The operation is favored by a low labor rate and a large proportion of refuse in the raw product affording simple opportunity for effective reduction in refuse and saving in handling charges by the initial cleaning operation.

Even with these favorable conditions, preliminary hand picking does not justify itself economically, principally because of loss of coal (presumably recoverable in part if transported to washery) in the refuse.

However, as a means of preparing railroad fuel, the method appears to be particularly adapted to this field because it results in a product admirably adapted to hand firing so far as size is concerned.

Also, the burning characteristics of the fuel are substantially improved, probably more than would appear just by examination of the ash content. Although there is generally a reduction of 4 percent of ash by hand picking, this involves removal of about 10 percent of noncombustible refuse, which greatly improves the practical burning characteristics of the fuel.

STORAGE OF COAL

Information on coal storage and consulting service on coal-storage problems were given various industries and government establishments. Studies are now being made of approximately 11,000 field experiences in storing different kinds of coal.

Storage of Low-Rank Fuels

Subbituminous coal can be stored successfully in open pits if precautions are taken to minimize entrance and circulation of air. During 4 years of observations on methods for storing subbituminous coal, involving the handling of about 30,000 tons of slack coal, it was demonstrated that storage in large open pits is feasible, and the loss of heating value of the coal is as low as 1.5 percent in 1 year.[43]

When coal is stored in several benches 2 to 3 feet thick in a pit made either of concrete or earth, the only entrance of air to augment heating or to support spontaneous combustion is from the top of the pile. If the coal is compacted as each bench is placed, a resistance to flow of air is set up, and thereafter the rate of air entering the coal is not rapid enough to support spontaneous combustion, and the rate of oxidation is low. As air enters the coal by diffusion, it combines with the coal to form CO_2, but some oxygen is absorbed directly by the coal without forming gaseous products of reaction, and it adds to the weight of the coal. The result is a slight increase in weight and a corresponding decrease in heating value. If the entrance of air is impeded further by a cover of fine coal or a veneer of asphalt, the coal is immersed in a water-saturated atmosphere of

43/ Goodman, John B., Parry, V. F., and Landers, W. S., Storage of Subbituminous Slack Coal in Open Pits: Bureau of Mines Rept. of Investigations 3915, 1946, 37 pp.

CO_2 and N_2. No degradation can occur unless there is slight oxidation resulting from air entrained by changes in temperature and barometric pressure.

Practical tests of these theories were made in cooperation with the Great Western Sugar Co., which was interested in finding a safe way to store coal without immersing it in water. Each year this company stored 150,000 to 200,000 tons of coal under water. However, some of the pits have developed leaks and can no longer retain water without excessive maintenance costs. Storage trials were made over a 3-year period to determine the best procedure for placing and retaining the coal for periods of about 8 months.

In 1942, a small concrete pit was used to conduct preliminary studies on the behavior of coal in dry storage. Two hundred tons of subbituminous slack coal was placed in 3-foot benches and compacted by leveling and raking. No troubles developed, and there were no significant changes in physical or chemical properties.

During 1943, 13,000 tons of coal was placed in 4-foot benches in dry storage in a large pit at Brush, Colo., where it was observed periodically to determine behavior and condition. A few local hot spots developed as the result of errors made in placing the coal, but, again, there was no serious trouble. It was observed during this storage trial that almost all oxygen beneath the coal surface disappeared after a few weeks and the coal was enveloped in inert gases. A few hot spots developed near the surface, and these were traced to areas where the coal was segregated and not properly compacted. A few hundred pounds of coal was lost that year, and the average heat loss due to oxidation was estimated to be 1.0 to 2.0 percent.

The same pit was used the following year, but greater care was exercised in cleaning the empty pit and in compacting the coal in 3-foot benches. About 15,000 tons of coal was stored in the pit, and a bulk density of 56 pounds per cubic foot of coal was attained by careful leveling and packing of each bench. This coal remained in storage for 8 months without trouble. Periodic observations were made to determine the temperature history and the composition of gases within the coal. It was generally concluded that the procedure employed was adequate for safe storage of low-rank coal.

