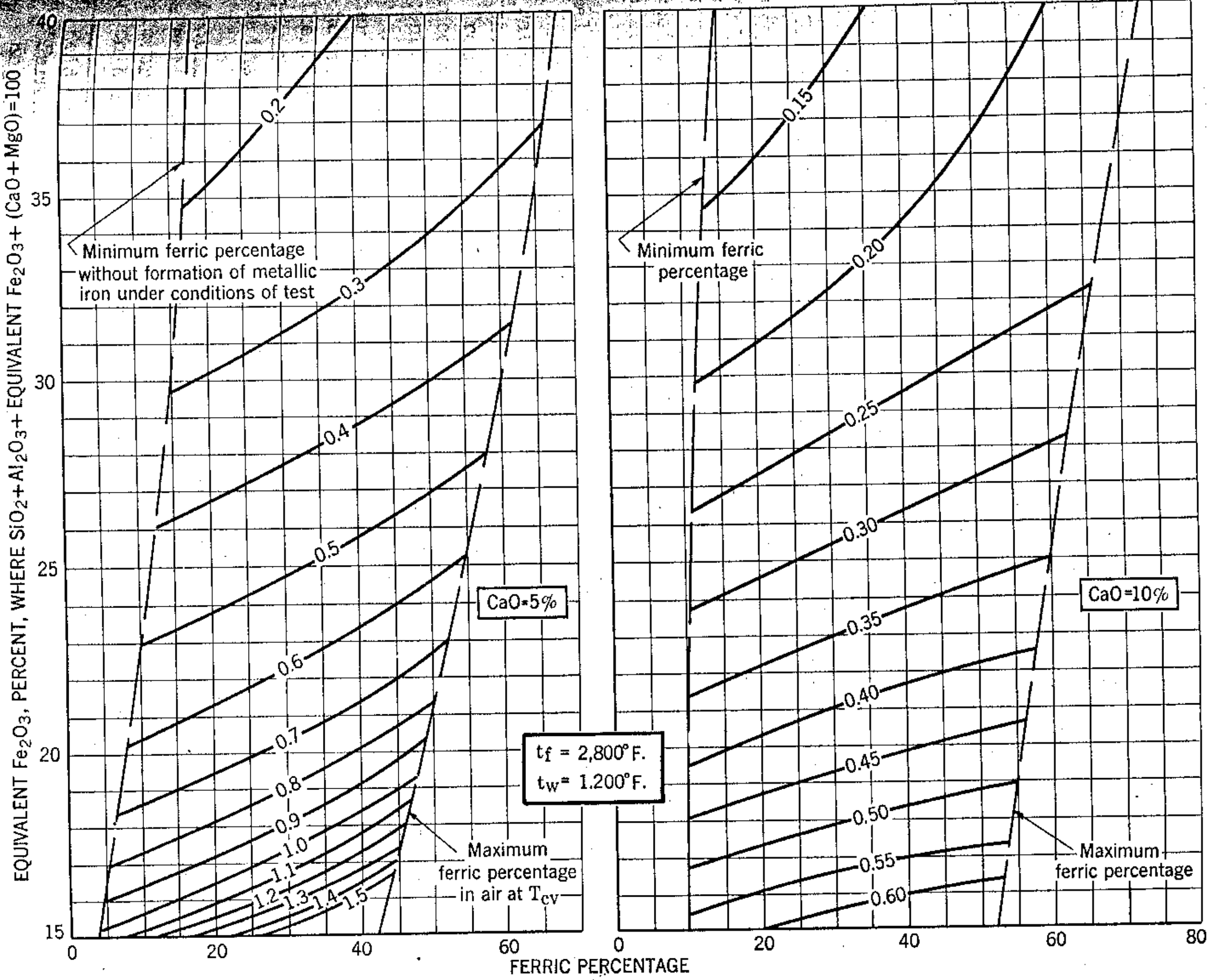

Figure 16. - Relative thickness of slag deposits as a function of composition and ferric percentage for a silica : alumina ratio of 2 : 1.

