Under the chairmanship of a representative of the Bureau of Mines, a subcommittee of the American Society for Testing Materials revised seven standard methods of analysis relating to boiler water.

Smoke Abatement

Civic interest in smoke abatement continued to increase throughout the year. Many cities made requests of the Bureau of Mines for publications and consulting service on smoke abatement. These cities included Omaha, Neb.; Grand Junction, Colo.; Clarksburg, W. Va.; Cleveland, Ohio; Fort Washington, Wis.; Boise, Idaho; Winnepeg, Canada; Oak Ridge, Tenn.; Tacoma, Wash.; Hagerstown, Md.; Pontiac, Mich.; Westmount, Quebec, Canada; and York, Pa. The chief smoke-regulation engineer of Atlanta, Ga., requested several hundred copies of a number of publications covering fuel-burning equipment operation for the purpose of distributing them to various boiler plants in Atlanta to aid in the abatement of smoke. At the request of the smoke-regulation engineer of the District of Columbia, a representative of the Bureau served as a member of a committee to investigate fly-ash complaints of property owners in one area of the city. At the request of the Office of the Chief of Ordnance, War Department, a 2-day survey was made of air-pollution difficulties at Morgantown, W. Va., the local Chamber of Commerce having complained that the Morgantown Ordnance Works was the source of excessive pollution of the city air. A visual survey of the principal area of the city and an inspection of the plant in question were made. Certain changes in plant operation were recommended, and means were suggested for determining the contaminants of the air over a period of time. A report, entitled "Tentative Example Sections for a Smoke-Regulation Ordinance," was completed by the American Society of Mechanical Engineers Smoke Law Committee, of which a Bureau of Mines representative is chairman. Hundreds of copies of this report have been requested by many different interests.

Determination of Solid-Fuel Reactivity by Ignitibility

The absolute reactivity of a solid fuel is an extremely important property for evaluating the behavior of coal between the extremes of the slow rate of combustion occurring in a storage pile and the high specific rate of combustion of pulverized coal in a gas-turbine combustor. To date, however, no method for determining reactivity will give an unequivocal value, for any given fuel, that can be correlated with the behavior of that coal in storage or burned on a grate or in pulverized form.

To investigate the many factors that affect the determination of reactivity by the ignition-point method, for the purpose of developing a reliable and simple procedure, numerous tests were run with coal from the Pittsburgh seam in the conventional ignitibility apparatus. It has been found that the reproducibility of results in the same apparatus and the agreement of results with different apparatuses of the same design were improved considerably by suitable placement of the thermocouples. Also, it has been found that the order of the reaction with respect to oxygen concentration is less than 1, and that the reactivity is directly proportional to the specific surface of the sample.

In measuring the reactivity by the ignition-point method, it is essential that the thermocouples be resistant to corrosion, generate relatively large voltages, and be made of uniform thermo-elements to secure reproducibility. Chromel-alumel elements, which possess the first two of these properties, were tested thoroughly for uniformity. It was found that a sulfur-vapor bath affords an excellent means for calibrating couples. Additional annealing improves the quality of 28-gage "standard-oxidized" wire, and the "bright-annealed" wire is quite uniform at low temperatures, but unstable.

External Corrosion of Furnace-Wall Tubes

This research has been extended to obtain quantitative determinations of the effect of temperature and concentration of SO_3 on iron oxides, alkali-metal sulfates, mixtures of iron oxide and alkali-metal sulfates, metallic iron and aluminum, and these metals in contact with synthetic enamel-type deposits.

In addition, experiments have been made to determine the quantity and the kind of gases evolved from coal ash during sintering and slagging processes. This phase of the investigation was conducted to confirm the mechanism of attack of furnace tubes that are covered with deposits which are predominantly alkali-metal sulfates - the so-called enamel-type, which is a term descriptive of the appearance of these deposits on the tubes shortly after the furnace is shut down.

Experiments have been conducted to determine the mechanism of attack of furnace tubes when the deposit consists mainly of iron sulfide, magnetic iron oxide, and carbon. Attack of tubes under these conditions has been dubbed "sulfide-type" to distinguish it from that which occurs when sulfate deposits predominate. On the assumption that pyrites from the coal, which adheres to certain tubes in certain furnaces, initiates the sulfide type of attack, some success in clarifying the mechanism has been obtained from experiments, under controlled laboratory conditions, with solid-solid reactions between iron sulfide and metallic iron, and iron disulfide and metallic iron.

Smokeless Packaged Fuel for Domestic Use

As the result of renewed interest and activity in smoke control in large cities, and the interest of domestic consumers of solid fuels in improved methods of hand-firing, an investigation was made of the burning characteristics of certain special packaged fuels containing low-volatile bituminous coal and asphaltic binder; high-volatile bituminous coal and binder; a mixture of the latter with a special "activator" composed of a liquid hydrocarbon and coal; and a mixture of high-volatile bituminous coal, low-temperature coke, and binder.

The experiments were conducted in a typical domestic hot-water boiler equipped for determining continuously the burning rates and smoke emission, and for fuel-bed photography, under controlled operating conditions. The characteristic receiving particular attention was the smoke produced by each blend, and for this purpose a specially designed photoelectric-type smoke meter was used to determine the factors important from the standpoint of smoke control - instantaneous smoke density and total relative smoke.

The total relative quantity of smoke produced during burning of the packaged fuels increased with the volatile content of the fuel.

The addition of low-temperature coke to high-volatile bituminous coal reduced the total relative quantity of smoke but resulted in lower burning rates, more ash-pit losses, and firing difficulties.

All the fuel mixtures studied produced coke strong enough to prevent crumbling in the fuel bed and resulted in burning rates high enough to meet domestic requirements.

High percentages of high-volatile bituminous coal in the packages required the use of secondary air to prevent excessive smoking caused by the formation of a plastic layer on the top of the fuel bed.