Several characteristics of the storage of subbituminous slack coal in open pits were observed. Self-heating is accelerated during the first 3 weeks of storage, and the temperature rises at a rate of 2° to 3° F. per day until a temperature of 100° to 130° F. is reached. Thereafter, the temperature tends to level off and to decrease until the coal is removed. It is indicated that during the first 3 weeks of storage the rate of oxidation is relatively rapid; however, the reaction slows as the concentration of oxygen diminishes. The temperature in the coal is highest near the surface, where air enters by diffusion, and decreases with the depth of the coal. Products of oxidation, consisting of approximately 12 percent carbon dioxide, 87 percent nitrogen, traces of oxygen, and other gases, fill the void spaces of the pit after a few weeks in storage, and thereafter losses by oxidation are minimized. About 45 percent of the oxygen passing into the coal mass is absorbed by the coal, and the net decrease in heating value is 1.0 to 2.0 percent over a period of a year.

In storing subbituminous coal in open, dry pits, the following general points should be considered:

1. The walls of the storage pit should be tight, preferably made of concrete or excavated in dense earth or clay.

2. It is important to avoid segregation of sizes in the coal as it is being unloaded or placed in the pit. The accumulation of zones of fine and coarse coal provides air entry courses, which will supply oxygen to the interior of the stored coal. The entire mass of stored coal should be as homogeneous as possible.

3. In placing the coal in the pit, care should be taken to store it in shallow benches 2 to 3 feet in depth. Observations have shown the latter to be both practical and economical. Each bench should be leveled and compacted to as high a packing density as is practical. A bulk density of 56 pounds per cubic foot can be attained readily with slack coal.

4. It has been demonstrated that uniform compaction of the pit should be practiced, taking care of the marginal edges as well as the inner areas. Remnants of old coal remaining from the previous storage should be spread out in thin, uniform layers over the bottom of the pit before benches of new coal are placed in storage. Observations have revealed that snow, weeds, and other debris that have accumulated on the bottom of the pit or on benches of coal should be removed before any new coal is placed, as they preclude dense packing and eventually become loosened void spaces, which enable air to circulate.

5. The finished stored coal should be level in appearance and, if possible, flush with the top edge of the pit walls to avoid entrainment of wind currents. Valleys and peaks appearing on the surface of the storage pile should be leveled, because irregularities will catch wind currents and will induce air circulation to cause self-heating.

6. In a pit with tight side walls, air can enter only through the top surface. To impede movement of air into the coal mass, the surface should be compacted by rolling or scraping to break down the top few inches of slacked coal into fines.

UTILIZATION OF COAL

Combustion

Fuel-Engineering Service

Fuel engineering service to government establishments in the inspection, selection, and use of fuels and fuel-burning equipment was continued. At the request of the Veterans Administration, total operating cost comparisons were made when using oil, gas, and coal, and the type of fuel-burning equipment was recommended for 38 new projects.

At the request of the War Department, a fuel engineer was sent to the Ninth Service Command, West Coast Area, to study the operating conditions of the heating plants of that area. Vancouver Barracks, Barnes Hospital, Fort Lawton, Port of Embarkation, Vancouver General Hospital, Baxter General Hospital, and Fort Lewis, all in the State of Washington; Camp Adair, Oregon; Fort Douglas, Utah; Chico Army Air Field, Camp Beale, and installations in San Francisco and Sacramento, California, were visited. At many plants he found that the boilers were running at the extremely low ratings of 25 to 30 percent. The ratings were increased with resulting improvement of efficiency of about 10 percent. In one instance, an extreme case at Baxter General Hospital, coal consumption was reduced 50 percent, saving 65 tons per month. Boiler-room instruments were corrected and put in operation, keeping of daily records was begun, stokers were adjusted, and operators were trained.

At the request of Howard University, the possibility of their purchasing part of their electric current was studied; consideration was also given to the possibility of enlarging the present heating plant to provide the necessary heat for a number of new buildings. Consulting and inspection service was given regarding the new heating plant of the Bureau of Mines at Bruceton, Pa., as to installation of boilers, brickwork and fuel-burning equipment, and type of boiler-water treatment. Consulting service as to the purchase of fuel appropriate for the equipment was given the Justice Department and Office of Indian Affairs for all of their plants and also for a number of plants of the Federal Public Housing Authority, the Veterans Administration, the War Department, and the Navy Department. At the request of the Procurement Division, recommendations were made as to specifications for Federal purchases of charcoal and coke. Consulting service on various special problems was given some 30 different government agencies.

