INTRODUCTION AND SUMMARY

This report, summarizing the Bureau of Mines research and technologic work on coal and coal products for the period July 1, 1950, to July 1, 1951, is based largely on publications issued during the year. The sixteenth in an annual series, it gives footnote references to publications giving further details of the research and technologic work described, except in a few cases where research data presented herein has not been published previously.

During the year, the national fuels situation was generally one of plentiful supply.3/ Mineral-fuel resources appeared adequate for several hundred years at reasonably increasing rates of supply. Coal-production capacity was in excess of demand; petroleum supplies were adequate; and natural gas use was limited only by pipeline capacity. However, it was pointed out that a world war would drastically change this situation of relative plenty, particularly with regard to supplies of petroleum and its products. Conversion to the use of coal on a large scale would be required, and improved methods of mining and of processing and using coal in solid or fluidized form or converted to liquid fuels could materially contribute to our national safety.

Turning from the future, a historical review, prepared in connection with the 75th anniversary of the founding of the American Chemical Society, gave a graphic picture of the development of gas and fuel technology in this country from 1876 to 1951.4/ This development by industry, as well as by the Bureau of Mines and other research organizations, is the background for present Bureau of Mines research programs on coal that are directed toward providing the technical data necessary for the most-effective use of this abundant natural resource.

With the onset of the Korean situation and the stimulus of the national defense program, transportation difficulties and shortages developed, particularly of special coals and chemicals needed in the defense program.5/ These emphasized the need for continuing research and technologic development to provide the basic technical data needed for the most efficient development and proper conservation-in-use of our mineral-fuel resources. The Bureau of Mines research on the mining, preparation, and utilization of coal has been directed toward developing more complete information on the extent and quality of coal reserves, encouraging safer and more efficient mining practices, and preparing and utilizing coals to the best advantage, now and in the future.

3/ Fieldner, Arno C., The National Fuels Situation: Eng. Exp. Sta. News, Ohio State University, vol. XXIII, No. 1, February 1951, pp. 12-17, 38-42.

4/ Fieldner, A. C., Gauger, A. W., and Yohe, G. R., History of Gas and Fuel Chemistry in the U. S.: Ind. Eng. Chem., vol. 43, No. 5, May 1951, pp. 1039-1048.

5/ Boyd, James, Synthetics in Defense: Proc. Am. Petrol. Inst., vol. 30, sec. III, 1950, pp. 6-19.

4981

In December 1950 additional research facilities became available with the completion and occupancy of the new laboratory at Grand Forks, N. Dak., which was dedicated on September 29, 1951, as the Charles R. Robertson Lignite Research Laboratory. (See fig. 1.) Also, in December 1950, construction was started on a wing to the Anthracite Research Laboratory at Schuylkill Haven, Pa., to provide in this laboratory the space and facilities originally planned. (See fig. 2.) A garage-warehouse is also under construction.

To insure that coal purchased by the Government met guarantees, the Bureau continued its analytical services to Federal agencies in their purchases of coal by sampling and analyzing coal purchased on a guaranteed analysis basis. Consulting services were given Federal agencies on their fuel purchases. For this purpose, proximate, sulfur, heating value, ultimate, and other analyses were made on 10,850 samples of coal and coke from Government purchases and from tipple and breaker inspections. Analysis of 5,401 samples of coal-mine dusts enabled mine inspectors to determine the adequacy of rock dusting. Following its traditional pioneering assistance in the establishment of fuel standards, the Bureau cooperated with an Economic Commission for Europe committee working to establish an international standard coal classification system. The Bureau's description of methods for analyzing coal and coke has been revised to incorporate recent improvements.

As part of the Bureau's cooperation under the Point-Four Program, technical assistance on coal mining and preparation was extended to South American countries.

In this country the investigation of known recoverable reserves of coking coals was continued in central and southern Pennsylvania, southern West Virginia, and eastern Kentucky to provide data on potential sources of metallurgical coke needed to maintain high rates of steel production. Recoverable reserves of 3,662 million tons of coking coal in beds 28-inches or more thick were shown for two counties in central Pennsylvania and one in eastern Kentucky. Studies of the preparation and carbonizing properties of coking coals in the eastern states were continued simultaneously with investigations of reserves of coking coals as the second and third phases of the coking-coal investigations. In the preparation phase the studies indicated which of the coals studied were suitable for metallurgical use or could be made so by conventional washing methods or special treatments. In the third phase the carbonizing properties and the yield and quality of coke and chemical products were determined for selected coals.

