The ultra-clean coal required coking and calcination before it was ready for electrode manufacture. Coking was carried out in conventional-type byproduct ovens at high temperatures. Calcination was effected in continuous-feed, vertical-shaft kilns. When the volatile content of the coke was 5 percent or more, no auxiliary fuel was required to operate the kilns. Coke of less than 5 percent volatile matter required producer gas for heating. The calcined carbon from the kilns was crushed, mixed with pitch, pressed or extended to form electrodes, and baked in resistance-type electric furnaces.

## Briquetting of coal

To meet the many requests for information on the briquetting of coal and other carbons, the Bureau of Mines compiled a selected bibliography on the subject.40/

## Drying Low-rank Coals

### Flash-drying Process

Experimental work on the removal of natural bed moisture from low-rank fine coals was continued with the construction and operation of two additional pilot plants, the later plant having a capacity of about 25 tons per day.

The general problem of drying coals of high bed moisture was discussed.41/ The problem of removing natural moisture is somewhat different than that of removing surface moisture. In the first instance time must be allowed for heat to penetrate into each piece of coal to liberate the moisture, whereas in the latter only sufficient heat must be supplied to evaporate the surface moisture, and the time factor is not so important. Because of the mechanical difficulties involved in handling fine sizes of wet (high-surface-moisture) coal, this study was confined to removal of natural bed moisture of low-rank coals with relatively low surface moisture. A theoretical study of the problem indicated that the time required to heat particles of coal should vary approximately as the square of the diameter of the particle. In other words, a 1/16-inch particle of coal should require about 3 seconds for complete drying at a moderate temperature, whereas a 1/4-inch piece of coal should require about 48 seconds under the same conditions.

A particle of coal can be suspended in a rapidly moving current of hot gas or in a slower moving fluidized bed to achieve drying. The experimental program covered both phases, but during 1949 more attention was devoted to the study of drying in fluidized beds, because there is more latitude in handling larger sizes under these conditions. Experiments made with the pilot plant shown in figure 18 were conducted in fluidized beds on coal sizes up to 1/4 x 0 inch. In this unit, coal is propelled into the drying column pneumatically and comes in contact with jets of high-temperature gases. The coal particles are fluidized and move upward to the cyclone separators. The time of contact of the coal particles and hot gases, ranging from 20 to 50 seconds, is adjusted by controlling the rate of coal and gas feed. In practice, the velocity of gases in the top of the drying column reaches 15 feet per second, which establishes a light-phase fluidized bed, and the time of contact of the particles is adjusted to approach the theoretical time.

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40/ Fisher, Paul L., A Selected Bibliography of Briquetting of Coal and Other Carbons: Bureau of Mines Inf. Circ. 7469, 1948, 15 pp.

41/ Parry, V. F., Goodman, J. B., and Wagner, E. O., Drying Low-rank Coals in the Entrained and Fluidized State: Min. Eng., vol. 1, No. 4, 1949, pp. 89-98.

Experience with the pilot plant has shown that approximately 600 pounds of moisture can be removed from coal per hour per square foot of drying-column area. The unit removes moisture from low-rank coals at efficiencies of about 90 percent, and the process has promise for low-cost drying. Table 4 gives operating data when typical Wyoming subbituminous coal and Texas and Greek lignites were dried in the unit.

Drying and Utilization of Greek Lignites

The Bureau has cooperated with the Economic Cooperation Administration, State Department, in examining Greek fuels to outline methods of production and utilization. Two substantial shipments of low-grade lignite from the Megara and Ptolemais areas of Greece were studied during 1949 to determine how these fuels can be upgraded to make them suitable for industrial purposes. In the natural state, these lignites contain 50 to 62 percent moisture, and it is necessary to dry the lignite before use in the pulverized form.

Drying tests were conducted on the Megara and Ptolemais Greek lignites in the pilot plant. The moisture in the Megara fuel was reduced from 48 to 8.5 percent, and that in the Ptolemais lignite (see table 5) was reduced from 58.8 to 6.8 percent. Several experiments with the drying unit indicated these fuels can be flash-dried readily to low-moisture content to make them suitable for industrial use in pulverized fuel-burning equipment.

A large sample of the dried Megara lignite was pulverized and then burned in a combustion system of 600 cubic foot furnace volume simulating a cement kiln. Flame temperature of 2,700° F. was attained while releasing heat at a rate of about 20,000 B.t.u. per hour per cubic foot. These tests demonstrated that the dried, pulverized Greek lignites are suitable for industrial purposes. Table 5 gives operating data on the drying plant during the processing of the Ptolemais lignite.