Mineral Wool from Rhode Island Anthracite

Eight tests were made with a slagging-type gas producer to secure slag from Cranston coal that would be suitable for the manufacture of mineral wool. To date, the operating experience for a wide variety of test conditions, such as various arrangements of the tuyeres and tap hole and different charges of limestone and coal, show that the initial period of the formation of slag and tapping is followed by displacement upward of the reaction zone in the fuel bed. This causes cooling of the shaft and the tuyere zone, so that tapping ceases within a relatively short time. It is believed that, although adequate tapping might be obtained merely by making minor changes in the arrangement of the tuyeres, tap hole, and floor of the producer, the flexibility of operation would be exceedingly narrow unless the blast air is preheated to at least 1,000° F. Accordingly, with the information from the tests that have been made, optimum arrangement of the component parts of the producer has been adopted; and an oil-fired preheater, designed to heat 2,000 pounds of air per hour to 1,200° F., is now under construction.

Developments in Switzerland

The economic situation with regard to fuels in Switzerland during recent years has resulted in theoretical studies and engineering developments that otherwise might not have been undertaken.[46] The high cost of coal led to turbine developments by three companies. The companies have an optimistic attitude regarding the solution of the abrasion problem in coal-fired gas turbines. Some combustion turbines, of Swiss design, were built in Germany.

46/ Rose, Harold J., Recent Engineering Developments in Switzerland on Gas Turbines and Steam Generators: Bureau of Mines Inf. Circ. 7403, 1947, 38 pp.

An oil-fired turbine locomotive was tested and accepted in Switzerland, but its use was discontinued owing to the shortage of fuel oil. The heat pump has been used in Switzerland for space heating, air conditioning, industrial drying, and evaporation.

CARBONIZATION AND GASIFICATION

Laboratory Tests of Coking Coals

Small-scale laboratory carbonization tests made on various coals to evaluate their metallurgical coke-making properties as part of the survey of the gas- and coke-making properties of American coals include the United States Steel Corp. high-temperature distillation test, the Fischer low-temperature carbonization assay, and the Bureau of Mines agglutinating-value test. Technical papers[47] giving carbonization assays on 3 eastern and 28 western coals and agglutinating indices for 3 eastern and 89 western coals have been published. Agglutinating values of the western coals examined showed a better relationship to the coking quality of the coals than have those from Appalachian coals, which have shown poor correlation of agglutinating-value tests with shatter and tumbler tests of cokes made from these eastern coals. Most of the western coals examined are deficient in agglutinating materials, whereas many of the Appalachian coals have more of such materials than is required to form good coke. It is believed that agglutinating-value tests distinguish better between coals with a deficiency of such material than between those with an excess.

Agglutinating-value tests were made of 104 drill-core, outcrop, and mine samples of coal submitted in connection with investigations to determine minable reserves of coking coals for steel plants. The coals were from the Coosa field in St. Clair County, Ala., the Coal Creek district in Gunnison County, Colo., and the Georges Creek and Castleman Basin fields in western Maryland. Agglutinating values of drill-core and mine samples from the Coosa field in Alabama ranged from 5.2 to 12.0 kilograms and those of outcrop samples from 0.0 to 6.7 kilograms. The results indicate that many of the coals are strongly coking. Low values for most of the outcrop samples are probably due to oxidation of the coal by weathering. Agglutinating values of Castleman Basin and Georges Creek coals of Maryland ranged from 5.8 to 11.9 kilograms, which are satisfactory for coking coals. The Coal Creek coals of Colorado had agglutinating values ranging from 1.9 to 6.2

47/ Reynolds, D. A., Davis, J. D., Brewer, R. E., Ode, W. H., Wolfson, D. E., and Birge, G. W., Carbonizing Properties of Western Coals: Bureau of Mines Tech. Paper 692, 1946, 79 pp.
Reynolds, D. A., Davis, J. D., Ode, W. H., Wolfson, D. E., and Birge, G. W., Carbonizing Properties of Velva Lignite from Ward County, North Dakota, and Monarch Coal from Sheridan County, Wyoming: Bureau of Mines Tech. Paper 695, 1946, 41 pp.
Reynolds, D. A., Davis, J. D., Brewer, R. E., Ode, W. H., and Wolfson, D. E., Carbonizing Properties of Elkhorn No. 3-bed Coal from Wheelwright Mine, Floyd County, Ky.: Bureau of Mines Tech. Paper 697, 1947, 41 pp.

kilograms. These results have been incorporated in a progress report[48] in which it is shown that coals occur in the Coal Creek district that are equal to the Sunnyside coal of Utah for making metallurgical coke.

Agglutinating-value tests on drill-core and mine sample of coal taken in connection with an investigation[49] of coal deposits in the Lookout Mountain field, DeKalb and Cherokee Counties, Ala., showed that many of the coals examined were strongly coking.

In connection with a survey of the effects of oxidation of coal during storage on the carbonizing properties of coking coals, agglutinating values of 15 coal samples were determined. The coals were from the Black Creek bed, Marion County, Ala.; Raton bed, Colfax County, N. Mex.; Pittsburgh bed, Allegheny County, Pa.; Eagle bed, Kanawha County, W. Va.; and Naricual Basin, Venezuela. From data that have been obtained on changes in agglutinating values of coals during storage, it was concluded that the agglutinating value is one of the best criteria of the extent of oxidation of stored coking coals.

Agglutinating-value tests were made on 29 samples of coal from Kentucky, Maryland, New Mexico, Pennsylvania, and West Virginia to determine whether these coals have sufficient coking properties to be suitable for export to blend with certain European coals for making metallurgical coke. The results showed that the coals ranged from weakly coking to strongly coking.

Agglutinating-value tests were made of six samples of coal from the Gorgas experimental mine, Pratt bed, Walker County, Ala., in connection with the preparation of this mine for experimental underground gasification tests. The values ranged from 6.9 to 8.5 kilograms, indicative of a quite strongly coking coal.