To provide data for development of safer and more efficient mining methods and equipment in the anthracite region of Pennsylvania, a German lightweight universal shearing machine was found adaptable to steep-pitch mining, and problems relating to roof control and to mine flood-water dangers were studied.

Commercial development of the first Diesel mine locomotive to be approved under Bureau of Mines Schedule 22 was brought much closer by tests on three units and the working out of necessary modifications with the manufacturers.

Great improvement in coal-mine safety in recent years was shown in studies of coal-mine explosions, fires, and fatalities, and the major causes and means of avoiding these accidents were pointed out. A schedule was developed for approval of respiratory protective devices, and arrangements were made for testing this type of equipment for Bureau approval. About 14,000 samples of mine air were analyzed to determine adequacy of coal-mine ventilation; over 1,600 dust-concentration and particle-size determinations were made; various types of electrical mine equipment were tested; and roof-bolting studies were made in the Bureau's continued efforts to increase mine safety and efficiency.

4931

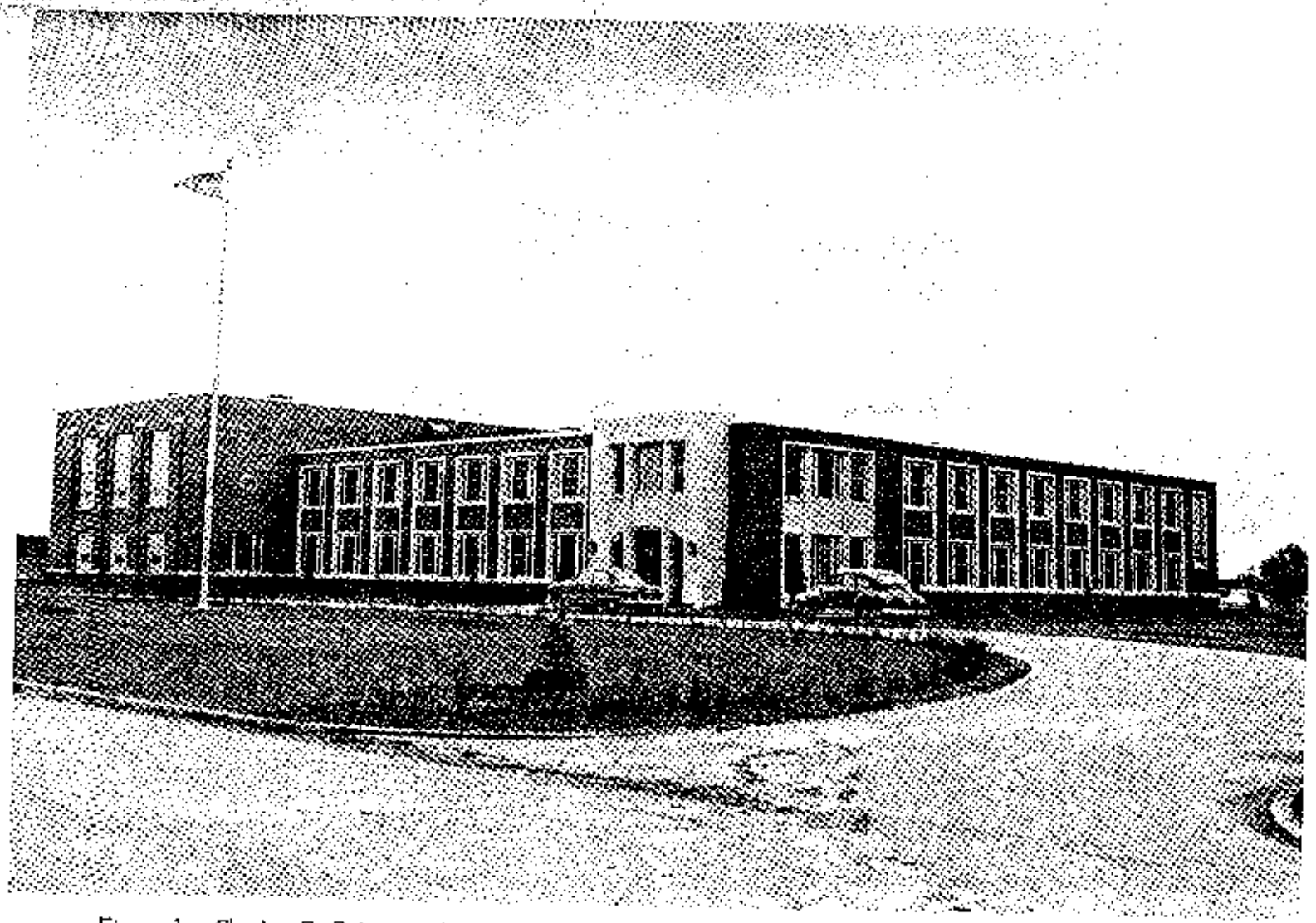

Figure 1. - Charles R. Robertson Lignite Research Laboratory of the Bureau of Mines, Grand Forks, N. Dak.

