The yields of carbonization products in the 18-inch BM-AGA retort test at 900° C. were: Coke, 82.8 percent; gas, 10,500 cubic feet; tar, 3.5 gallons; light oil in gas, 1.32 gallons; and ammonium sulfate, 11.6 pounds, all expressed on the basis of a ton of coal. The coke was blocky, fine-grained, and stable; the gas had a specific gravity of 0.280 and a heating value of 504 B.t.u. per cubic foot (2,650 B.t.u. per pound of coal); and tar contained a relatively high percentage of residue on distilling to 350° C. and relatively low percentages of neutral oil and acids. Blending with 70 and 80 percent Pittsburgh-bed coal decreased the coke yield and increased the yield of by-products. Oxidation for 16.1 days virtually destroyed the coking property.

Previous investigations have indicated that the coke-making properties of predominantly splint coals are unlike those of bright coals of similar rank. A comparative study[76] was made of the carbonizing properties and petrographic composition of four medium-volatile bituminous coals, all from the Appalachian region. These coals were from the Lower Banner, Sewell, Lower Freeport, and Bakerstown beds. The Lower Banner bed contained 36 area-percent of bright coal, 53 of semisplint, and 11 of cannel; it contained 68 area-percent of attrital components as compared with 35 for Sewell and 31 for Lower Freeport and Bakerstown coals. The four coals are of nearly identical rank. In the order named, the percentages of fixed carbon in these coals, on the dry, mineral-matter-free basis, are 76.9, 77.5, 73.4, and 77.1, respectively. Judging from the chemical analysis alone, virtually the same carbonizing properties would be expected for the four coals. The marked differences found for the various carbonizing properties of Lower Banner coal as compared with the other three coals must be attributed to its peculiar type or petrographic composition.

Lower Banner coal, predominantly splint, differs from three medium-volatile Appalachian bright coals in that it yields weaker coke and contracts during carbonization. This difference is believed to be due to the dissimilar plastic properties of Lower Banner coal, which permit its volatile decompostion products to escape through the plastic layer easily and at relatively low pressures. Two explanations are indicated: (1) Splint and cannel constituents increase the fluidity of plastic coal and (2) splint and cannel constituents reduce the agglomeration or cohesive property below that necessary to retard the escape of volatile products. It seems apparent from these comparisons of medium-volatile bituminous coals of nearly identical rank that certain carbonizing properties are not predictable from chemical analyses and that petrographic composition may modify carbonizing properties more than has been generally recognized.

Coke from Blends of Coal and Its Coke Breeze

Pittsburgh-bed coal crushed to pass 1/4 inch was blended with 1, 3, and 5 percent of coke-oven breeze produced from this coal. The coke breeze was used in two sizes (1) fine coke crushed to pass 14-mesh and (2) coarse coke

76/ Reynolds, D. A., and Davis, J. D., Coal Carbonization - Carbonizing Properties of Medium-Volatile Coals of Different Types: Bureau of Mines Rept. of Investigations 3749, 1944, 8 pp.

crushed to pass 4-mesh Tyler sieve. Table 10 shows the yields and physical properties of the cokes made from the coals and the several blends. Blending increased the yield of coke but did not significantly change the apparent specific gravity. Blending with 1 percent of coke breeze, either fine or coarse, affected but slightly the significant indexes defining physical properties of the coke. Additions of 3 percent of breeze raised the 1-1/2-inch shatter index from 61.0 to 70.3 when the breeze was fine; coarse breeze was somewhat less effective. The 1-inch tumbler index was increased somewhat with fine breeze but decreased sharply as the coarse breeze was raised to 5 percent. The 1/4-inch tumbler index was lowered by blending with both sizes of breeze; the effect was much more pronounced when coarse breeze was used in the larger proportions.