Eleven samples of Upper Cretaceous coal from northern Alaska were tested by the Fischer low-temperature carbonization assay to determine their value as a potential source of liquid fuel. The samples were collected in the summer of 1946 by the Federal Geological Survey in connection with Navy Department petroleum investigations in Naval Petroleum Reserve 4. The range of yields of carbonization products on an air-dried coal basis was as follows: Carbonized residue, 62 to 86 percent; tar, 9.6 to 37.6 gallons per ton; light oil, 0.85 to 2.7 gallons per ton; and gas, 1,200 to 3,360 cubic feet per ton. One of the coals formed a nonswollen coke that was very weak and friable. The carbonized residues from two samples were very slightly fused, with a few small cells. All of the other coals were noncoking in the Fischer assay, as carbonized residues were loose powders.

48/ See footnote 14, p. 22.
49/ See footnote 15, p. 26.

Survey of Carbonizing Properties of American Coals

Studies on the carbonizing properties, plasticity, expansion, and oxidation of coal were continued. Only one coal was received for the complete series of tests by the BM-AGA method of determining gas-, coke-, and byproduct-making properties; it represented the Lower Banner bed and mine 56, Dante, Russell County, Va. Other investigations were made on nine high-volatile A coals that were tested mainly for yields of carbonization products in cooperation with the Republic Steel Corp., three samples of asphaltita for the Argentine Government, and one sample of coal for the Government of Venezuela. Further work was done on the small vertical expansion oven, and a paper for publication showing that it is not reliable for determining expanding properties of coal was prepared. Eleven coking coals previously tested for sensitivity to oxidation in the fresh state were carbonized after exposure in thin layers at room temperature (average, about 70° F.) for a maximum of 3-1/2 years.

Table 10 gives the analyses of all coals carbonized at 900° C. during the year, table 11 the yields of carbonization products, table 12 the physical and chemical properties of the gas, tables 13 and 14 the physical properties of the coke, and table 15 the analysis of tar distillate and light oil. Expanding properties and deterioration on oxidation were also determined.

The Lower Banner coal from Russell County, Va., (coal 91) yielded less coke and more byproducts than sample 58 from Keen Mountain mine, Buchanan County, Va. The 900° C. yields from coals 91 and 58 were, respectively: Coke, 70.3 and 79.2 percent; gas, 11,000 and 10,150 cubic feet per ton; tar, 6.9 and 3.2 percent; light oil, 3.21 and 1.92 gallons per ton; liquor, 4.7 and 4.2 percent; and ammonium sulfate, 24.2 and 15.2 pounds per ton. These differences in yields accord with the rank of the samples, for the latter (No. 91) ranks as high-volatile A, whereas the former (No. 58) was a medium-volatile coal. Variations in the yields caused by changing the carbonizing temperature were normal for high-volatile A coals. The minimum yield of coke (69.8 percent) and the maximum yields of ammonium sulfate (28.8 pounds per ton) were obtained at 800° and 700° C., respectively. The 900° C. coke was slightly weaker than the average coke from 25 high-volatile coals, as indicated by the following comparison of strength-test indexes of cokes from Lower Banner and average high-volatile A coal, respectively: 1-1/2-inch shatter, 67.3 and 70.4; 1-inch tumbler, 48.1 and 50.8; 1/4-inch tumbler, 66.7 and 72.2. The heating value of the gas from Lower Banner coal was high; the 900° C. gas had heating values of 605 B.t.u. per cubic foot and 3,330 B.t.u. per pound of coal. This gas contained a moderate proportion (210 grains per 100 cubic feet) of hydrogen sulfide. The tar contained only 2.7 percent acids, or about half the proportion generally found in high-volatile A coals; this exception may be related to the low oxygen content (6.5 percent on the as-received basis) of Lower Banner coal. The 900° C. light oil contained 76.2 percent benzene, which is higher than average.

TABLE 10. - Analyses of coals, as-received basis[1]

Coal 28 - Pittsburgh bed, Warden mine, Allegheny County, Pa.
Coal 72 - Thick Freeport bed, Harmar mine, Harmarville, Allegheny County, Pa.
Coal 91 - Lower Banner bed, No. 56 mine, Dante, Russell County, Va.
Coal 291 - Thick Freeport bed, Indianola mine, Allegheny County, Pa.
Coal 292 - Thick Freeport bed, Russellton mine, Allegheny County, Pa.
Coal 293 - Pittsburgh bed, Crescent mine, Washington County, Pa.
Coal 294 - Pittsburgh bed, Clyde mine, Washington County, Pa.
Coal 295 - Elkhorn bed, Republic Kentucky mine, Pike County, Ky.
Coal 312 - America bed, Virginia mine, Jefferson County, Ala.
Coal 308 - Mary Lee bed, Sayreton No. 2 mine, Sayreton, Jefferson County, Ala.
Coal 309 - Mary Lee bed, Sayreton Nos. 1 and 2 mines, Sayreton, Jefferson County, Ala.
Coal 313 - Mary Lee bed, Sayre mine, Jefferson County, Ala.
Coal 301 - Pocahontas No. 3 bed, Keystone mine, McDowell County, W. Va.
Coal 302 - Illinois No. 6 bed, Old Ben No. 9 mine, West Frankfort, Franklin County, Ill.
Coal 303 - Elkhorn No. 3 bed, Weeksbury No. 1 mine, Weeksbury, Floyd County, Ky.
Coal 310 - Sample No. 1, Argentine asfaltita.
Coal a310 - Sample No. 2, Argentine asfaltita.
Coal b310 - Sample No. 3, Argentine asfaltita.
Coal 311 - No. 9 bed, Santa Maria mine, Naricual Coal Basin, Venezuela, South America.