permit measurement of the thermal gradient due to the flow of heat from the inner to the outer cylinder through the slag, the heat being generated by a small platinum resistor inserted in the inner cylinder. Although the design of the concentric cylinder cell was based on mathematical analyses, a large number of tests at room temperature with model cells constructed of brass and using water as the liquid were necessary to obtain correct location of thermocouples and proper arrangement of the internal heater. Based on these tests, it is expected that the cell will permit measurements of thermal conductivity with an error not exceeding ± 5 percent. Assembly of other apparatus has been completed, including a multiple-wound furnace in which the temperatures does not vary more than 2° F. along a 6-inch length at 2,600° F. The special platinum cell has been received, as well as the intricate porcelain shapes necessary for spacing and support of thermocouples and the internal winding.

External Corrosion of Furnace-Wall Tubes

Since 1942 many large central-station boiler furnaces burning pulverized coal and removing the ash as molten slag have experienced severe loss of metal from the external surfaces of the tubes making up the walls of the furnace. An investigation in cooperation with the Combustion Engineering Company, in which 16 furnaces in 13 stations were examined, showed that this corrosion was associated with two distinct types of deposits,[64] one of which consisted largely of sodium and potassium sulfate in a complex form, and the other of iron sulfide. This corrosion was found to occur at temperatures normal for furnace-wall tubes, usually not exceeding 700° F., while the maximum temperatures observed did not exceed 900° F. Rates of heat release and the rated capacity of the boilers in which corrosion was found were nominal, and the rate of heat transfer in corrosion areas was not essentially different from that in adjacent areas where there was no loss of metal. One difference noted was the presence of carbon monoxide in amounts up to about 5 percent in areas where corrosion was occurring, but this was taken to indicate the presence of flame from which the alkali metals could be condensed, rather than as a constituent in the corrosion eeaction. Although corrosion was usually found to be active beneath deposits of slag, it was considered unlikely that the slag itself was reacting with the tube surface, since the temperature at the interface was approximately 1,000° F. lower than that at which the slag becomes a solid on cooling.

Studies of the sulfate types of deposit[65] showed it to consist largely of a solid solution of sodium and potassium sulfates and complex alkali-metal ferric trisulfates, such as $K_3Fe(SO_4)_3$. It was shown that the deposits occurring on boiler tubes in the corrosion areas could be reproduced in the

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64/ Reid, W. T., Corey, R. C., and Cross, B. J., External Corrosion of Furnace-Wall Tubes - I. History and Occurrence: Trans. Am. Soc. Mach. Eng., vol. 67, 1945, pp. 279-288.

65/ Corey, R. C., Cross, B. J., and Reid, W. T., External Corrosion of Furnace-Wall Tubes - II. Significance of Sulfate Deposits and Sulfur Trioxide in Corrosion Mechanism: Trans. Am. Soc. Mech. Eng., vol. 67, 1945, pp. 289-302.

laboratory by heating a mixture of sodium or potassium sulfate and iron oxide at temperatures up to 1,000° F. in an atmosphere containing small amounts of SO_3. These reactions suggested that the mechanism of corrosion involved the removal of the normally protective oxide on the furnace tube by (a) condensation on the relatively cool tubes of alkali-metal oxides from the flame in the furnace, these oxides being converted to the sulfate by the small amount of SO_3 normally present in the furnace gases, and (b) subsequent reaction of the iron oxide on the tube and the alkali-metal sulfates with the larger amounts of SO_3 evolved as the result of slagging reactions in the coal ash deposited mechanically in that area. Figure 17 illustrates the entire series of reactions, including the final state at E, where deslagging has removed the slag layer and exposed the reaction products to high temperatures, causing their decomposition. To prevent external corrosion, it would be necessary (a) to use a tube or to protect its surface with a metal or alloy which alkali-metal sulfates and SO_3 do not affect, or (b) to prevent these constituents from reaching the tube surface in sufficient concentration to be dangerous. By means of burner changes or "air-belting," the tube surfaces, in some instances, have been sufficiently well ventilated with air to prevent further corrosion. It is believed that the beneficial results are principally from dilution and that the disappearance of carbon monoxide at the point of corrosion can be taken as evidence of ample ventilation. Experimental evidence is lacking on the need of flame contact to deposit alkali-metal oxides or sulfates on the tube surface. If it is shown that the flame envelope is the principal source of the alkalies, then the presence of air along the wall would prevent deposition of alkalies and effectively stop further corrosion. Work is being continued on this phase, as well as on the mechanism of formation of the sulfide-type deposits.