Coke from Blends of Coal and Low-Temperature Coke

A study was made of 90:10 and 80:20 blends of Pittsburgh-bed, Warden mine coal (coal i28) and "Disco" low-temperature coke made from the same coal to determine the effect of 10- and 20-percent additions of Disco on the yields and physical properties of the resulting cokes. The results are given in table 11, with those for cokes made from two 100-percent Warden coals and for two cokes produced from blends containing 80 percent of Warden coal and 20 percent, either of Pocahontas No. 3-, or of Pocahontas No. 4-bed coal. Disco coke of two different volatile-matter contents was used in two different sizes. Compared with Warden coal i28-1, the yields and apparent specific gravity of the resulting cokes were increased by both sizes of Disco. The addition of minus 1/16-inch Disco coke lowered the 1-1/2-inch shatter index in three out of four tests but raised the 1-inch and 1/4-inch tumbler indexes in all eight tests. The effects of the minus 1/8-inch Disco were more variable. In most tests Disco containing 17.8 percent of volatile matter was superior to that containing 19.9 percent. The Pocahontas No. 3 coal contained 17.4 and the Pocahontas No. 4 coal 16.0 percent volatile matter. Their blends with 80 percent of Warden coal gave larger yields of stronger cokes than cokes produced from blends containing 80 percent of Warden coal and 20 percent of Disco. It is evident that the volatile content of the low-volatile constituent of a coal blend is not the sole factor in determining the yield and quality of coke. Nor do the results obtained on blends of Warden coal and Disco coke mean that other high-volatile coking coals would react exactly the same as the Warden coal when used with the Disco coke in blends.

Laboratory Tests of Coking Properties of Western Coals

Coking coals are not abundant in the Western States, and considerable search is being conducted for suitable coals to make metallurgical coke. Southern Colorado and northern New Mexico have supplied most of the coke for steel making, but new plants at Fontana, Calif., and at Geneva, Utah, have placed greater emphasis on coals from Carbon County, Utah. These coals are high in oxygen and have relatively poor coking properties, but good performance in the blast furnaces can be obtained from cokes made from these coals, provided sized coke, ore, and limestone are charged. However, their coking power is affected rapidly by oxidation during storage.

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TABLE 10. - Yields and physical properties of cokes from Pittsburgh bed coal and blends of Pittsburgh coal with coke breeze

Test No.	Percent coke in blend	Yield of coke, percent	Apparent specific gravity of coke	Shatter test, cumulative percent upon- 2-inch screen	Shatter test 1-1/2-in. screen	Shatter test 1-inch screen	Shatter test 1/4-inch screen	Tumbler test, cumulative percent upon- 2-inch screen	Tumbler test 1-1/2-in. screen	Tumbler test 1-inch screen	Tumbler test 1/4-inch screen
1	-	67.7	0.89	21.0	61.0	88.4	97.5	0.0	12.4	47.5	72.8
				(Fine coke 1/ in blends)							
2	1	68.2	.88	23.5	59.9	88.5	97.7	.7	17.0	52.1	72.3
3	3	67.7	.90	42.4	70.3	90.6	98.0	.0	22.7	52.8	71.3
4	5	69.5	.92	51.6	71.8	89.7	97.8	4.3	27.3	50.9	67.1
				(Coarse coke 2/ in blends)							
5	1	69.1	.88	42.6	67.9	86.8	97.3	.0	11.0	45.0	70.3
6	3	69.2	.89	41.1	69.6	84.6	96.8	.0	5.6	33.4	65.0
7	5	69.7	.89	50.2	69.1	83.8	96.3	.0	5.0	20.1	55.5

1/ Crushed to pass 14-mesh Tyler sieve.
2/ Crushed to pass 4-mesh Tyler sieve.

TABLE 11. - Yields and physical properties of coke from blends of Pittsburgh-bed (Warden mine) coal and low-temperature Disco coke carbonized in 18-inch retorts at 900° C.