When the Ptolemais Greek lignite is dried to 6.8 percent moisture, a fuel of the following proximate analysis results:

| | Percent |
|---|---|
| Moisture | 6.8 |
| Volatile matter | 44.3 |
| Fixed carbon | 33.2 |
| Ash | 15.7 |
| | 100.0 |
| Sulfur | 1.2 |
| B.t.u./lb. | 8,760 |

It is evident that a pulverized fuel of the foregoing analysis will burn satisfactorily in industrial equipment; therefore, no combustion tests were made on the limited sample. After determining that the Ptolemais lignite had a relatively high content of extractable waxes, tests were made to determine the possibilities of briquetting the dried fuel without binder. A substantial sample was briquetted in a high-pressure rotary briquet press to make small briquets for stoker or domestic use. These briquets are satisfactory as regards physical properties if kept covered, but they will disintegrate on exposure to weather. Other small samples of Greek fuels of higher rank than the low-grade lignites were analyzed and tested. It was generally concluded that any of the Greek fuels can be utilized satisfactorily if they are dried before use.

TABLE 5. - Experimental data on drying subbituminous coal and lignite obtained in Golden, Colo., flash-drying pilot plant No. 4

| Kind of coal | Lignite | Lignite | Subbituminous C |
|---|---|---|---|
| Source | Greece | Texas | Wyoming |
| Materials and moisture data: | | | |
| Coal charging rate, lb./hr. | 810 | 1166 | 1464 |
| Coal charging rate, lb./hr./sq. ft. | 1032 | 1485 | 1865 |
| Inert gas used for moving coal, cu. ft./lb. | 2.6 | 1.8 | 1.5 |
| Moisture in raw coal, percent (as charged) | 58.8 | 39.2 | 30.2 |
| Moisture in dried coal, percent | 6.8 | 3.4 | 3.2 |
| Dust loss, percent | 1.23 | 0.95 | 0.21 |
| Heating system data: | | | |
| Natural gas used, c.f.h. | 749 | 723 | 707 |
| Net heat supplied, M B.t.u./hr. | 659.1 | 636.2 | 622.2 |
| Net heat supplied per lb. of raw coal, B.t.u. | 814 | 546 | 425 |
| Hot gas used to dry coal, cu. ft./lb. | 17.4 | 12.7 | 9.8 |
| Products of combustion recirculated, c.f.h. | 3813 | 4561 | 3938 |
| Mass velocity in column, lb./hr./sq. ft. | 1939 | 1992 | 1917 |
| Mean space velocity in column, ft./second | 14.9 | 14.2 | 13.3 |
| Contact time of coal, seconds | 19.0 | 31.6 | 44.2 |
| Temperature in system, °F.: | | | |
| Combustion chamber, point 1 | 2240 | 2105 | 2140 |
| Bottom of column, point 2 | 990 | 460 | 400 |
| Top of column, point 3 | 410 | 300 | 280 |
| Coal from separator, point 4 | 310 | 290 | 270 |
| Gas outlet from separator, point 5 | 310 | 290 | 270 |
| Gas outlet from secondary separator, point 6 | 310 | 285 | 265 |
| Heat balance | | | |
| Net heat used, B.t.u./lb. raw coal charged 1/ | 738 | 498 | 380 |
| Net heat required to dry coal, B.t.u./lb. 2/ | 684 | 464 | 355 |
| Drying efficiency, excluding radiation, percent 1/ | 92.7 | 93.2 | 93.4 |
| Over-all efficiency, percent, including radiation | 84.0 | 85.0 | 83.5 |

1/ Total net heat, excluding radiation.
2/ Includes heat used for heating coal-carrier gas, excludes radiation.

## Drying of Lignite

Several samples of lignite from each of five mines (two underground and three strip mines) from the north, east, central, and southwest regions of the North Dakota deposits, were dried by a modified Fleissner process with steam up to 400 pounds pressure per square inch. Among the drying characteristics quantitatively determined was the steam requirement for two strip-mine lignites, in pounds of steam to remove 1 pound of water. The average figure was found to be 0.8 lb. steam per pound of water removed at pressures between 300 and 400 p.s.i., with very little variation between the two lignites tested.

## STORAGE OF COAL

### Storage of Low-Rank Coals

Field investigations on storage of low-grade coals were continued, with periodic observations on two model coal piles, each containing 5,000 tons of subbituminous slack. These remained in excellent condition after a year of storage. The piles were formed under the supervision of Bureau engineers to demonstrate correct methods of storing low-rank coals, and the following general rules were followed in placing the coal:

1. Form the pile in benches of 6 to 12 inches by leveling and compacting with a bulldozer.

2. Distribute each bench of coal to form sides with slope of less than 20°. The sides must be compacted, and it should be feasible to drive a passenger car over any surface of the pile.