Utilization of Mixtures of Bituminous Coal and Anthracite

The Solid Fuels Administration for War has encouraged the use of anthracite fines: (1) To alleviate the general fuel shortage in the Eastern states; (2) to find increased markets for the fines incidental to the production of domestic sizes of anthracite; and (3) to relieve the acute shortage of low-volatile bituminous coking coal by decreasing the quantity required in coke-oven mixes through the substitution of anthracite fines. The Bureau of Mines has cooperated in the technical problems involved to meet these objectives.

Plant studies and tests were continued throughout the Eastern Seaboard regional headquarters of the War Department. This work included an initial survey, a general plan of procedure, and training of plant operators. Where it appeared that anthracite fines could be added, further tests were made on mixtures with bituminous coal; this work resulted in the continued use of anthracite fines at many plants using 30 to 50 percent of anthracite. At many plants, studies showed that too many boilers were being used to carry the load; much equipment, particularly control equipment, was not in proper working order; and low efficiencies were being obtained. In all instances, higher efficiencies and, consequently, large annual savings resulted from the work. Examples of these savings included: Fort Devens, Mass., laundry plants, $5,000; Lovell General Hospital, $8,500; Waltham General Hospital, $15,500; and Presque Isle, Maine, laundry and hospital plant, $21,700. Mixtures of bituminous coal and anthracite were used successfully