Test No.	Composition of charge	Disco coke: Volatile matter, percent	Disco coke: Size through, inch	Resulting coke: Yield percent	Resulting coke: Apparent specific gravity	Resulting coke: 1-1/2-in. shatter index	Resulting coke: 1-in. tumbler index	Resulting coke: 1/4-in. tumbler index
128-A-1	90 percent Warden coal and 10 percent Disco	19.9	1/8	70.6	0.87	78.7	50.6	65.0
128-A-2	90 percent Warden coal and 10 percent Disco	19.9	1/16	70.5	.88	68.7	51.6	68.2
128-B-1	80 percent Warden coal and 20 percent Disco	19.9	1/8	72.0	.87	69.9	50.8	65.4
128-B-2	80 percent Warden coal and 20 percent Disco	19.9	1/16	71.9	.91	69.0	51.1	68.8
128-C-1	90 percent Warden coal and 10 percent Disco	17.8	1/8	70.8	.86	79.8	50.4	67.3
128-C-2	90 percent Warden coal and 10 percent Disco	17.8	1/16	70.7	.89	68.6	53.3	71.1
128-D-1	80 percent Warden caol and 20 percent Disco	17.8	1/8	71.0	.89	72.4	51.0	68.6
128-D-2	80 percent Warden coal and 20 percent Disco	17.8	1/16	72.3	.89	77.6	54.3	68.6
128-1	100 percent Warden coal			69.0	.86	76.9	50.8	67.3
28 1/	do			68.8	.88	68.0	55.2	71.5
56A	80 percent Warden coal and 20 percent Pocahontas No. 3-bed coal			84.0	.90	77.0	58.8	71.4
57A	80 percent Warden coal and 20 percent Pocahontas No. 4-bed coal			84.3	.91	79.5	60.3	71.8

1/ Original sample.

The Golden (Colo.), Field Station has conducted systematic tests on coking properties of coals from western mines. Since November 1943 about 75 samples from Colorado, New Mexico, and Utah have been tested and the results summarized in table 12. The coking indexes given in the table have certain significance. For example, a coal having a combined coking index of less than 2.50 is a noncoking coal and will not fuse when carbonized. If the combined coking index is between 3.00 and 4.00, the coal has possible commercial coking properties, and, if the index is more than 4.00, the coal is suitable for coking in byproduct ovens. Likewise, the calculated coking index, obtained from the ultimate analysis of the coal,77/ is a guide in estimating coking or plastic properties of the coal. If the calculated coking index is less than 1.00 the coal is noncoking. If this index is between 1.00 and 1.10 it is a borderline coking coal and if above 1.20 the coal can be coked in byproduct ovens. The coking properties improve as the index increases in value.

Blending of different coals is being tried to improve coke structure. Low-volatile coking coal is in demand but because of the scarcity of coal of this rank in the Rocky Mountain region, Arkansas coal is now shipped to the west coast for blending purposes. It has been observed at the Kaiser coke plant, Fontana, Calif., that about 12 percent of low-volatile Arkansas coal with Carbon County (Utah) coal improves the structure of coke.

Byproduct Coke-Oven Tests of Washington Coals

The increased industrial activity on the West coast as a result of war conditions, curtailment of shipping, the Government program for utilization of water power from the Bonneville and Grand Coulee Dams, and the stimulus given by the national defense and war programs have all contributed to the expansion of the coking industry. An investigation was made to explore the possibilities of installing a Curran-Knowles byproduct coking plant in the Puget Sound area of Washington for utilizing Roslyn, McKay, and Wilkeson coals alone, in combination, or mixed with petroleum carbon or petroleum coke.78/ The principal problem, aside from that involving markets and other economic questions, concerned the suitability or amenability of the proposed method of coking in sole-heated ovens, the yields, and physical and chemical properties of coke made from representative coals under typical operating conditions.

77/ See footnote 59, p. 34.
78/ Yancey, H. F., Daniels, J., McMillan, E. R., and Geer, M. R., Byproduct Coke-Oven Tests of Washington Coals: Bureau of Mines Rept. of Investigations 3717, 1943, 46 pp.