3. The leveling and compacting of each bench should be as uniform as possible to minimize segregation and to build up to the maximum density. Proper distribution of the coal should achieve a bulk density of 65 to 70 pounds per cubic foot.

Good progress was made in the storage of lignite at the Garrison Dam in North Dakota. This work is being done in cooperation with the Corps of Engineers, U. S. Army, as part of the Missouri Basin Development Program. During excavation of the dam, approximately 5 million tons of lignite will be uncovered and placed in storage. A demonstration storage pile of lignite comprising about 60,000 tons, formed approximately as outlined above during November 1948, was in good condition on June 30, 1949, but trouble was expected in one section of the pile, where the recommendations for satisfactory storage were not followed. The smaller storage piles of 10,000 to 20,000 tons have been in place for about 18 months with no evidence of spontaneous combustion.

### Storage of Dried Lignite

Observation of two storage piles of dried lignite, one continuously exposed to the weather and one protected from the weather, was continued. The exposed pile has been under observation for over 18 months, during which time periodic measurement of both temperature and moisture content have been made. The protected storage pile has been under observation for over a year. During this period of observation there has been no tendency to ignite spontaneously.

During these storage periods there have been fluctuations in the moisture content of both piles, depending on the weather. The moisture content of the exposed pile has fluctuated widely but averages about 17 percent. The moisture content of the protected pile has progressively decreased to an average value of about 11 percent. It has now been established that dried lignite, properly prepared and piled, can be stored successfully.

## UTILIZATION OF COAL FOR COMBUSTION

### Fuel-Engineering Service

As in previous years, fuel engineering service was rendered to Government establishments in the selection and use of fuel and fuel-burning equipment and in the economical use of steam. Total boiler-plant operating-cost comparisons were made for the use of oil, gas, and coal and the type of fuel-burning equipment recommended for 37 projects for the Veterans Administration and 6 for the Department of the Army. Studies of boiler-plant equipment and operations were made at the Lyons, N. J., and Richmond, Va., veterans' hospitals, which resulted in reduction of smoke and recommendations for equipment and fuel purchase that will save $26,000 per year. A steam-production cost survey at the Wildlife Refuge, Carbondale, Ill., requested by the Fish and Wildlife Service, indicated that costs could be reduced $54,000 per year by the installation of suitable steam lines and changing from oil to coal firing. At the request of the Department of the Navy, boiler plant operation and equipment at Naval Barracks, Arlington, Va., were studied, and changes were recommended that will reduce excessive fly-ash emission and fuel costs by $1,600 per year. Acceptance tests were made of steam-generating equipment at the new Federal West-Central Heating Plant, Washington, D. C., at the request of the Federal Works Agency. As a result of these tests, many changes had to be made, which have very greatly improved the performance and reliability of the equipment. Service on 125 special problems was given 34 Government agencies. A representative of the Bureau of Mines served as chairman of the Bureau of Federal Supply interdepartmental Federal Fuel-Purchasing Committee, which made a complete study of past Government coal-purchasing procedures; the work resulted in the establishment of revamped and new procedures, which were adopted throughout the Government service. An information circular[42/] covering basic information on the use of propane and butane fuels was published to satisfy requests from many prospective users. This covered the properties of the fuels, the safety precautions to be observed in their use, the methods of transportation, the various purposes for which the fuels are used, the equipment needed, and the amounts used in the United States. There are also published a bulletin[43/] describing the operations of the National Fuel Efficiency Program during the war, including the functioning of the central office, the division of the Nation into working areas, the acquiring of volunteer workers, the functioning of the area officers, and public-relations work. Representative fuel savings resulting from this program at a number of individual plants are listed, as well as the estimated over-all accomplishments.

Under the Presidential edict of January 17, 1948, "Order for Conservation of Fuel Oil, Gasoline, and Gas," which carried the following clause: "No Federal equipment shall be installed for burning fuel oil or gas, or liquefied petroleum gas, and no permanent building or establishment shall be converted to these fuels, without the prior approval of the Bureau of Mines ...," 425 projects were studied and approvals or disapprovals given. This edict was revoked on January 13, 1949.

Cooperative work with The Air Preheater Corp., of Wellsville, N. Y., on the prevention of deposits and corrosion on air preheaters was continued. Contrary to common belief, extended field trials demonstrated that many special alloy steels now in general use for resisting corrosion rapidly disintegrated in air preheater service. This was particularly true of the high-chromium alloy steels, which failed much more quickly than some of the low-alloy steels. A number of types of coatings on metals also were tried, but these failed rapidly in service.