Figure 2. - Bureau of Mines Anthracite Research Laboratory, Schuylkill Haven, Pa.

Methods of evaluating coal-preparation-equipment performance and a description of the Bureau-developed kerosine-flotation process for cleaning small sizes of coal were described by Bureau engineers at the First International Conference on Coal Preparation, held in Paris, France, in June 1950. To aid the defense program by providing information on improvement of coking coals and use of coal fines, major attention in the Bureau's coal-washing research and testing programs was focused on: (1) Study of the preparation characteristics of coking coals in the eastern States as the second phase of the coking-coal investigations, and (2) the testing and improving of equipment to clean and dewater fine sizes of coal.

Research to improve the fuel-utilization value of high-moisture western coals indicated that the continuous fluidized-bed dryer is suitable for drying any noncoking fuel, and equipment size and capacity can be calculated. Drying lump lignite with high-pressure steam in the batch autoclave process required 0.8-pound steam per pound of water removed.

To aid in purchasing the most efficient fuel-burning equipment and in obtaining maximum operating efficiency, with a minimum of maintenance and outage, the Bureau continued to give consulting engineering services to Federal establishments in selecting, testing, and use of fuel-burning equipment and in boiler feed-water conditioning and testing. Analyses and recommendations were made on 9,714 samples of boiler water. Distribution of 1,148 Bureau field water test kits, 12,764 bottles of reagents, and 14,781 test-kit-replacement items from a central source saved the Government about $20,000 over individual open-market purchases. Essential information needed by boiler-plant operators was provided in a handbook on boiler-water treatment. Air-pollution prevention in the United States and the growth of the western coal industry were reviewed, and the properties of packaged fuels were studied.

The Bureau cooperated with the American Society of Mechanical Engineers in heat-absorption studies in large power boilers to improve design and reduce fuel consumption; studies of incinerator designs were made to assist the Atomic Energy Commission in the problem of radioactive waste disposal.

As the third phase of the coking-coal investigations, pilot-scale coal-carbonization tests were made on coals and blends from 15 Appalachian region coal beds. Most of the coals made satisfactory metallurgical coke with proper blending and carbonizing temperatures. Similar tests were made on 2 coals from Washington and 14 from Columbia, South America, and a comparison was made between the BM-AGA and the experimental slot-type oven. Expansion tests indicated the coals that might injure commercial ovens, and spontaneous heating tests showed coals that require special attention in storing.

Results of research on the pressure gasification of coal by the Lurgi process were reported, and operation of the annular metal retort pilot plant for gasifying lignite continued. The firing stage of the second underground gasification experiment at Gorgas, Ala., was completed. Tests on the first pilot-scale gasifier to produce synthesis gas for production of synthetic liquid fuels were completed, and new pilot plants to produce synthesis gas by atmospheric and pressure gasification were constructed. A synthesis-gas purification pilot plant for removal of both H_2S and CO_2 was tested and improved.

The Bureau's fundamental research on the production of synthetic liquid fuels was continued, with studies of the mechanism of synthesis-gas production, hydrogenation of coal, catalyst investigations, and production, separation, and identification of coal-hydrogenation gases and products and of gas-synthesis products.

4981

The Coal-Hydrogenation Demonstration Plant at Louisiana, Mo., completed several successful liquid- and vapor-phase tests, and much of the gasoline produced has been used by the Army in transport vehicles. The Gas-Synthesis Demonstration Plant and a new vertical coal-dust gasifier were completed, and all units of the system were individually tested. Detailed cost estimates were prepared for planning commercial synthetic fuel plants to suit specific fuel and other conditions as interest mounted in the economic aspects of the production of synthetic liquid fuels and coal chemicals from coal by hydrogenation and by gas-synthesis processes.