Work was continued on the research at the power plant of the Washington Navy Yard, where unusual accumulations of deposits and corrosion on boiler tubes were occurring. As these deposits consisted largely of various types of sulfate compounds, an investigation was made as to the amount of sulfur trioxide in the products of combustion under various operating conditions. In the attempt to use the code method of the American Society of Mechanical Engineers for making this determination, it was found that satisfactory results could not be obtained. The inhibitor used in the test to prevent oxidation of the sulfur dioxide to sulfur trioxide would not maintain its effectiveness. After extended studies, important modifications of the test code method were developed that, as far as studied, permit satisfactory and reproducible results. A series of tests was then made to determine the sulfur trioxide in the products of combustion from two different types of stoker-fired boilers operating at different ratings. Calculations of these data have not yet been completed. It is planned to vary certain operating features of the stokers to reveal the exact operating conditions under which the deposits are at a minimum. The studies to date have made possible much better operating conditions from the standpoint of boiler outage and corrosion.

Cooperating with the Commonwealth of Pennsylvania, test equipment and procedures at the Philadelphia State Hospital, Philadelphia, Pa., were studied to determine the comparative economy of burning low-ash and high-ash anthracite barly on McClave stokers under water-tube boilers.

The cooperative work with the Air-preheater Corporation, New York City, on the study of deposits and corrosion in air preheaters was continued. Studies were made of the accumulation and type of deposits and resulting corrosion on air-preheater plates from installations in New York and New Jersey. In all cases, the deposits were acid and belonged to a family of sulfate compounds. A number of experimental plates of many different types of material were installed at a plant in Indianapolis, Ind., for the purpose of making comparative studies. Special studies are also being made at a plant in New Jersey where the air preheater is subjected to unusually high temperatures. Problems of continuous cleaning of the air preheater plates are being studied, using air and steam saturated and also superheated. Correlation of the deposits and corrosion difficulties is being made with different types of fuel and fuel-burning equipment.

National Fuel Efficiency Program

Owing to the withdrawal of funds for all war projects, work on the National Fuel Efficiency Program ceased early in the fiscal year. The work of the same general nature as described in the annual report for the fiscal year 1945 was continued for about 2 months. Although officially closed in the central offoce at Washington, volunteer activity in the field was continued even as late as March 1946 by individuals, on their own initiative, who considered that work on fuel conservation should be carried on in their particular areas. Considerable literature was prepared, some thirty articles appearing in the press, of which representative articles are listed.[44]

[44] National Fuel Conservation and Smoke Abatement. Address by R. R. Sayers, Director, Bureau of Mines, read at the convention of the Smoke Prevention Association of America, Inc., at Columbus, Ohio, October 17, 1945, and published in Proceedings of the Smoke Prevention Association of America, pp. 15-19, incl; Solid Fuel Engineer, vol. 5, No. 5, pp. 6, 7, and 8, Feb. 1946; and Mechanization, vol. IX, No. 12, pp. 133 and 135, Dec. 1945.
Saving Fuel is Good Business. Article on the National Fuel Efficiency Program published in Heating, Piping and Air Conditioning, vol. 17, No. 11, p. 623, Dec., 1945; vol. 18, No. 1, Jan., 1946.
Barkley, J. F., Points to Remember in Operation of Boiler Plants: Solid Fuel Engineer, Oct. 1945, p. 5.
Barkley, J. F., Some 1945 Ideas About the Use of Coal for Locomotives. Proceedings, Railway Fuel and Traveling Engineers Association, 1945, pp. 134-152.

Good cooperation was had with industrial and publishing concerns on publicity matters. Ten publishers of magazines requested complete files of the quiz sheets and expressed their intention of publishing many of them. Material was prepared for inclusion in an Illinois Central Railroad movie film on fuel conservation. A National Fuel Efficiency Program "slug" was completed for inclusion in the general advertisements of industrial concerns. A number of concerns agreed to carry the small "slug" in some appropriate corner of their advertisement.

Thousands of fuel-consuming plants were visited by volunteers throughout the United States, 15,858 signed pledges of cooperation being returned to Washington. The plants and buildings represented in this group consumed approximately 100 million tons of coal equivalent. A great number of instances of individual savings were reported to Washington, ranging from a few percent of the fuel up to some 40 percent. Based upon such reports as received, it is apparent that about 5 million tons of coal equivalent was being saved per annum during the last 12 months of the program's life. Had the program been continued under the impetus built up, it is believed that a much higher per annum saving would have accrued in the next 12 months.

Recognition of the fine work done by thousands of volunteers was given to the extent possible. Commendatory certificates were given to the members of the advisory National Fuel Efficiency Council and to scores of Coordinators heading up individual areas in the United States. A somewhat similar commendatory card was given several thousand volunteer regional engineers. A great number of individuals and organizations expressed their satisfaction in having been associated with this work, and many expressed their opinion that a national fuel-efficiency program should be a peacetime effort of the Federal Government.