42/ Barkley, J. F., Questions and Answers on Propane and Butane Fuels: Bureau of Mines Inf. Circ. 7519, 1949, 9 pp.

43/ Barkley, J. F., Cheasley, Thos. C., and Waddell, K. M., The National Fuel Efficiency Program During the War Years 1943-45: Bureau of Mines Bull. 469, 1949, 100 pp.

## Boiler Feed-Water Conditioning

Analyses and resulting recommendations were made on 8,742 samples of boiler water during the fiscal year, as follows: 5,771 from the Army and Air Forces; 1,568 from the Veterans Administration; 264 from the Public Housing Administration; 251 from the Post Office Department; 236 from the District of Columbia; 181 from the Navy Department; 173 from the Office of Indian Affairs; 169 from the Department of Justice; 41 from the Public Health Service; 21 from the Federal Security Agency, 20 from the Department of Agriculture; 19 from the Public Buildings Administration; 16 from the Department of Commerce; 5 from the Bureau of Mines; 3 from the Smithsonian Institution; and 2 from the Legislative Branch. This is about a 7-percent increase over the previous fiscal year.

Reports and recommendations covering 26 analyses of various scales, sludges, and deposits, 8 miscellaneous special analyses, and 11 covering analyses of boiler compounds were made.

Two hundred and sixty-four special Bureau of Mines field water-test kits, 12,005 bottles of chemical reagents (an increase of about 36 percent over the previous fiscal year), and 10,040 test-kit replacement items were distributed to various Government activities.

Visits were made to seven heating plants operated by various Federal agencies in the local area of the District of Columbia to determine difficulties, advise on boiler-water treatment, give instructions in boiler-water testing, and inspect boilers for scale and sludge. At the request of the Veterans Administration, special water surveys were made at its boiler plants at Roanoke, Va., and Sunmount, N. Y., to solve unusual operating difficulties. Consulting service was given to District government on the use of amines and sodium sulfite for boiler-water treatment that saved about $800 per annum; to the Veterans Administration, Fort Howard, Md., on boiler-water treatment and testing that greatly reduced the time for boiler cleaning; to the Public Buildings Administration on tests for phosphate and on return-line corrosion; to the Navy Department on boiler-water testing, on the preparation of a boiler water-treatment manual, on the use of a pH meter, on the construction of color comparators for testing phosphate and tannin in boiler water, and on the treatment of boiler water by passing it through silica spheres; to the Naval Ordnance Plant, Alexandria, Va., on general boiler-water testing; to the Department of the Air Force on the preparation of instructions on the use of sodium silicate to control magnesium phosphate scales; to the Civil Works Department of the U. S. Engineers on general boiler-water treatment and testing; to the Post Office Department on boiler-water treatment for low-pressure boilers, on corrosion of pipe fittings, and on the use of amines for sodium metaphosphate; to the Capitol Power Plant on testing condensate for contamination; to the Korean Power Commission on general boiler-water treatment; to the Canadian Bureau of Mines on the set-up and work of boiler water-conditioning service; to the Government of India on boiler-water testing; to the Children's Hospital, Washington, D. C., on boiler-water testing; to the Boston Navy Yard on boiler-water treatment; to the Public Works Administration on water softening at the Blair House, the present residence of the President; and to the Bureau of Federal Supply on boiler compounds and on feedwater problems at Moffet Field.

## Boiler Water Research

Research was continued on the use of amines in boiler water. Corrosion in the piping that returns the condensed steam to the boilers is caused by carbonic acid in the condensate. The acid originates in the carbonate content of the raw make-up water for the boilers; in the boiler, carbonate loses carbon dioxide to the steam, and carbonic acid forms when the steam condenses. Chemical treatment neutralizes this acidity; stable, volatile, alkaline chemicals introduced into the boiler with the feed water leave with the steam, and the piping is safeguarded because the condensate is then slightly alkaline. It was found that the more highly volatile amines were especially useful in low-pressure and relatively ventless plants.44/, 45/, 46/

Recommendations resulting from the studies pointed out that cyclohexylamine was especially useful in the lowest pressure group of heating plant boilers, but that plants operated at pressures of 60 p.s.i. and higher probably would find that treatment with morpholine was much less expensive. Tests in three representative Naval heating plants and in three large area-heating systems in housing developments of a midwestern city had shown savings of 30 to 60 percent when morpholine was substituted for cyclohexylamine (Coravol) as the treatment chemical for the prevention of corrosion in condensate return lines. During the studies of chemical treatment, many tests were run to determine the corrosiveness of the condensate. The measured rates of corrosion did not appear to agree too well with the concept that there was a simple relationship between corrosiveness and rate of flow. Also, the condensate temperature seemed to have considerably more influence on corrosion than was indicated by published data. The corrosion studies are being continued under carefully controlled conditions in laboratory-scale apparatus. The amines used for the chemical treatment of steam are relatively expensive, as compared to ammonia. The latter, however, is known to attack brass and other copper alloys under certain conditions of use, and therefore might cause deterioration of valves and other nonferrous components of steam systems. Tests are being made to determine whether there are conditions under which relatively inexpensive ammonia can be used successfully for chemical treatment to prevent corrosion in low-pressure systems.