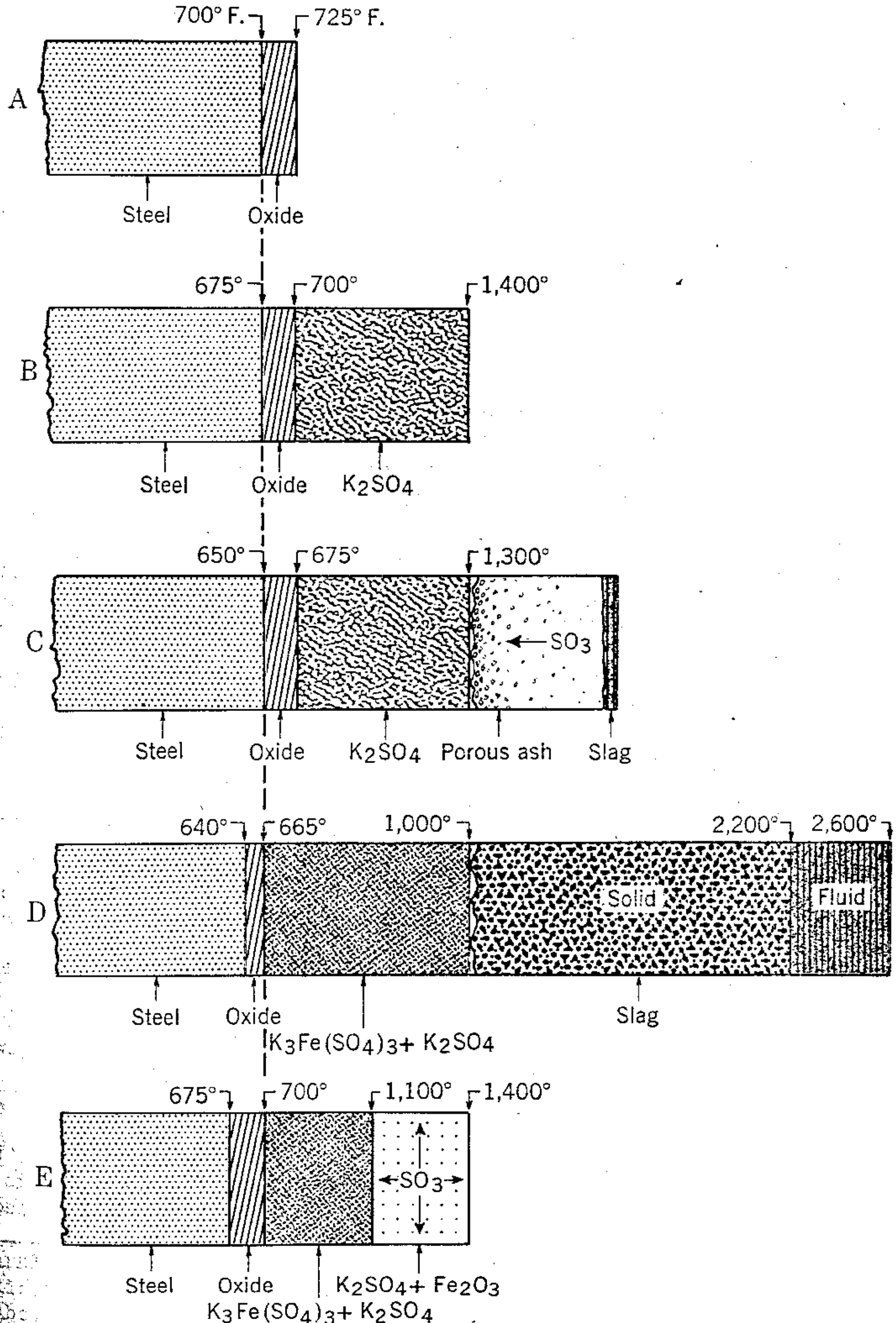

Figure 17. - Mechanism of corrosion of wall tubes by sulfate deposits.

at several Navy Department land projects in the Eastern area; at Bainbridge, Md., a 50:50 mixture is used in all the equipment.

From these studies an appreciable amount of new technical information was developed and published.[66] This paper summarizes the results of Bureau of Mines work on four projects: (a) The burning of mixtures of small anthracite and bituminous slack coal on stokers; (b) methods of producing and burning "packaged fuel" made from anthracite fines; (c) the use of anthracite fines in the production of coke; and (d) the use of barley anthracite (No. 3 Buckwheat size) in gas producers.

Burning of mixtures of barley anthracite and bituminous slack on underfeed stokers showed that an addition of about 15 percent of anthracite was usually enough to reduce caking. Increased percentages of anthracite decreased the pressure drop through the fuel bed, decreased the manual attention to the fuel bed, decreased the smoke, increased the fly ash, increased the unburned combustible in the fly ash and refuse, and, in general, improved the clinkering conditions. The load-carrying capacity of the stoker was affected by the relative proportions, compositions, and properties of anthracite and bituminous coal present. In general, the efficiencies obtained on single-retort stokers with a reasonable range of anthracite admixtures were about the same as with straight bituminous coal.

Cooperative experiments by the Bureau of Mines and a large industrial company were conducted on the manufacture and testing of coal blocks containing various percentages of anthracite fines. Physical and chemical properties and burning characteristics of packaged fuel produced in experimental runs indicated that large percentages of anthracite fines could be successfully briquetted with bituminous coal by use of an asphaltic binder. As a result of these research and technical studies, a commercial plant for the production of packaged-coal blocks, with a capacity of 150,000 tons per year, was erected at Philadelphia Pa. The first run used a mixture of about 80 percent anthracite, 15 percent bituminous coal, and 5 percent asphaltic pitch.