Coal No.	Dry, mineral-matter-free, fixed carbon, percent	Proximate, percent			Ultimate, percent						Air drying loss, percent	Heating value, B.t.u. per lb.	Softening temperature of ash, °F.	Real specific gravity[2]	Carbon dioxide[3]
		Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur					
28	62.6	1.8	35.1	57.7	5.4	5.3	79.0	1.6	7.8	0.9	0.7	14,140	2,740	-	0.27
72	61.7	2.8	35.3	55.6	6.3	5.4	77.4	1.5	8.2	1.2	1.3	13,810	2,300	1.33	.33
91	62.1	1.9	35.2	56.6	6.3	5.3	79.5	1.6	6.5	.8	1.1	14,170	2,340	1.32	1.65
291	61.1	2.4	35.5	54.4	7.7	5.3	76.2	1.5	8.1	1.2	1.1	13,660	2,500	1.35	.24
292	61.6	2.7	34.6	53.8	8.9	5.3	74.9	1.5	8.2	1.2	.9	13,400	2,500	1.36	.15
293	62.3	3.3	34.2	55.0	7.5	5.4	76.0	1.5	8.6	1.0	1.9	13,550	2,720	1.34	.06
294	61.0	3.1	35.7	54.6	6.6	5.5	76.4	1.6	8.6	1.3	1.7	13,650	2,500	1.34	.23
295	64.1	4.0	31.7	54.8	9.5	5.2	73.7	1.5	9.5	.6	2.7	13,170	2,660	1.36	.01
312	75.8	7.0	21.0	62.5	9.5	5.0	74.3	1.4	8.9	.9	6.3	13,060	2,730	1.37	.37
308	69.2	5.0	27.1	58.7	9.2	5.1	74.8	1.5	8.7	.7	4.4	13,270	2,910+	1.36	.26
309	68.8	7.4	26.7	56.6	9.3	5.2	72.5	1.5	10.8	.7	6.8	12,860	2,840	1.36	.34
313	67.0	6.7	28.0	54.4	10.9	5.3	71.0	1.6	10.3	.9	5.7	12,570	2,780	1.38	.10
301	82.2	1.6	16.9	74.4	7.1	4.3	82.4	1.2	4.4	.6	.9	14,290	2,340	1.37	.74
302	59.8	8.3	33.7	48.5	9.5	5.3	67.0	1.5	15.6	1.1	4.4	11,940	2,470	1.40	.23
303	59.9	3.3	38.1	56.4	2.2	5.6	80.3	1.5	9.9	.5	1.1	14,290	2,150	1.30	.33
310	68.4	1.0	30.0	63.1	5.9	5.9	81.6	1.7	2.8	2.1	.3	14,990	2,190	1.30	1.32
a310	54.2	1.6	43.7	51.0	3.7	7.2	82.3	1.6	2.9	2.3	1.1	15,690	2,590	1.21	1.13
b310	53.5	.9	44.8	51.0	3.3	7.3	83.4	1.6	2.1	2.3	.4	15,990	2,210	1.21	.97
311	54.8	3.6	42.6	51.7	2.1	6.0	76.2	2.3	12.9	.5	1.5	13,730	1,990	1.28	.27

1/ Analyses made under supervision of H. M. Cooper, chemist, Bureau of Mines.
2/ Air-dried coal.
3/ Determined on air-dried coal; total carbon not corrected for this carbon.

TABLE 11. - Yields of carbonization products at 900° C., as-carbonized basis

Coal 28 - Pittsburgh bed, Warden mine, Allegheny County, Pa.
Coal 72 - Thick Freeport bed, Harmar mine, Harmarville, Allegheny County, Pa.
Coal 91 - Lower Banner bed, No. 56 mine, Dante, Russell County, Va.
Coal 291 - Thick Freeport bed, Indianola mine, Allegheny County, Pa.
Coal 292 - Thick Freeport bed, Russellton mine, Allegheny County, Pa.
Coal 293 - Pittsburgh bed, Crescent mine, Washington County, Pa.
Coal 294 - Pittsburgh bed, Clyde mine, Washington County, Pa.
Coal 295 - Elkhorn bed, Republic Kentucky mine, Pike County, Ky.
Coal 312 - America bed, Virginia mine, Jefferson County, Ala.
Coal 308 - Mary Lee bed, Sayreton No. 2 mine, Sayreton, Jefferson County, Ala.
Coal 309 - Mary Lee bed, Sayreton Nos. 1 and 2 mines, Sayreton, Jefferson County, Ala.
Coal 313 - Mary Lee bed, Sayre mine, Jefferson County, Ala.
Coal 301 - Pocahontas No. 3 bed, Keystone mine, McDowell County, W. Va.
Coal 302 - Illinois No. 6 bed, Old Ben No. 9 mine, West Frankfort, Franklin County, Ill.
Coal 303 - Elkhorn No. 3 bed, Weeksbury No. 1 mine, Weeksbury, Floyd County, Ky.
Coal 310 - Sample No. 1, Argentine asfaltita.
Coal 310A - 50 percent sample No. 1 and 50 percent sample No. 2 (a310).
Coal 310B - 50 percent sample No. 1 and 50 percent sample No. 3 (b310).
Coal 311 - No. 9 bed, Santa Maria mine, Naricual Coal Basin, Venezuela, South America.
Coal 311A - 90 percent coal 311 and 10 percent Venezuelan pitch.