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4981

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ORIGIN, COMPOSITION, AND PROPERTIES OF COAL

Inspection, Sampling, and Analysis

Production of coal during the fiscal year 1951 was equal to or in excess of demand, and Federal agencies had no difficulty in obtaining bids covering their requirements. All agencies were able to make their purchases on a guaranteed analysis basis, including penalties for delivery of substandard coal. The Navy Department purchased coal for the Army, Air Force, and Navy and is the largest Federal purchasing agency of coal. In general, other departments purchase their own coal supply, except that the Federal Supply Service purchases the supply for some agencies whose requirements are small. Contracting for coal for the fiscal year 1952 started in March and continued through the balance of the fiscal year 1951.

Coal requirements of Federal agencies for the fiscal year were estimated at approximately 5,200,000 tons. Requests from Federal agencies for analyses for use in evaluating bids continued at about the same rate as the previous year, which was the largest in history. This was caused by strict adherence to specification requirements that eliminated mines on which there are no Bureau of Mines analysis records.

Urgent requests from Federal agencies, mine operators, and coal-sales agencies for service in obtaining mine tipple analyses continued throughout the year. A total of 1,521 tipple samples was collected at 549 mines in 17 States. At the beginning of the year, requests for sampling 350 mines were on file; although additional requests were received daily, the number of requests on file at the close of the year had been reduced to about 300. For carbonization, grindability, hydrogenation, electrode carbon, and other special tests, 602 samples were collected at 539 mines.

At the request of the Navy department, review and recommendations for improving sampling methods were made at one station, and recommendations for sampling equipment and establishing a sampling system were made for another.

Proximate, sulfur, heating value, ultimate, and other analyses were made on 10,850 samples of coal and coke from Government purchases and from tipple and breaker inspections. About two-thirds of these samples came from branches of the Department of National Defense, the rest from civilian agencies of the Government. In addition to ash-fusion temperature determinations on 3,494 samples and Hardgrove grindability indexes on 443 samples, free-swelling indexes were reported on 772 samples at the request of the Army for information on the caking properties of coal, since the Army was considering incorporating this item in their future coal specifications.

To insure that adequate rock dust was being used in coal mines to prevent propagation of coal-dust explosions, the Bureau's coal-mine inspectors submitted 3,401 samples of road, roof, rib, and gob dusts, representing 1,235 mine inspections. As the analyses are used for making recommendations on safety, the samples were in most cases received, analyzed, and reported the same day.

A total of 20,658 samples of coal, coke, char, tar residues, coal-mine dusts and other carbonaceous materials was analyzed during the year, requiring 268,116 chemical and physical tests.

Analyses of Miscellaneous Materials

As a further aid in maintaining safe and healthful conditions in coal mining, laboratory examination of 20 samples of limestone and 1 of dolomite showed these materials were suitable for rock-dusting coal mines to prevent coal-dust explosions, but 3 other materials were found unsuitable. To assist in making recommendations for improving feed-water treatment at Government steam plants, 12 boiler-water scales or deposits and 7 boiler compounds were analyzed. For use in research problems in the Bureau relating to coal carbonization, gasification, and combustion and production of synthetic liquid fuels, chemical constituents were determined for 66 samples of coal ash and slag, fly ash, and related materials, including a material claimed to be a fuel saver and 2 soot removers.

Constitution, Properties, and Analytical Methods

Coal Classification

Increased world trade in coal since World War II has shown the need for international methods of analyzing, testing, and classifying coals to provide a common language for evaluating coals of various countries. The Bureau of Mines is cooperating with the Classification Working Party of the Coal Committee, Economic Commission for Europe, in working toward an international standard classification system. A report was prepared for the committee discussing the relationship of the free-swelling index to volatile matter on the dry, ash-free basis for certain caking coals of the United States. It was shown that the free-swelling index alone is not a significant indicator of rank classification for American coals. (See fig. 3.)

Petrographic Studies of Coal

A complete petrographic study, including thin section and broken coal analysis, was made of a column sample representing approximately 8 feet of coal from the Illinois No. 6 bed, Darmstadt No. 1 mine, St. Clair County, Ill., collected for laboratory hydrogenation tests. The thin-section analysis reveals a bright-type coal, which, except for mineral matter, is rather uniform throughout the bed. The coal is composed predominantly of anthraxylon, as shown in table 1.

TABLE 1. - Petrographic composition of coals from No. 6 bed, Illinois, and Coalburg bed, West Virginia, as-received basis

	No. 6 bed, percent	Coalburg bed, percent
Anthraxylon	65.0	17.4
Translucent attritus	24.7	43.1
Opaque attritus	2.7	34.1
Fusain	2.9	1.9
Translucent mineral matter	2.8	3.5
Pyrite	1.9	-

A complete thin-section analysis was made of a column sample of the Coalburg bed from the Silush mine, located in Boone County, W. Va. The microscopic analysis revealed that this coal contained 68 percent splint and 32 percent semisplint. It had the highest percentage of splint coal of any sample yet examined in this laboratory. The high-percentage opaque matter and fusain in this coal, as shown in table 1, would probably exclude its use for coking or hydrogenation purposes.