Boiler Feedwater Conditioning

Analyses and resulting recommendations were made on 13,404 samples of boiler water during the fiscal year, as follows: 11,800 from the War Department; 707 from the Veterans Administration; 266 from the Office of Indian Affairs; 265 from District plants; 178 from the Department of Justice; 54 from the Public Health Service; 43 from the National Housing Agency; 43 from the Post Office Department; 19 from the Navy Department; 15 from the Department of Agriculture; 8 from the Commerce Department; 4 from the Federal Works Agency; and 2 from the National Advisory Committee for Aeronautics. Special analyses with recommendations were made on 12 samples of various types of water for the War Department, Veterans Administration, and Public Health Service. Reports and recommendations covering 15 analyses of various scales, sludges, and deposits and 7 covering analyses of boiler compounds were made for government agencies. Two hundred and thirty five special Bureau of Mines field water test kits, 12,321 bottles of chemical reagents, and 14,448 test-kit replacement items were distributed to various government activities. At the request of the District Government, an acceptance test was made on a Zeolite softener installed at Gallinger Hospital. At the request of the Post Office Department, cooperative arrangements were completed to clean condensate lines at the new city post office, Washington, D. C.; some of these lines are in concrete columns and are nearly filled with rustlike deposits. Consulting service was given the District Government on corrosion control in oil-fired boilers used in a number of high schools, the Public Health Service on corrosion from distilled water, and the Washington National Airport on corrosion control in high-pressure drips. At the request of the Transportation Corps Board of the Army, a study was made of a type of organic compound being used to treat locomotive-boiler water at all posts; a report was submitted to the Army explaining the action of this compound in boiler water and why it could not be so used universally. Instructions on boiler-water treatment and testing were given operating engineers at numerous government heating plants. Studies were made of the effect of boiler-water sludge on determining the values of total dissolved solids by hydrometer; on changes of the chemical composition of boiler-water samples between the time of sampling and analysis; on methods for eliminating the interference of tannin in colorimetric tests for phosphate; on the stability of stannous chloride reagents; on the determination of total dissolved solids in boiler waters by electrical conductivity; and on the determination of chloride in boiler waters containing tannin.

Boiler Water Research

Field studies were made with special corrosion-test apparatus in condensate lines, which gave further information on the corrosiveness of condensate-containing carbonic acid; it was shown that corrosive rates are satisfactorily reduced when the acidity is neutralized with an amine having proper volatility and alkalinity. The knowledge gained during the study of the physical and chemical behavior of one amine, cyclohexylamine, in the steam system has permitted material economies in using the amine treatment and has extended its application to systems for which it had previously been regarded as being too expensive. New applications will be made at many of the veterans hospitals, where the increased costs of boiler-water treatment can readily be justified in preventing failures and unscheduled outages, which cannot be tolerated in hospitals. The field studies also reveal that the fundamental relationship between corrosion rates, dissolved gases, flow rates, and temperatures are not known and that many of the prevailing concepts are not consistent with the available data. Common errors made in the evaluation of such data have been shown to result from unwarranted extrapolation and improper averaging.45/ As a better understanding of the corrosion process and the factors involved would be expected to result in improved methods of prevention and control, laboratory investigation of the influences of several of these factors has been started.

Laboratory testing with the embrittlement detector showed that potassium hydroxide, like sodium hydroxide, could concentrate in the seams and tube ends of boilers to cause intercrystalline corrosion and cracking of

45/ Berk, A. A., Discussion of "The Evaluation of Data": Proc., Sixth Annual Water Conference, Engineers' Soc. Western Pennsylvania, 1945.

the boiler metal.[46] This conclusion was corroborated by tension tests in which stressed test specimens were exposed to the attack of hot concentrated potassium hydroxide solutions. Therefore, the treatment of boiler waters with potassium instead of sodium chemicals is not a method of preventing boiler-metal embrittlement. However, the practical methods of preventing embrittlement trouble in waters containing alkaline sodium compounds are also effective when potassium treatment is used. The data obtained from these researches do not support a recently announced theory for the mechanism of the intercrystalline cracking of mild steel.[47] Six cases of stationary boiler cracking were reported for analysis and correlation during the fiscal year. The operating pressures ranged from 100 to 465 psi. at steaming rates up to 100,000 pounds per hour. Failures ranged in severity from a single tube end to widespread seam cracking that necessitated the replacement of the entire boiler. Embrittlement detector tests had been run in units attached to two of the boilers, and the results had shown the boiler water to be dangerous before the cracks were discovered. The accumulated results of embrittlement detector tests in almost 1,000 stationary plants have confirmed the effectiveness of nitrate treatment to prevent cracking. Treatment with quebracho has also been satisfactory in many instances, and no test specimens have failed when all the causticity in the water was replaced with the hydrolytic alkalinity of trisodium or tripotassium phosphate. A most satisfactory decrease in the number of cracks found in the boilers of Chesapeake & Ohio Railway locomotives also has resulted from the application of nitrate treatment.