Coal No.	Retort diameter, inches	Yields, percent by weight of coal[1]							Yields per ton of coal[1]		Light oil, gal.		
		Coke	Gas	Tar	Light oil	Free ammonia	Liquor	Total	Gas, cubic feet	Tar, gallons	in gas	Tar to 170° C.	$(NH_4)_2SO_4$, pounds
28	18	68.8	14.5	7.3	1.01	0.110	6.4	98.1	10,650	14.9	2.79	0.75	19.0
72	18	67.8	15.2	7.3	1.22	.158	6.7	98.4	10,500	15.1	3.39	.69	19.7
91	18	70.3	16.0	6.9	1.17	.188	4.7	99.3	11,000	13.8	3.21	.71	24.2
291	18	68.7	14.9	7.2	1.24	.185	6.6	98.8	10,350	14.8	3.43	.73	20.8
292	18	68.8	15.2	6.5	1.32	.179	7.0	99.0	10,300	13.1	3.62	.50	19.5
293	18	68.2	14.0	7.0	1.28	.184	8.0	98.7	10,100	14.4	3.56	.72	21.9
294	18	66.7	15.0	7.4	1.32	.197	8.2	98.8	10,450	14.9	3.63	.54	22.1
295	18	70.4	13.7	5.3	1.02	.188	7.9	98.5	9,850	10.9	2.82	.50	22.4
312	18	75.3	11.4	3.2	.66	.176	9.3	100.0	9,650	6.6	1.83	.28	22.6
308	18	72.7	12.9	5.4	.77	.171	8.3	100.2	10,050	10.9	2.14	.40	26.1
309	18	70.7	12.4	5.0	.86	.168	10.5	99.6	9,650	10.3	2.40	.49	27.6
313	18	69.9	12.8	5.4	.84	.180	10.9	100.0	9,300	11.2	2.34	.46	26.6
301	13	83.6	10.2	1.3	.42	.118	2.6	98.2	10,050	2.6	1.14	.16	10.8
302	13	63.9	14.7	5.0	.97	.120	13.4	98.1	9,750	10.3	2.66	.63	28.3
303	13	66.0	16.5	6.9	1.22	.108	7.4	98.1	10,950	14.2	3.38	.91	20.3
310	13	72.3	19.8	3.3	1.51	.220	1.7	98.8	12,550	6.9	4.13	.66	17.1
310A	13	65.6	22.4	5.7	2.14	.151	1.5	97.5	13,350	11.7	5.86	.81	11.7
310B	13	65.6	23.1	6.1	2.38	.167	1.1	98.4	13,450	12.5	6.50	.94	13.0
311	13	59.6	23.1	6.2	1.16	.126	7.9	98.1	12,550	12.9	3.22	.95	29.6
311A	10	58.9	24.2	8.2	1.76	.169	4.3	97.5	12,900	16.8	4.81	1.33	19.9

1/ Coke, tar, ammonia, and light oil are reported moisture-free; gas is reported as stripped of light oil and saturated with water vapor at 60° F. and under a pressure of 30 inches of mercury.

TABLE 12. - Physical and chemical properties of gas at 900° C.

Coal 28 - Pittsburgh bed, Warden mine, Allegheny County, Pa.
Coal 72 - Thick Freeport bed, Harmar mine, Harmarville, Allegheny County, Pa.
Coal 91 - Lower Banner bed, No. 56 mine, Dante, Russell County, Va.
Coal 291 - Thick Freeport bed, Indianola mine, Allegheny County, Pa.
Coal 292 - Thick Freeport bed, Russellton mine, Allegheny County, Pa.
Coal 293 - Pittsburgh bed, Crescent mine, Washington County, Pa.
Coal 294 - Pittsburgh bed, Clyde mine, Washington County, Pa.
Coal 295 - Elkhorn bed, Republic Kentucky mine, Pike County, Ky.
Coal 312 - America bed, Virginia mine, Jefferson County, Ala.
Coal 308 - Mary Lee bed, Sayreton No. 2 mine, Sayreton, Jefferson County, Ala.
Coal 309 - Mary Lee bed, Sayreton Nos. 1 and 2 mines, Sayreton, Jefferson County, Ala.
Coal 313 - Mary Lee bed, Sayre mine, Jefferson County, Ala.
Coal 301 - Pocahontas No. 3 bed, Keystone mine, McDowell County, W. Va.
Coal 302 - Illinois No. 6 bed, Old Ben No. 9 mine, West Frankfort, Franklin County, Ill.
Coal 303 - Elkhorn No. 3 bed, Weeksbury No. 1 mine, Weeksbury, Floyd County, Ky.
Coal 310 - Sample No. 1, Argentine asfaltita.
Coal 310A - 50 percent sample No. 1 and 50 percent sample No. 2 (a310).
Coal 310B - 50 percent sample No. 1 and 50 percent sample No. 3 (b310).
Coal 311 - No. 9 bed, Santa Maria mine, Naricual Coal Basin, Venezuela, South America.
Coal 311A - 90 percent 311 and 10 percent Venezuelan pitch.

Coal No.	Retort diameter, inches	Specific gravity	Gross heating value[1/] B.t.u. per cubic foot Determined	Gross heating value B.t.u. per cubic foot Calculated	Gross heating value B.t.u. per pound of coal	H_2S, grains per 100 cubic feet	Composition, dry, percent by volume CO_2	Illuminants	O_2	H_2	CO	CH_4	C_2H_6	N_2
28	18	0.362	607	595	3,230	200	1.0	4.4	0.3	53.7	6.5	31.9	1.0	1.2
72	18	.385	617	608	3,240	320	2.0	4.9	.2	51.8	6.3	32.3	1.5	1.0
91	18	.385	605	585	3,330	210	1.9	4.6	.4	53.1	6.0	32.8	.0	1.2
291	18	.384	615	591	3,180	440	1.9	4.9	.3	52.1	6.0	32.9	.2	1.7
292	18	.392	606	599	3,120	450	2.2	5.4	.4	51.4	6.1	33.4	.0	1.1
293	18	.369	598	576	3,020	400	2.0	4.7	.4	54.0	6.6	31.1	.0	1.2
294	18	.382	586	582	3,060	500	2.1	4.7	.4	52.9	6.7	32.1	.0	1.1
295	18	.370	595	587	2,930	250	1.8	4.4	.3	53.2	6.2	31.8	.8	1.5
312	18	.313	559	541	2,700	190	1.3	2.4	.4	61.0	3.7	29.8	.0	1.4
308	18	.340	572	567	2,870	180	1.3	3.4	.4	57.3	4.6	31.9	.0	1.1
309	18	.343	572	560	2,760	190	1.4	3.4	.4	58.1	4.7	30.9	.0	1.1
313	18	.365	591	566	2,750	310	1.8	3.2	.2	55.0	5.9	32.5	.0	1.4
301	13	.269	481	480	2,420	80	1.2	1.4	.4	69.1	4.1	22.7	.0	1.1
302	13	.399	545	537	2,660	430	3.6	3.6	.4	53.3	9.9	28.0	.1	1.1
303	13	.398	601	588	3,290	190	2.4	5.2	.4	51.1	7.8	31.7	.3	1.1
310	13	.420	710	689	4,450	110	1.1	9.5	.4	46.2	2.8	38.8	.0	1.2
310A	13	.446	746	718	4,980	290	1.3	9.2	.4	41.5	2.9	43.7	.0	1.0
310B	13	.455	729	763	4,900	330	1.4	10.4	.4	41.2	2.6	42.6	.3	1.1
311	13	.490	614	600	3,850	120	5.2	6.9	.4	44.3	10.0	32.2	.0	1.0
311A	10	.500	679	661	4,380	180	3.9	9.3	.4	41.0	8.1	36.3	.0	1.0