The results of studies of the use of anthracite fines in coke-oven mixes for the production of coke and of the use of barley-size anthracite for gasification in gas producers will be discussed under Carbonization and Gasification, pages 93 and 101.

Burning Solid Fuels on Traveling Grates

As a part of its extensive studies on burning solid fuels on grates, the Bureau of Mines investigated the factors affecting the burning of fuels on cross-feed principle.[67] This paper describes the study of ignition travel

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66/ Barkley, J. F., and Seymour, W., The War Problems of Increasing the Utilization of Small Anthracite: Mech. Eng., vol. 67, 1945, pp. 457-462. Abs. Combustion, vol. 16, July 1944, p. 41; Coke and Smokeless-Fuel Age, vol. 6, December 1944, p. 240.

67/ Carman, E. P., and Reid, W. T., Ignition Through Fuel Beds on Traveling- or Chain-Grate Stokers: Trans. Am. Soc. Mech. Eng., vol. 67, 1945, pp. 425-463; discussion, pp. 436-437.

through a fuel bed and the important factors affecting it. The investigation was conducted in relatively small-scale laboratory apparatus where the many variables involved were subject to close control. The study showed that in fuel beds on traveling-grate stokers ignition and burning proceed according to unrestricted underfeed principles until ignition reaches the grate. At constant air rate, underfeed ignition proceeds at a steady rate unless certain factors alter the **air** distribution or fuel-bed characteristics. These factors include development of blowholes, with consequent maldistribution of air; turbulence or "boiling" of the bed, which may give mechanical mixing of ignited and unignited fuel; slow initial ignition; drying of moist coal before ignition; heating of coal with preheated primary air; and burning of highly reactive fuels in very thin burning layers. After ignition reaches the grate, burning is overfeed, and increase of air will give proportional increase of burning rate, at least within the range where stable bed conditions prevail. Slow initial ignition of the top layer of fuel on traveling-grate stokers is followed by relatively slow rates of ignition travel through the bed, being slowest at the top, increasing with progress of ignition into the bed, and tending to approach, as ignition nears the grates, the steady, higher ignition rates found with rapid initial ignition. Rates of ignition as affected by added moisture, size of fuel particle, preheating of primary air, ash content of coal, and the use of high-temperature coke, coke breeze, anthracite, high-volatile A and C bituminous coals, subbituminous B coal, and lignite were thoroughly considered in relation to air rates, burning rates of the fuel, and fuel-bed characteristics.

Certain factors affecting the burning of solid fuels on traveling grates were studied further during the past fiscal year. Tests were made on raw and on steam-dried lignite and on a Pennsylvania low-volatile bituminous coal. Observations of these thin fuel beds corroborated previous evidence that, with highly-reactive fuels where the burning layers are very thin, the effect of loss of heat to the environment is important in controlling the rate at which the plane of ignition travels through the raw fuel. Thus, the temperature of the furnace itself will affect the rate of travel of the plane of ignition by influencing the heat lost from the fuel bed by radiation; even decreased heat losses resulting from an overlying layer of spongy clinker increased the rate of travel perceptibly.

Because of the importance of disposing usefully of the smaller sizes of coal, a study was made of the burning properties of coals in sizes smaller than 3/32-inch to determine the limitations under which such coals can be burned successfully in this type of equipment. Such information is valuable not only during periods of fuel shortages such as resulted from the war, but also to improve the economic status of coal utilization during peace times by preventing needless waste of a useful product. Problems in the utilization of small coals and the recovery through up-grading of useful fuels from otherwise wasted colliery refuse in England and comparisons with certain American practices were reviewed.68/

68/ Reid, W. T., Review of "Proceedings of a Conference on Problems in the Utilization of Small Coals" (Brit. Coal Util. Research Assoc., London, Cheney and Sons, Branburg, England, 1944, 294 pp.: Jour. Appl. Physics, vol. 16, May 1945, p. 312