A discussion of certain geological and petrographic aspects of American lignites, developed in an investigation of solvent extractable waxes from domestic lignites, was published.6/ In the Gulf Coastal Plain area of the States of Alabama, Mississippi, Tennessee, Arkansas, Louisiana, and Texas, numerous deposits of lignite, mostly local in extent, are found in the Wilcox formation of the Lower Eocene age. The Northern Great Plains States of South Dakota, North Dakota, Montana, and Wyoming are underlaid with rather extensive blanket-like beds of lignite occurring in the Fort Union formation, which is of the Paleocene age. Along the Pacific coast area of northern California, Oregon, and Washington, there are spotty occurrences of lignite, which are of the Eocene age.

6/ Parks, B. C., Petrography of American Lignites: Econ. Geol. vol. 46, No. 1, January-February 1951, pp. 23-50.

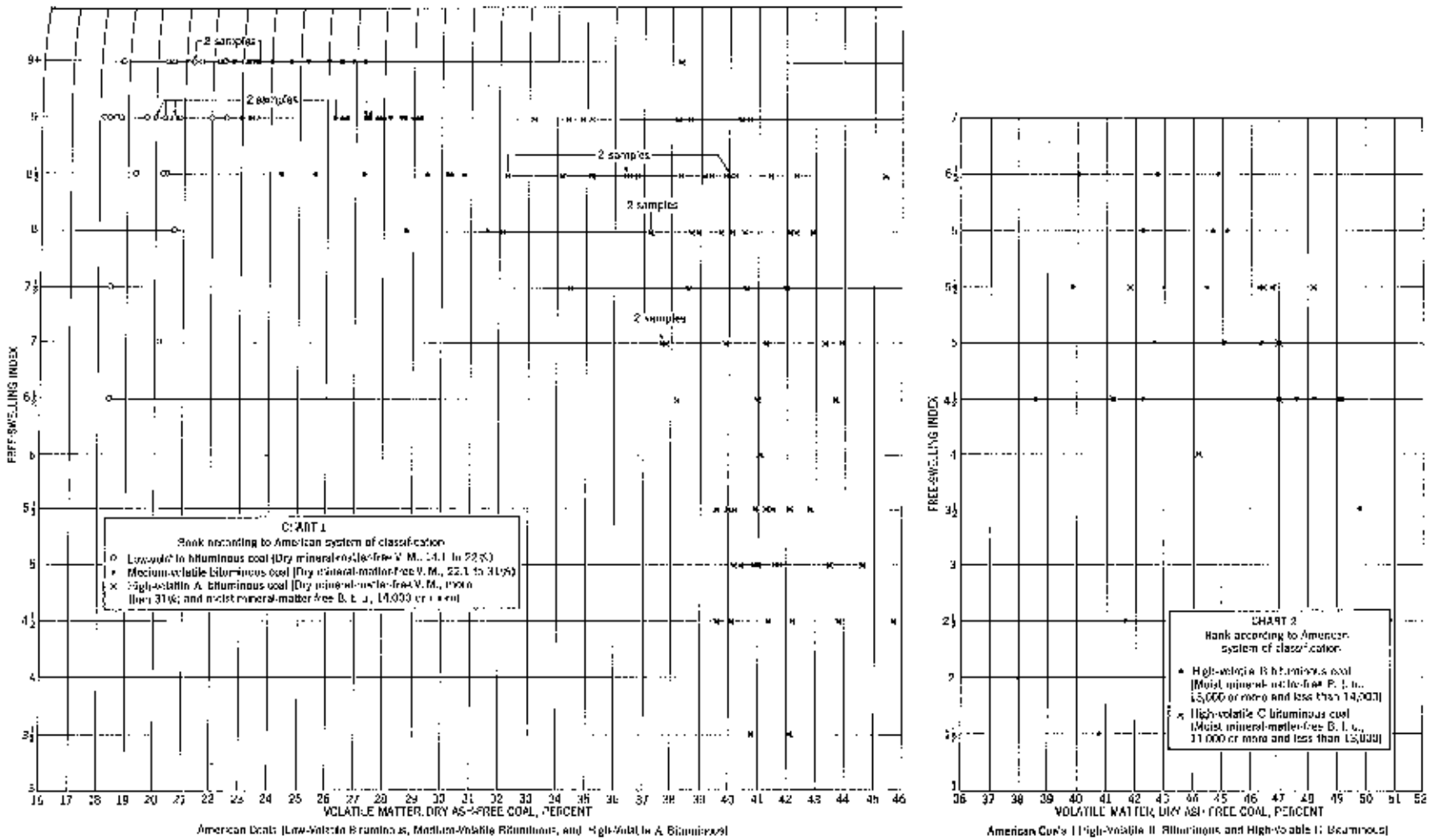

Figure 3. - Free-swelling index of American low- and medium-volatile and high-volatile A bituminous coals and American high-volatile B and C bituminous coals as a function of percent volatile matter.

Petrographic Variety	Color variation	Profile section (megascopic)	Megascopic description (Surface examination)	Microscopic description (Thin section examination)	Typical quantitative determination of petrographic composition (Thin section analysis)	Typical photomicrographs	Magnification	Typical solvent extraction yields: Benzene	Benzene-alcohol 80-20%
Xylain	Brown to dark brown		Relatively hard, firmly consolidated, banded coal. Made up of alternating layers and lenses of smooth, semi-bright, and of dull, grainy coal. Occasional thin layer and lens of black, soft fusain. Most layers and lenses of all components are less than 1/4 inch thick. Occasional thick "woody" layers easily recognizable with unaided eye to be of wood derivation. Brownish streak. Wet surface, blank; dry, dark brown.	Orange translucent bands and lentils of anthraxylon, the predominant coal component present. Anthraxylon usually shows distinct cellular structure of wood tissue in transverse or longitudinal cross sections. Attrital coal has opaque matter and particles of fusinite, but consists mostly of brownish red humic degradation matter in very fine shreds and particles. Yellow translucent attritus of minor importance. Occasional thin layers and lenses of fusain showing woody structure and mineralization.	Anthraxylon 83% Translucent attritus 17 Opaque attritus 0 Fusain 0		65x 132x 330x	S. Dak. 1.7 Texas 2.0	2.8 4.8