1/ Stripped of light oil and saturated with water vapor at 60° F. and under a pressure equivalent to 30 inches of mercury.

TABLE 13. - Physical properties of coke at 900° C. (Bureau of Mines method)

Coal 28 - Pittsburgh bed, Warden mine, Allegheny County, Pa.
Coal 72 - Thick Freeport bed, Harmar mine, Harmarville, Allegheny County, Pa.
Coal 91 - Lower Banner bed, No. 56 mine, Dante, Russell County, Va.
Coal 291 - Thick Freeport bed, Indianola mine, Allegheny County, Pa.
Coal 292 - Thick Freeport bed, Russellton mine, Allegheny County, Pa.
Coal 293 - Pittsburgh bed, Crescent mine, Washington County, Pa.
Coal 294 - Pittsburgh bed, Clyde mine, Washington County, Pa.
Coal 295 - Elkhorn bed, Republic Kentucky mine, Pike County, Ky.
Coal 312 - America bed, Virginia mine, Jefferson County, Ala.
Coal 308 - Mary Lee bed, Sayreton No. 2 mine, Sayreton, Jefferson County, Ala.
Coal 309 - Mary Lee bed, Sayreton Nos. 1 and 2 mines, Sayreton, Jefferson County, Ala.
Coal 313 - Mary Lee bed, Sayre mine, Jefferson County, Ala.
Coal 301 - Pocahontas No. 3 bed, Keystone mine, McDowell County, W. Va.
Coal 302 - Illinois No. 6 bed, Old Ben No. 9 mine, West Frankfort, Franklin County, Ill.
Coal 303 - Elkhorn No. 3 bed, Weeksbury No. 1 mine, Weeksbury, Floyd County, Ky.

Coal No.	Retort diameter, inches	True specific gravity	Apparent specific gravity	Cells, percent	Shatter test, cumulative percent upon- 2-inch screen	1-1/2-inch screen	1-inch screen	1/4-inch screen	Tumbler test, cumulative percent upon- 2-inch screen	1-1/2-inch screen	1-inch screen	1/4-inch screen
28	18	1.85	0.88	52.5	33.1	68.0	93.2	98.6	1.8	20.4	55.2	71.5
72	18	1.87	.82	56.1	42.3	76.5	91.9	98.0	.1	18.4	52.6	71.8
91	18	1.89	.88	53.4	34.1	67.3	91.7	97.9	.6	11.1	48.1	66.7
291	18	1.91	.89	53.4	35.3	66.3	89.2	97.9	.0	13.2	49.2	70.7
292	18	1.92	.90	53.1	41.4	68.9	88.2	97.8	.3	14.4	49.1	72.8
293	18	1.91	.85	55.5	33.2	70.6	92.6	97.9	1.6	20.2	53.9	70.2
294	18	1.92	.83	56.8	28.4	68.0	92.0	98.1	.0	16.5	54.4	71.9
295	18	1.92	.82	57.3	59.9	83.4	92.8	97.9	8.7	35.9	56.5	70.7
312	18	1.94	.87	55.2	64.8	86.7	95.0	98.3	9.3	36.8	58.2	67.0
308	18	1.93	.85	56.0	61.6	87.4	95.9	98.4	13.0	44.4	64.7	70.4
309	18	1.92	.85	55.7	55.9	87.4	96.4	98.5	9.4	40.1	63.2	68.7
313	18	1.96	.82	58.2	54.9	85.1	95.8	98.4	9.0	36.9	61.8	68.9
301	13	1.91	.91	52.4	49.2	80.2	95.2	98.8	.0	15.5	54.6	71.1
302	13	1.95	.75	61.5	22.1	49.7	78.6	97.0	.0	1.1	25.8	68.7
303	13	1.87	.74	60.4	11.3	40.2	79.6	97.9	.0	.8	30.8	74.8

TABLE 14. - Physical properties of coke at 900° C. (Columbia Steel Co. methods)

Coal 310 - Sample No. 1, Argentine asfaltita.
Coal 310A - 50 percent sample No. 1 and 50 percent sample No. 2 (a310).
Coal 310B - 50 percent sample No. 1 and 50 percent sample No. 3 (b310).
Coal 311 - No. 9 bed, Santa Maria mine, Naricual Coal Basin, Venezuela, South America.
Coal 311A - 90 percent coal 311 and 10 percent Venezuelan pitch.