The invention embodied in U. S. Patent 2,454,258 relates to a method of water treatment to prevent embrittlement cracking (boiler-seam cracking) in boilers operated with distilled water make-up or its equivalent.47/ The basic principle is the elimination of causticity (caustic alkalinity) from the boiler water; instead the alkalinity essential to good boiler operation is provided by trisodium phosphate. Hydrolysis of this phosphate imparts to the water a desirable level of alkalinity, which cannot, however, be increased in the seams to the hydroxide concentration required to produce seam cracking. The patent was assigned to the Government of the United States acting through the Secretary of the Interior and is available for unrestrictive license. The embrittlement-detector-test program correlates the results for tests conducted in over a thousand embrittlement detectors mounted on stationary boilers. These results have shown that the zero-causticity method of boiler-water treatment is very effective for preventing seam cracking. Its usefulness is greatest for boilers operated with distilled water, and there are no operating-pressure limitations. One very useful feature of the method is that no inhibitor is added to the boiler water to increase the total dissolved solids; the use of phosphate instead of caustic alkalinity adds no new chemical to the water, and the total dissolved

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44/ Berk, A. A., and Nigon, J., Amine Volatility and Alkalinity in Relation to Corrosion Control in Steam-Heating Systems: Bureau of Mines Tech. Paper 714, 1948, 63 pp.

45/ Berk, A. A., Corrosion Prevention Through the Chemical Treatment of Steam: Proc. Nat. Dist. Heating Assoc., vol. 38, 1947, pp. 273-292 (issued Sept. 1948).

46/ Berk, A. A., El tratamiento quimico del vapor reduce la corrosion en la caneria de retorno: Ingienieria e Industria, vol. 16, 1948, pp. 79-83.

47/ Schroeder, W. C., and Berk, A. A., Water Treatment to Prevent Embrittlement Cracking: U. S. Patent 2,454,258, Nov. 16, 1948.

solids in the water are not necessarily increased. The embrittlement detector tests have shown also that sodium nitrate treatment has been entirely effective for preventing seam cracking in boilers operated in a range between 100 and 700 p.s.i. Similar success was obtained with nitrate treatment of locomotive boilers; as a result, a very large reduction in the incidence of seam cracking has been reported by the railroad.48/, 49/ One railroad has reported that the cost of treatment is approximately $14 per locomotive per year, or 20 cents per million gross-ton miles in terms of service.

Smoke Abatement

Smoke-abatement problems continued to hold the interest of various cities that requested Bureau of Mines publications and consulting service. These cities included Winston-Salem, N. C.; Spartanburg, S. C.; Fredericton, New Brunswick; Kansas City, Kans.; Boise, Idaho; Indianapolis and Fort Wayne, Ind.; Utica, N. Y.; Waynesboro, Va.; Moncton, New Brunswick; Charleston, W. Va.; Los Angeles, Calif.; Marietta, Ga.; Gadsden, Ala.; Long Island City, N. Y.; Youngstown, Ohio; Dayton, Ohio, and Washington, D. C. Information and consulting service were also given the County of Allegheny, Pa. In considering smoke problems in the cities of Detroit, Mich., and Windsor, Ontario, Canada, the authorities, having no jurisdiction over vessels in the Detroit River, an international boundary, appealed to the International Joint Commission for help in abating smoke from these vessels, which was polluting the air of these cities appreciably. This Commission, created to handle boundary disputes, is making a study of the matter through a committee of three technical experts from Canada and three from the United States, one of whom is a representative of the Bureau of Mines. The Model Smoke Law Committee of the American Society of Mechanical Engineers, of which a Bureau of Mines engineer is chairman, completed a guide for the use of cities adopting or changing smoke ordinances.50/

Domestic Stoker- and Hand-Firing of Coal; Comparison with Oil

A research program designed to assist householders in selecting automatic coal-burning equipment and to assist coal producers in preparing coal for domestic-stoker use has been completed.51/ Coal of all ranks is available in Washington State. During the study, a total of 165 burning trials, involving the determination of overall efficiencies and all losses, were made on 19 coals mined in Washington and Oregon. The coals ranged in rank from semianthracite through lignite.