Attrital	Brown to dark brown		Relatively hard, compact non-banded coal. Surface dull and grainy texture. Occasional thin layers and lenses of smooth textured semi-bright coal. Brownish streak. Wet surface, dark brown; dry, brown.	Contents mostly of brownish red humic degradation matter with thin layers and lenses of anthraxylon. Opaque attritus and fusinite common. Occasional layers and lentils of fusain. Yellow translucent attritus in subordinate amounts.	Anthraxylon 10.6% Translucent attritus 80.0 Opaque attritus .4 Fusain .0		66x	Ark. 7.6 Calif. 9.5	11.6 13.8
	Light brown		Tough, compact, non-banded coal. Surface dull and grainy. Occasional thin layer and lens of smooth textured coal. Occasionally particles of yellowish resin visible on surface. Stink "oily" trace on freshly cut surface. Light brown streak. Wet surface, brown; dry, light brown.	Brownish red humic matter and yellow translucent attritus with occasional thin layers and lentils of anthraxylon. Opaque matter of minor importance. Petrain particles and fusain layers and lentils rare. Yellow translucent attritus very finely striated - particle size dominately less than 30 microns. Few large (50-80 microns) rounded bodies.	Anthraxylon 8.6% Translucent attritus 89.1 Opaque attritus .4 Fusain .0		66x	Ark. 6.9 Calif. 18.8	11.6 21.4
	Light brown		Tough, compact, non-banded coal. Surface dull and grainy. Occasional thin layer and lens of smooth textured coal. Grainy particles of resin common. Fragments of leaf-type resin several millimeters in size occasionally found. Light brown streak. Wet surface, brown; dry, yellowish brown. Stink "oily" trace on freshly cut surface.	Brownish red humic matter and yellow translucent matter with occasional anthraxylon layer and lentils. Opaque matter and fusinite rare. Abundance of coarse yellow translucent attritus. Round resinous bodies and cuticular material present, and relatively of large size.	Anthraxylon 8.1% Translucent attritus 91.6 Opaque attritus .3 Fusain .0		66x	Ark. 10.9	15.7

Figure 4. - Petrographic descriptions and solvent extraction yields of different varieties of American lignite.

The important deposits of lignitic coals in the United States are classed as lignite according to the American Society for Testing Materials system of classification by rank, but there are a few scattered, small deposits that would be classified as brown coal. These brown coals are of much later geological age, are too limited in extent to be of commercial significance, and hence are chiefly of scientific interest.