Coal No.	Retort diameter, inches	True specific gravity	Apparent specific gravity	Cells, percent	Shatter test, cumulative percent upon-				Tumbler test, cumulative percent upon-			
					1-1/2-inch screen	1-inch screen	3/4-inch screen	1/2-inch screen	1-1/2-inch screen	1-inch screen	3/4-inch screen	1/2-inch screen
310	13	1.88	-	-	-	-	-	-	0.0	1.4	11.6	31.4
310A	13	1.90	0.84	55.8	27.8	53.8	66.1	77.2	.0	17.8	30.7	43.7
310B	13	1.90	.69	63.7	33.8	60.1	69.1	79.1	1.1	19.6	32.1	43.5
311	13	1.88	.77	59.0	-	-	-	-	.0	16.2	40.6	54.4
311A	10	1.89	.80	57.7	-	-	-	-	.0	17.4	40.6	60.0

TABLE 15. - Analysis of tar distillate and light oil at 900° C.

Coal 28 - Pittsburgh bed, Warden mine, Allegheny County, Pa.
Coal 72 - Thick Freeport bed, Harmar mine, Harmarville, Allegheny County, Pa.
Coal 91 - Lower Banner bed, No. 56 mine, Dante, Russell County, Va.
Coal 291 - Thick Freeport bed, Indianola mine, Allegheny County, Pa.
Coal 292 - Thick Freeport bed, Russellton mine, Allegheny County, Pa.
Coal 293 - Pittsburgh bed, Crescent mine, Washington County, Pa.
Coal 294 - Pittsburgh bed, Clyde mine, Washington County, Pa.
Coal 295 - Elkhorn bed, Republic Kentucky mine, Pike County, Ky.
Coal 312 - America bed, Virginia mine, Jefferson County, Ala.
Coal 308 - Mary Lee bed, Sayreton No. 2 mine, Sayreton, Jefferson County, Ala.
Coal 309 - Mary Lee bed, Sayreton Nos. 1 and 2 mines, Sayreton, Jefferson County, Ala.
Coal 313 - Mary Lee bed, Sayre mine, Jefferson County, Ala.
Coal 301 - Pocahontas No. 3 bed, Keystone mine, McDowell County, W. Va.
Coal 302 - Illinois No. 6 bed, Old Ben No. 9 mine, West Frankfort, Franklin County, Ill.
Coal 303 - Elkhorn No. 3 bed, Weeksbury No. 1 mine, Weeksbury, Floyd County, Ky.
Coal 310 - Sample No. 1, Argentine asfaltita.
Coal 310A - 50 percent sample No. 1 and 50 percent sample No. 2 (a310).
Coal 310B - 50 percent sample No. 1 and 50 percent sample No. 3 (b310).
Coal 311 - No. 9 bed, Santa Maria mine, Naricual Coal Basin, Venezuela, South America.
Coal 311A - 90 percent coal 311 and 10 percent Venezuelan pitch.

Coal No.	Retort diameter, inches	Distillate, percent by volume of dry tar: Acids	Bases	Neutral oils	Neutral tar oil, percent by volume: Olefins	Aromatics	Paraffins and naphthenes	Refined light oil from gas, percent by volume: Benzene	Toluene	Paraffins	Solvent naphtha	Olefins in crude light oil from gas, percent by volume
28	18	4.8	1.6	26.2	12.3	84.6	3.1	72.7	19.5	2.4	5.4	8.4
72	18	7.3	1.8	28.1	8.8	86.2	5.0	63.0	20.7	6.2	10.1	13.0
91	18	2.7	1.5	21.7	11.9	86.6	1.5	76.2	17.6	3.2	3.0	7.6
291	18	6.0	1.7	27.2	9.6	87.0	3.4	65.0	21.8	5.5	7.7	11.4
292	18	3.7	1.8	22.6	10.3	89.0	.7	72.8	19.7	2.7	4.8	8.7
293	18	6.2	2.1	27.7	9.5	87.2	3.3	65.0	20.3	7.5	7.3	11.1
294	18	6.8	1.9	22.8	9.9	88.7	1.4	67.8	20.7	4.6	6.9	9.7
295	18	6.4	2.1	28.5	9.3	87.5	3.2	65.7	21.2	5.7	7.4	12.0
312	18	2.4	1.3	22.6	8.8	77.1	14.1	69.0	18.4	5.1	7.5	10.6
308	18	3.2	1.8	21.8	11.3	78.2	10.5	69.8	19.0	5.3	5.9	12.6
309	18	3.4	1.0	22.4	10.3	79.4	10.3	71.7	18.1	5.1	5.1	12.0
313	18	6.5	2.0	27.4	10.0	81.0	9.0	66.4	19.2	7.9	6.5	12.4
301	13	1.3	1.3	11.3	14.1	85.2	.7	69.7	21.1	2.4	6.8	11.8
302	13	7.2	3.1	27.5	10.6	88.5	.9	72.7	22.0	1.6	3.7	11.2
303	13	6.6	1.5	27.8	12.9	83.9	3.2	72.0	18.6	5.4	4.0	11.3
310	13	.5	1.7	27.6	12.5	84.4	3.1	79.3	17.1	1.2	2.4	9.2
310A	13	.7	.9	20.8	16.0	83.2	.8	84.2	11.7	2.4	1.7	8.8
310B	13	.5	.9	23.9	7.9	90.7	1.4	80.0	16.6	1.7	1.7	8.0
311	13	6.0	3.5	29.5	12.5	85.3	2.2	72.5	18.9	3.8	4.8	13.7
311A	10	2.9	2.7	26.9	14.1	84.6	1.3	80.1	15.1	3.1	1.7	9.0

The principal high-volatile coals for metallurgical coke are obtained from a number of sources. The Thick Freeport and Pittsburgh beds in Pennsylvania and the Elkhorn bed in Kentucky furnishes large quantities. Mixtures of medium- to high-volatile Mary Lee and America coals are used in Alabama. Low-volatile coals for blending with the Freeport, Pittsburgh, and Elkhorn are purchased on the open market, and it has not been possible to obtain low-volatile coal of uniform quality for the various plants using these coals. Recovery of byproducts from several plants has differed considerably and it was desired to know how much of the differences in yields could be charged to differences in coals used. Accordingly, it was decided to test the coals, in cooperation with the Republic Steel Corp., by the BM-AGA method and thus obtain a reliable basis for comparing them. Blending with miscellaneous low-volatile coals at byproduct-oven plants complicated the comparison, but only small amounts of these coals are used, and in some cases BM-AGA results are available on them.