The coals were tested at various feed rates, sized and unsized, under various operating conditions, on three stokers, to determine the best methods of burning each kind of coal and the relative suitability of each for the three types of stokers employed. The same hot-water boiler was used in all trials. In addition, seven of the

48/ Berk, A. A., Railroad Boiler Seam Cracking Controlled by Nitrate Treatment: Ind. and Eng. Chem., vol. 40, 1948, pp. 1371-5.
49/ Berk, A. A., Prevention of Seam Cracking in Locomotive Boilers: The Steam Engineer, vol. 18, 1948, pp. 102-104.
50/ Amer. Soc. of Mech. Engs., Example Sections for a Smoke Regulation Ordinance: Inf. Bull., May 1949, 12 pp.
51/ Yancey, H. F., Johnson, K. A., Cordiner, J. B., Jr., Lewis, A. A., and Lunde, K. E., Burning Washington Coals on Different Types of Domestic Stokers in the Same Hot-Water Boiler; Comparison with Hand and Oil Firing: Bureau of Mines Bull. 475, 1949, 96 pp.

coals were burned in the same boiler by hand firing to obtain a direct comparison with stoker firing, and the same boiler was also used in oil-burning trials of three domestic oil burners. The efficiency of burning coal on the three stokers under favorable conditions was about the same or only slightly lower than with similar good conditions when oil was used as the fuel. Over-all efficiency ranged up to a maximum of about 79 percent with coal and 80 percent with oil.

The seven coals used for the hand-firing trials ranged in rank from medium-volatile bituminous to lignite, and in caking properties from good-caking to noncaking. The caking coals formed coke masses that required considerable attention but delivered heat to the boiler at a relatively uniform rate over a long period. Noncaking coals ignited easily and required little attention during the firing period but tended to burn out more rapidly than caking coals. Virtually no clinkers were formed during any of the tests. The efficiencies were only 3 to 10 percent lower than those for corresponding coals on the clinker-type underfeed stoker, principally because of low firing rates and care in shaking the grates and adding fresh coal. Results of hand-firing and burning on the clinker-type underfeed stoker showed similar relationships between efficiency and rank of coal fired; that is, the efficiency tended to rise as the rank of coal became higher.

When tested in the same boiler as the stokers, three domestic oil burners operated with over-all efficiencies of 78 to 80 percent, about the same as the maximum obtained in favorable medium-rate burning trials on the coal stokers. When the coal stokers were operated intermittently, the losses from combustible and sensible heat in the flue gases remained low, and the over-all efficiencies were only slightly less than those obtained under continuous operation. The fire continued to act as an efficient, positive source of heat throughout the idle periods when fresh coal was not being supplied - that is, when the stoker was not operating - a condition obviously attained only in solid-fuel combustion.

## Measurement of the Reactivity of Solid Fuels by the Crossing-Point Method

The reactivity of coal is one of the properties considered in the evaluation of the suitability of given coals for particular commercial applications, and the need has long existed for a convenient, rational method for determining this property of solid fuels. Many different procedures have been developed and recommended for the purpose of determining the reactivity of coals, but some serious objections to all of them have been raised. The crossing-point method seemed to be most promising, and this method was investigated with the objective of developing it into an acceptable procedure.

The experimental factors affecting the crossing-point test were studied systematically, and several deficiencies of the original procedure were disclosed. On the basis of this study, modification of the procedure was devised.[52] Rigorous examination showed that this method had the necessary qualification of reproducibility and consistency for a standard method. By eliminating much of the error of temperature measurement of the old procedure, the new procedure reduces to an acceptable minimum the effects of unavoidable differences in apparatus construction and permits absolute measurements to be realized.

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52/ Jonakin, J., Cohen, P., Corey, R. C., and Jain, B. C., Measurement of the Reactivity of Solid Fuels by the Crossing-Point Method: Proc. Am. Soc. Test. Mat., vol. 48, 1948, pp. 1269-1289.

The Bureau of Mines, cooperating with the ASME Special Research Committee on Furnace-Performance Factors, began the first phase of an investigation of such factors. Improved methods of measuring temperature and composition of furnace gases were applied to the determination of heat absorption in industrial furnaces. The study of one unit, a pulverized-coal-fired boiler using tangential burners, has been completed[53/] and work on a second unit is in progress.