TABLE 12. - Agglutinating, swelling, and plastic properties of Colorado, Utah, and New Mexico coals

Colorado

Coal No.	Date sampled	Mine	Bed	County	B.S.S.T.1/	Agglut. index	Plastometer			Coking indexes	
							Index	S.P., °C.	M.P., °C.	Comb.	Calc.
15	11/43	Tripple S	Fruita	Archuleta	5.14	4.6	3.68	375	433	4.46	1.10
16	11/43	Yellow Jacket	Yellow Jacket	do.	8.13	6.1	4.54	371	418	6.58	1.38
33	12/43	Carbon Junction	Unknown2/	La Plata	8.25	4.4	2.66	381	442	5.42	1.26
26	11/43	Castle	-	do.	5.38	4.6	3.87	372	421	-	-
34	12/43	Coal King	Hesperus	do.	5.91	3.7	3.97	373	424	4.72	1.15
12	10/43	Dufur	do.	do.	5.03	3.6	3.16	381	434	4.19	1.11
13	10/43	Durkan	do.	do.	1.97	2.2	1.94	385	435	2.50	.99
17	11/43	Fort Lewis	-	do.	4.47	4.1	3.74	375	428	4.32	1.11
14	11/43	Haygulch	Hesperus	do.	1.81	.2	.67	395	446	-	-
27	11/43	King	-	do.	5.81	3.8	2.73	383	436	-	-
-	1/44	King Coal	Hesperus	do.							1.23
32	12/43	Morning Star	-	do.	6.44	4.7	4.86	363	408	-	-
24	11/43	O.K.	-	do.	1.63	.3	.77	382	437	-	-
-	1/44	Peacock	Hesperus	do.							1.23
28	11/43	Sunshine	-	do.	8.28	4.1	4.16	368	416	-	-
35	1/44	Supreme	Hesperus	do.	4.88	4.3	3.42	374	428	4.79	1.28
25	11/43	Victory	-	do.	6.58	4.3	4.05	370	417	5.50	1.33
10	10/43	Wright #1	Hesperus	do.	4.91	4.2	4.03	372	418	4.77	1.22
11	10/43	Wright #2	do.	do.	5.21	3.9	3.74	377	424	4.69	1.21
50	5/44	Anchor (Eureka)	Unknown	Las Animas	5.19	5.20	4.25	369	420	5.17	1.23
54	5/44	Baldy	No. 2	do.	2.62	2.50	1.24	385	440	3.52	1.39
58	5/44	Bear Canon 6	Bear Canon 6	do.	8.64	6.0	4.73	366	412	6.69	1.36
55	5/44	Berwind Canyon	Tabasco	do.	2.00	2.1	2.11	385	437	3.74	1.48
60	4/44	Boncarbo	Primero	do.	7.62	7.2	4.46	366	418	5.78	1.32
45	4/44	Frederick	Frederick	do.	8.75	9.4	5.30	366	396	8.30	1.56
57	5/44	Green Canon	Alta	do.	2.50	2.8	1.32	384	441	2.93	1.13
53	5/44	Grey Creek	No. 4	do.	7.62	4.3	3.29	376	430	6.05	1.50
59	5/44	Lovato No. 2	Primero	do.	8.50	7.7	4.35	368	415	6.88	1.32
44	4/44	Morley	Lower Seam	do.	5.50	4.6	3.93	371	423	5.53	1.42
51	5/44	3/	Cameron	do.	1.75	.1	.44	390	426	-	-
56	5/44	Taylor	Tabasco	do.	5.12	4.3	3.42	375	433	4.85	1.28
49	5/44	Thor	-	do.	3.62	3.5	3.45	371	436	-	-

51	5/44	3/	Cameron	do.	[illegible]	4.3	3.42	375	433	4.85	1.20
56	5/44	Taylor	Tabasco	do.	5.12	4.3	3.42	375	433	-	-
49	5/44	Thor	-	do.	3.62	3.5	3.45	371	436	-	-

TABLE 12. - Agglutinating, swelling, and plastic properties of Colorado, Utah, and New Mexico coals (Cont'd.)