Extractable Waxes from American Lignites

A comparative study by microscopical observations was made of the melting behavior of waxy products extracted from lignite, of domestic and imported montan wax from lignite, of natural vegetable wax and resin, and of resin hand-picked from coal. The natural waxes tested had low melting points and a narrow temperature range between the initial melting and the free flowing melt. The resins had a relatively high initial melting point and a wide temperature range in complete melting and gave rather viscous melts. Melting of the benzene-extracted products of lignite closely simulated melting behavior of montan wax and natural vegetable wax, whereas the melting characteristics of alcohol-benzene extraction products of lignite indicated a relatively high content of resinous substances. The melting temperature of wax and resin is important in evaluating their commercial usefulness.

Some significant results obtained in the study of the petrography and extractable waxes from American lignites can be summarized as follows:

1. The physical composition of lignitic coals can be determined by microscopic analysis, and a type classification made, based on determined proportions of anthraxylon and attritus present.

2. Attrital lignites tested gave the highest yields of solvent extractable products. Xyloid lignites, that is, those consisting predominantly of anthraxylon, gave very low yields of extractable product.

3. The quality of the extract from attrital lignite can be predetermined to a certain extent by petrographic analysis, since the ingredients in the attritus can be identified with the microscope.

4. The technique of microscopic analysis and type classification should prove to be a useful tool in further consideration of American lignite deposits as domestic sources of extractable waxes.

The megascopic and microscopic descriptions of different varieties of American lignites are given in figure 4, with typical petrographic analyses and solvent extraction yields. Photomicrographs of the lignites as seen in thin section are included in the figure and show the nature of anthraxylon and attritus.

The survey of the wax-extraction yields of American lignites was continued by examination of two lignites from Alabama, four from South Dakota, and one from Texas. Table 2 shows the extraction yields, using benzene and a mixture of 80 percent benzene and 20 percent ethyl alcohol as solvents.

TABLE 2. - Wax extraction yields, air-dried coal basis

Source of lignite				Wax yields, percent	
State	County	Bed	Mine	Benzene	Benzene-alcohol
Alabama	Choctaw	Unidentified	Outcrop	2.8	7.0
Do.	Wilcox	do.	do.	.6	1.6
South Dakota	Dewey	Bell Creek	Dewey County	1.2	2.8
Do.	do.	do.	Isabel	1.0	2.2
Do.	do.	do.	Schnabel	1.1	2.7
Do.	Harding	Unidentified	Cave Hills	1.0	2.0
Texas	Freestone	do.	Drill Core	1.8	4.1

Methods of Analyzing Coal and Coke

To answer the many requests received by the Bureau regarding the methods used in its laboratories for analyzing coal and coke and for determining various physical and chemical properties of these fuels and their ashes, one of the Bureau's earliest technical papers has been revised and published as a bulletin.7/ First published in 1912 as Technical Paper 8, Methods of Analyzing Coal and Coke, by F. M. Stanton and A. C. Fieldner, it was revised and enlarged in 1913, 1926, 1929 and 1938 to incorporate new methods and improvements in existing methods. The present bulletin includes changes in the method for determination of carbon and hydrogen, methods for determining the agglutinating value and free-swelling index of coal, and tumbler test for coke.

Investigation of Abrasiveness of Coal

Experience in operating pulverized-fuel plants has demonstrated that some coals are much more abrasive than others. Recognizing the need for a method of estimating abrasiveness and in response to numerous requests for information on this important but heretofore unmeasured property of coal, the Bureau has developed and published8/ a tentative procedure believed suitable for trial in estimating coal abrasiveness. The suggested abrasion apparatus is illustrated in figure 5. Essentially, the test consists of rotating four removable wearing blades in a 4-kg. charge of air-dried 4-mesh to 0 coal for a fixed number of revolutions and then determining the loss in weight sustained by the blades. This loss in weight, expressed in milligrams, is considered the abrasiveness of the coal.

Abrasion results with 13 representative coal samples, a sandstone, and a coke are given in table 3.

These samples cover a wide range in rank and ash content. As with any empirical test method, the results are influenced by such variables as speed and duration of rotation, weight and size of coal employed, and clearance between the wearing blades and the walls of the mortar containing the coal. With proper control of these variables, the method gives results that can be reproduced within about 3 percent with very abrasive coals, but with coals of very low abrasiveness, variations up to 18 percent were found. However, this degree of precision probably is sufficient for most purposes.