### Corrosion of High-Pressure Steam Generators

Numerous cases of severe, pit-type, internal corrosion in high-pressure steam generators, principally of furnace-wall tubes, have been a source of concern to operators of high-capacity steam boilers. This corrosion has been ascribed to deposits consisting almost entirely of $Fe_3O_4$ and copper and its oxides. Opinions of the cause of this attack vary widely, but in the absence of conclusive experimental proof that thin deposits of $Fe_3O_4$, copper, or mixtures of these substances will cause pitting of steel under boiler conditions, the basis of the theories that have been proposed necessarily have been speculative. Published discussions of this problem have been reviewed critically,[54/] and an attempt has been made to correlate the experience with this type of corrosion and the meager amount of available theoretical data. This was to provide an objective background to the problem and to evoke discussion from others who may have the evidence that is needed to establish definitely the effect of deposits of $Fe_3O_4$ and copper in boilers.

## CARBONIZATION OF COAL

### Survey of Carbonizing Properties of American Coals

The scope of the survey of the carbonizing properties of American coals was narrowed at the start of the past fiscal year by limiting experimental carbonization to tests at high temperatures. Emphasis was placed upon research bearing directly on the manufacture of metallurgical coke. Coals of low-, medium-, and high-volatile bituminous rank were carbonized, both singly and as blends with coals of different rank. A relatively high proportion of the tests were made on blends, because most metallurgical coke is made from mixed coals; furthermore, the carbonizing properties of some coals carbonized singly are of little value in predicting the physical properties of coke made from their blends.

The source of coals and composition of blends investigated during the past year are given in table 6. Proximate and ultimate analyses of the coals are given in table 7.

The coke-, gas-, and byproduct-making properties of 20 coals were determined. Six were low-volatile coals, all from West Virginia, representing the following beds: Davy Sewell, Pocahontas No. 3, and Pocahontas No. 4, McDowell County; and Pocahontas No. 6 (three samples), Wyoming and Mercer Counties. Four were medium-volatile coals

53/ Reid, W. T., Cohen, P., and Corey, R. C., An Investigation of the Variation in Heat Absorption in a Pulverized-Coal-Fired, Water-Cooled Steam-Boiler Furnace. Part II. Furnace Heat Absorption Efficiency, as Shown by the Temperature, Composition, and Flow of Gases Leaving the Furnace: Trans. A.S.M.E., vol. 70, No. 5, 1948, pp. 569-585.

54/ Corey, R. C., Corrosion of High-Pressure Steam Generators; Status of Our Knowledge of the Effect of Copper and Iron Oxide Deposits in Steam-Generating Tubes: Proc. Am. Soc. Test. Mat., vol. 48, 1948, pp. 907-941.

representing the Mary Lee bed, Jefferson County, Ala.; Lower Kittanning and Upper Kittanning beds, Clearfield County, Pa.; and Fire Creek bed, Greenbrier County, W. Va. Ten coals of high-volatile rank included the Upper and Lower Freeport beds, Indiana County, Pa.; Pittsburgh bed, Fayette County, Pa.; Imboden bed, Letcher County, Ky.; No. 5 bed, Saline County, Ill.; Eagle bed, Fayette County, W. Va.; No. 2 Gas bed, Kanawha County, W. Va.; No. 5 Block bed, Wayne County, W. Va.; Stockton-Lewiston bed, Lincoln County, W. Va.; and an unnamed bed sampled by core-drilling in Gunnison County, Colo. Other Eagle and Pocahontas No. 3 coals constituted a byproduct-plant blend that was mixed at the plant. Sixteen of these coals were also carbonized as blends with coals of different rank.

TABLE 6. - Description of coals and blends

| Coal No. | Description |
|---|---|
| | Low-volatile coals |
| 345 | Davy Sewell bed, Twin Branch mine, McDowell County, W. Va. |
| 345A | Blend: 80 percent Pittsburgh (28) and 20 percent Davy Sewell (345). |
| 347 | Pocahontas No. 6 bed, Black Eagle No. 1 mine, Wyoming County, W. Va. |
| 347A | Blend: 80 percent Pittsburgh (28) and 20 percent Pocahontas No. 6 (347). |
| 357 | Pocahontas No. 3 bed, Lake Superior No. 3 mine, McDowell County, W. Va., 1.5 specific gravity float. |
| a357, b357, c357 | Pocahontas No. 3 bed. Special mine samples. |
| 358 | Pocahontas No. 4 bed, Lake Superior No. 4 mine, McDowell County, W. Va., 1.5 specific-gravity float. |
| a358, b358, c358 | Pocahontas No. 4 bed. Special mine samples. |
| 369 | Pocahontas No. 6 bed, Black Eagle No. 1 mine, Wyoming County, W. Va. |
| 369A | Blend: 80 percent Pittsburgh (28) and 20 percent Pocahontas No. 6 (369). |
| 370 | Pocahontas No. 6 bed, Louisville mine, Mercer County, W. Va. |
| 370A | Blend: 80 percent Pittsburgh (28) and 20 percent Pocahontas No. 6 (370). |
| 372 | Lower Kittanning (B or Miller) bed, Eureka No. 40 mine, Somerset County, Pa. |
| | Medium-volatile coals |
| 353 | Mary Lee bed, Jefferson County, Ala. Blend: 65 percent Sayerton mine and 35 percent Sayre mine. |
| 374 | Lower Kittanning (B or Miller) bed, Springfield No. 4 mine, Clearfield County, Pa. |
| 374A | Blend: 80 percent Pittsburgh (28) and 20 percent Lower Kittanning (374). |
| 374B | Blend: 70 percent Pittsburgh (28) and 30 percent Lower Kittanning (374). |
| 375 | Upper Kittanning (C) bed, Springfield No. 6 mine, Clearfield County, Pa. |
| 375A | Blend: 80 percent Pittsburgh (28) and 20 percent Upper Kittanning (375). |
| 375B | Blend: 70 percent Pittsburgh (28) and 30 percent Upper Kittanning (375). |
| 378 | Fire Creek bed, Laurel Creek mine, Greenbrier County, W. Va. |
| 378A | Blend: 80 percent Pittsburgh (28) and 20 percent Fire Creek (378). |