Coal No.	Date sampled	Mine	Bed	County	B.S.S.T.1/	Agglut. index	Plastometer			Coking indexes	
							Index	S.P., °C.	M.P., °C.	Comb.	Calc.
				Utah							
5	6/43	Columbia	Lower Sunnyside	Carbon	3.06	2.6	1.97	381	433	3.01	1.05
23	11/43	do.	do.	do.	4.82	3.3	2.43	382	436	3.85	1.10
4	6/43	Kaiser #2	do.	do.	4.44	2.9	3.41	372	438	3.86	1.08
21	11/43	do.	do.	do.	5.16	3.5	2.67	383	442	4.09	1.12
3	6/43	Sunnyside #1	do.	do.	4.72	2.8	4.00	370	421	4.25	1.17
20	11/43	do.	do.	do.	5.81	3.9	4.80	366	421	4.02	1.18
1	5/43	Castle Valley	Lower Hiawatha	Emery	2.00	.4	.57	383	418		
6	6/43	Geneva	Lower Sunnyside	do.	4.00	2.8	1.90	384	434	3.22	1.02
7	6/43	do.	do.	do.	4.44	3.0	2.76	382	432	3.74	1.09
8	8/43	do.	do.	do.	4.31	3.3	2.81	376	435	3.73	1.06
22	11/43	do.	do.	do.	4.25	3.2	1.74	383	435	3.36	1.03
2	5/43	Jim Peterson	do.	do.	4.60	3.1	3.15	374	425	3.75	1.02
				New Mexico							
41	4/44	Brilliant #2	Raton	Colfax	7.81	4.8	4.12	371	414	6.20	1.42
-	5/44	Brilliant #2	do.	do.	-	-	-	-	-	-	1.37
46	4/44	Dawson No. 6	do.	do.	5.60	6.0	5.22	361	415	5.87	1.29
47	5/44	Denton	-	do.	3.69	3.9	3.59	373	436	-	-
43	4/44	Franks	Unknown	do.	4.16	4.6	3.40	377	442	4.36	1.15
52	5/44	Joe Sonehar	-	do.	4.50	3.7	2.05	384	440	-	-
40	4/44	Koehler 1 & 2	Raton	do.	4.80	5.1	3.84	370	425	4.72	1.13
-	5/44	do.	do.	do.	-	-	-	-	-	-	1.18
48	5/44	New Yankee #1	-	do.	4.56	4.8	2.91	378	437	-	-
42	4/44	Van Houten #4	Raton	do.	4.72	4.5	3.76	370	425	4.71	1.21
-	2/44	Viava	Black Diamond	McKinley	-	-	-	-	-	-	.89
-	3/44	Boardman	Grenko	do.	-	-	-	-	-	-	.88
-	3/44	Formerly Morris	Upper Seam	do.	-	-	-	-	-	-	.86

TABLE 12. - Agglutinating, swelling, and plastic properties of Colorado, Utah, and New Mexico coals (Cont'd.)

New Mexico (Continued)

Coal No.	Date sampled	Mine	Bed	County	B.S.S.T.1/	Agglut. index	Plastometer Index	Plastometer S.P., °C.	Plastometer M.P., °C.	Coking indexes Comb.	Coking indexes Calc.
-	2/44	George	Aztee	McKinley	-	-	-	-	-	-	.86
-	2/44	Mentmore 1 & 2	No. 1	do.	-	-	-	-	-	-	.88
-	2/44	Mutual	Lower Measures	do.	-	-	-	-	-	-	.86
-	3/44	do.	No. 2	do.	-	-	-	-	-	-	.87
-	2/44	Navajo #5	No. 3-1/2 #5	do.	-	-	-	-	-	-	.88
-	3/44	Soper	-	do.	-	-	-	-	-	-	.90
-	2/44	South Western	Black Diamond	do.	-	-	-	-	-	-	.89
30	12/43	Amargo	Lower Seam	Rio Arriba	5.22	4.3	3.86	371	426	4.76	1.19
-	12/43	Caranta	Upper & Lower	do.							1.21
29	12/43	Rainbow	Upper Seam	do.	5.41	5.1	4.15	366	421	6.49	1.68
-	2/44	Black Diamond	Lower Bench	San Juan							.80
39	2/44	Morgan & Thomas	Local Seam	do.	3.90	3.5	.53	390	433	3.04	1.03
36	2/44	Smouse	Upper Bench	do.	1.00	.0	3.26	391	Slight	.23	.89
37	2/44	Stallings	Lower Bench	do.	1.00	.0	3.02	405	Slight	.29	.89
38	2/44	Toadlena	Unknown	do.	1.00	.0	2.00	400-415	Slight	.49	.86