Representatives of the Bureau of Mines have actively participated on A.S.T.M. committee work related to boiler-water research. A standard specification for the embrittlement detector test[48] has been prepared. Under the chairmanship of a representative of the Bureau of Mines, a subcommittee has prepared three new tentative specifications for methods of analysis, which have been adopted[49] by the A.S.T.M.

External Corrosion of Furnace-Wall Tubes

The investigation of external corrosion of furnace-wall tubes in large slag-tap furnaces, conducted in cooperation with the Combustion Engineering Co. since June 1942, has continued. The papers presented before

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[46] Berk, A. A., and Rogers, N. E., Embrittlement Cracking in Waters Containing Potassium Salts: Trans., Am. Soc. Mech. Eng., vol. 67, July 1945, pp. 329-334.

[47] Berk, A. A., Discussion of "Theory of Stress Corrosion of Mild Steel": Trans., Electrochem. Soc., vol. 87, 1945, p. 233.

[48] A.S.T.M. Designation D807-46T.

[49] Tentative Method of Test for Total Aluminum and Aluminum Ion in Industrial Waters: A.S.T.M. Designation D857-46T.
Tentative Method of Test for Manganese in Industrual Waters: A.S.T.M. Designation D858-45T.
Tentative Methods of Test for Silica in Industrial Waters: A.S.T.M. Designation D859-45T.

the American Society of Mechanical Engineers in December 1944,50/, 51/ based upon experiments at an arbitrary temperature of 1,000°F., afforded an explanation of the mechanism of attack where characteristic deposits found at the site of corrosion were the water-soluble, sulfate type, but it was fully recognized then that quantitative data were needed at lower temperatures, approaching the nominal metal temperature of the furnace tubes in high-pressure units. Accordingly, quantitative experiments have been made to determine the effect of concentrations of SO_3 from 0.10 percent to 1.0 percent at temperatures of 700° to 1,000°F. on (a) various alkali-metal sulfates, (b) iron oxides, (c) synthetic "enamel" deposits, (d) actual "enamel" deposits, (e) metallic iron, (f) various metals suitable for application to furnace tubes as protective coatings, and (g) these same metals in contact with both SO_3 and "enamels." The last item essentially was a series of corrosion tests in which the rate of attack of the respective metals was determined under conditions believed to simulate those favoring the attack on furnace tubes.

Furnace-tube corrosion associated with an external scale rich in iron sulfide and magnetite, referred to as the "sulfide" type of attack to distinguish it from the "enamel" type, does not occur as frequently as the latter, but wherever it has been found the degree of attack usually has been quite severe. Preliminary studies have been made, based upon the supposition that CO in furnace gases reduces alkali-metal sulfates to sulfides, which then react with the tube metal to form iron sulfide. Pure CO was passed over K_2SO_4, Na_2SO_4, glaserite, and $K_3Fe(SO_4)_3$ at 1,000° F., but the results to date cast doubt upon the validity of the assumed mechanism. Another approach has been to determine the effect of FeS, in an atmosphere of up to 5 percent oxygen and at various temperatures, upon the rate of corrosion of iron. It is believed that the data from these studies will provide a more rational explanation for the sulfide type of attack.

To account for local concentrations of SO_3 at the surface of furnace-wall tubes in slag-tap units that are higher than the over-all concentration of SO_3 in furnace gases, it has been assumed that when the coal ash adhering to the tubes begins to slag, sulfur gases are slowly evolved. Experiments are in progress to determine the composition and the rate of evolution of gases from several synthetic and actual coal ashes at various temperatures.

Experiments have been conducted to determine the manner in which alkali-metal sulfates are formed on furnace-wall tubes. The results to date demonstrate that alkali metal vapors in an atmosphere containing small concentrations of SO_3 will condense on relatively cool surfaces as simple or complex sulfates, depending on the source of the alkali-metal vapor.

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

51/ 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.