Nine coals were carbonized in duplicate in the 18-inch retort at 800°, 900°, and 1,000° C. The usual differences in yields of products were obtained on going from 800° to 1,000° C. That is, as the carbonizing temperature is raised, the yield of gas increases and that of tar decreases; the yield of coke at 1,000° C. is usually slightly higher than that at 900° C.

As two Thick Freeport- and two Pittsburgh-bed coals from mines only a short distance apart in each case were tested, the yields were calculated to the ash- and moisture-free basis to bring out differences in carbonizing properties of the coal substance. Results for the Harmar mine (coal 72), which is also a Thick Freeport bed coal from Allegheny County, and for Pittsburgh bed (coal 28), Warden mine, coal are also included. The yields from the Indianola and Harmar mine coals (table 16) are almost identical; the Russellton coal yields more gas, less tar, and slightly more light oil. It is believed that this increase in light oil is large enough to be considered significant.

Clyde coal gave a lower yield of coke and higher yields of tar and gas than the other two Pittsburgh-bed coals; the yields from Crescent and Warden coals were very similar. The yield of light oil from the latter was low, but this coal was tested more than 15 years ago when automatic cooling for the light-oil scrubbers had not been provided. Probably some of the light oil from the Warden coal was not removed from the gas. The figures for heat-in-gas per pound of coal carbonized indicate that this is true; they are 3,230 B.t.u. for Warden and 3,020 for Crescent. Elkhorn coal yielded more coke and less gas, tar, and light oil than Thick Freeport and Pittsburgh coals.

TABLE 16. - Yields of carbonization products in the 18-inch retort at 900° C., ash- and moisture-free basis

Coal No.	Coal bed	Mine	County	Percent of coal substance: Coke	Gas	Tar	Light oil	Free ammonia	Liquor	Total	Yields, per ton of coal: Gas, cubic feet	Tar, gallons	Light oil, gallons	$(NH_4)_2SO_4$, pounds
291	Thick Freeport	Indianola	Allegheny	67.7	16.0	8.0	1.38	0.206	4.7	98.6	11,500	16.5	3.8	23.1
292	do.	Russellton	do.	67.7	17.2	7.4	1.49	.202	4.9	98.9	11,650	14.8	4.1	22.1
72	do.	Harmar	do.	68.0	16.7	8.0	1.34	.170	4.3	98.5	11,550	16.6	3.7	21.7
293	Pittsburgh	Crescent	Washington	68.1	15.7	7.8	1.43	.210	5.3	98.5	11,320	16.1	4.0	24.6
294	do.	Clyde	do.	66.3	16.6	8.2	1.46	.210	5.7	98.5	11,570	16.5	4.0	24.5
28	do.	Warden	Allegheny	68.5	15.6	7.9	1.09	.120	5.0	98.2	11,470	16.1	3.0	20.5

Generally, the properties of the cokes correlate with rank of coal. The five high-volatile A coals representing the Thick Freeport, Pittsburgh, and Elkhorn beds coked less strongly than the higher-ranking Alabama coals. The 900° C. coke from Elkhorn coal was outstanding for the coal rank; the 1-½-inch shatter and 1-inch tumbler indexes of this coke were 83.4 and 56.5, respectively, whereas the corresponding averages for 25 high-volatile A coals were 70.4 and 50.8, respectively. The three Mary Lee coals ranked low in the medium-volatile classification or very high in the high-volatile A group, and America coal ranked high in the medium-volatile group. The cokes from these coals were definitely stronger than the cokes from the five high-volatile A coals, if judged by the 1-½-inch shatter and 1-inch tumbler indexes. The 1/4-inch tumbler indexes are not outstanding for either coal group. Although America coal ranked highest, its coking power approximately equaled that of Elkhorn coal. Previous investigations of coals from these beds indicate that they yield metallurgical coke if blended with coals of suitable rank and composition.

When the BM-AGA work was started, it appeared that crushing the coal for carbonization to pass ¼-inch corresponded to the average coke-oven practice; accordingly, this size was chosen for the testing, and coals were stage-crushed so that there was a minimum of fines. Now, however, finer crushing is practiced at coke plants; most plants crush to 0- to 1/8-inch with about 70 percent through 1/8-inch, particularly where it is necessary to blend several coals. The quality of the coke is believed improved thereby. It seems obvious that the BM-AGA preparation should be changed to correspond more closely with industrial practice, and tests of the effect of fine and coarse crushing on the physical properties of the coke have been made from time to time. To obtain more data on this effect, the five high-volatile coals were tested at 900° C. using both the 0- to ¼-inch and 0- and 1/8-inch sizes. The results are given in table 17. The improvement in the 1-inch tumbler index of the coke is definite, and the ¼-inch index generally is raised by the reduction in size. The 1-½-inch shatter index shows appreciable improvement for the Thick Freeport coals, but not for the Pittsburgh and Elkhorn coals. If the comparison is made on the basis of the 1-inch index, improvement is shown except for the Crescent coal.

The physical and chemical properties of the 900° C. gases shown in table 12 indicate that none of the North American coals tested rank high as gas coals. The heating values were highest for Thick Freeport and Pittsburgh coals; however, these ranged from 3,020 to 3,180 B.t.u. per pound of coal, whereas the average value for 39 high-volatile A coals is 3,220 B.t.u. per pound. The gases from the other coals had heating values lower than 3,000 B.t.u. per pound. The content of hydrogen sulfide in the 900° C. gases ranged from 180 to 500 grains per 100 cubic feet, the northern coals having the highest proportions. However, the samples of America and Mary Lee coals had been washed, which probably lowered the sulfur content of the coal appreciably.