7/ Fieldner, A. C., and Selvig, W. A., Methods of Analyzing Coal and Coke: Bureau of Mines Bull. 492, 1951, 51 pp.

8/ Yancey, H. F., Geer, M. R., and Price, J. D., An Investigation of the Abrasiveness of Coal and Its Associated Impurities: Min. Eng. vol. 3, March 1951, pp. 262-268.

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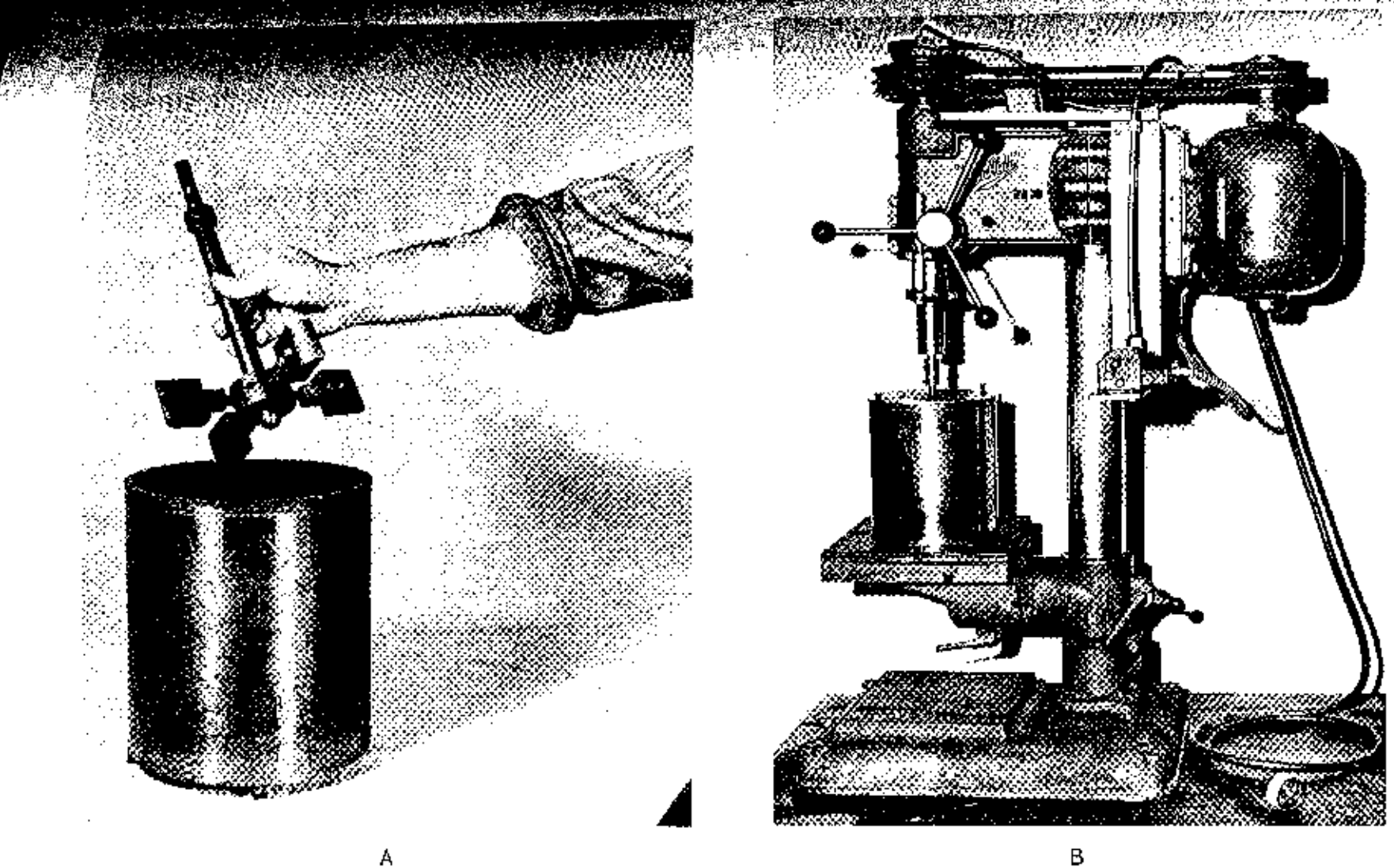

A B

Figure 5. - New apparatus for estimating abrasiveness of coal: A, Mortar, shaft-arm assembly, and wearing blades; B, Mortar and drill press used to drive wearing blades.