1/ British standard swelling test, average of 8 buttons.
2/ Bed 40 feet thick or more.
3/ Southern Black Diamond Coal & Oil Co.

The Curran-Knowles oven process is adapted to the carbonization of the coals mined at Roslyn and Wilkeson and will successfully coke blends of these coals with petroleum carbon. Box tests indicated that petroleum coke can be used as well as petroleum carbon. McKay coal, from Ravendale, does not appear at this time to be suitable for improving coke, but its value as a low-ash constituent should not be overlooked if future development of these coals warrant its use. All the coals and blends yielded commercial coke with relatively low sulfur, between 0.3 and 0.5 percent. The total yields, calculated on as-received basis, average 71.0 percent. The shatter and tumbler tests indicate generally that the coke breaks more readily than some of the cokes formerly available in local Northwest markets, but not to the extent that this property would be markedly disadvantageous. The conclusion was reached that these coals, or blends of generally similar combinations, will yield cokes suitable for domestic, smelter, general industrial, metallurgical, electrochemical, and electrometallurgical purposes. The phosphorus content might prohibit employing these coals for some highly specialized uses in the electrometallurgical field, especially for making ferro-alloys. Water-gas manufacture can be carried out with some of the strongest of these cokes, and some can be used for foundry and iron blast-furnace purposes if conventional operating practices are modified or if the present rigorous specifications for such cokes can be altered.

Tests of the Heliopore Coal-Carbonization Power-Plant Process

The Congress provided that the Bureau of Mines should erect and test a pilot plant embracing the principles of the Heliopore coal-carbonizing, power-plant process.[79] The plant was installed and put into operation at Golden, Colo. Preliminary tests showed that the Heliopore plant, as originally constructed, needed modification to enable the coal and char to flow through the retort so that fair tests could be conducted. In the main, the retort lacked adequate heat-transfer area. To remedy this condition, a coal drier was designed and installed on top of the retort. This unit dried and preheated the coal charge by means of the exhaust hot gas before the coal entered the retort proper. Further tests yielded data that should be of value in the further development of continuous retorts for coal carbonization. Hot gas at 1,629° F. supplied the retort with 411,000 B.t.u. per hour, of which 258,000 B.t.u. per hour or 62.8 percent was transferred to the retort and drier. The coal feed averaged 362 pounds per hour. The average effective coal-carbonization temperature attained was 1,331° F. The temperature differential between the hot gases and the char at the point where the hot gases entered the retort was 298° F. The average differential in temperature between the hot gas and the coal or char throughout the drier and retort was 316° F.

The byproducts from these tests, on the basis of percent by weight of coal as charged, were: Char, 52.3; tar, 4.4; liquor, 28.0; and gas, 15.3. The yield of gas, measured at 60° F., 30 inches of mercury pressure, and saturated with water vapor was 3.25 cubic feet per pound of coal as charged.

79/ Fieldner, A. C., Davis, J. D., Parry, V. F., Schmidt, L. D., Elder, J. L., Goodman, J. B., Landers, W. S., and Goodwin, E. W., Tests of the Heliopore Coal-Carbonization Power-Plant Process: Bureau of Mines Rept. of Investigations 3733, 1943, 36 pp.