TABLE 6. - Description of coals and blends (Cont'd.)

| Coal No. | Description |
| --- | --- |
| | Medium-volatile coals (Cont'd.) |
| 378B | Blend: 70 percent Pittsburgh (28) and 30 percent Fire Creek (378). |
| | High-volatile coals |
| b326 | Upper and Lower Freeport beds, Kent Nos. 1 and 2 mines, Indiana County, Pa. |
| a331 | Upper Freeport bed, Watson mine, Indiana County, Pa. |
| 346 | Upper and Lower Freeport bed, Kent Nos. 1 and 2 mines, Indiana County, Pa. |
| 346A | Blend: 30 percent Upper and Lower Freeport (346) and 70 percent Pittsburgh (28). |
| 346B | Blend: 70 percent Upper and Lower Freeport (346) and 30 percent Pittsburgh (28). |
| 348 | Pittsburgh bed, Banning mine, Fayette County, Pa. |
| 352 | Core-drill hole No. 26-23, Project 821, Lower bed, Gunnison County, Colo. |
| 356 | Imboden bed, Shady Side mine, Letcher County, Ky. |
| 356A | Blend: 80 percent Imboden (356) and 20 percent Pocahontas No. 3 (75). |
| 356B | Blend: 70 percent Imboden (356) and 30 percent Pocahontas No. 3 (75). |
| 361 | Illinois No. 5 bed, Sahara No. 16 mine, Saline County, Ill. |
| 361A | Blend: 80 percent Illinois No. 5 (361) and 20 percent Pocahontas No. 3 (75). |
| 361B | Blend: 70 percent Illinois No. 5 (361) and 30 percent Pocahontas No. 3 (75). |
| 362 | Eagle bed, Cannelton No. 3 mine, Fayette County, W. Va. |
| 362A | Blend: 40 percent Eagle (362), 40 percent No. 2 Gas (363), 10 percent Pocahontas No. 3 (357), and 10 percent Pocahontas No. 4 (358). |
| 362B | Blend: 35 percent Eagle (362), 35 percent No. 2 Gas (363), 15 percent Pocahontas No. 3 (357), and 15 percent Pocahontas No. 4 (358). |
| 362C | Blend: 40 percent Eagle (362), 40 percent No. 2 Gas (363), and 20 percent Pocahontas No. 3 (75). |
| 362D | Blend: 80 percent Eagle (362) and 20 percent Pocahontas No. 3 (357). |
| 362E | Blend: 35 percent Eagle (362), 35 percent No. 2 Gas (363), and 30 percent Pocahontas No. 3 (75). |
| 362F | Blend: 80 percent Eagle (362) and 20 percent Pocahontas No. 4 (358). |
| 363 | No. 2 Gas bed, Cannelton No. 100 mine, Kanawha County, W. Va. |
| 363A | Blend: 80 percent No. 2 Gas (363) and 20 percent Pocahontas No. 3 (357). |
| 364 | No. 5 Block bed, Northland mine, Wayne County, W. Va. |
| 366 | Stockton-Lewiston bed, H. G. Jones mine, Lincoln County, W. Va. |
| 371 | Thick Freeport bed, Harmar mine "low coal," Allegheny County, Pa. |
| 371A | Blend: 82.5 percent Thick Freeport (371) and 17.5 percent Lower Kittanning (372). |
| a371, b371, c371, d371, e371, f371 | Thick Freeport bed, Harmar mine, Allegheny County, Pa. Special channel samples. |