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**The Technical and Economic Aspects of the Use of Anthracite**

**Fines in By-Product Coke Production**

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**The School of Mineral Industries of the Pennsylvania State College**

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# The Technical and Economic Aspects of the Use of Anthracite Fines In By-Product Coke Production

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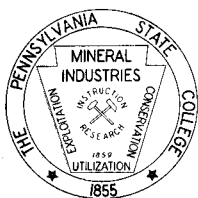
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Problems for investigation are selected by the Anthracite Research Advisory Committee the membership of which follows:

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## SUMMARY

The various attempts to manufacture and use coke made from coal mixtures containing various percentages of anthracite in admixture with bituminous coal and/or pitch are presented in chronological order in the introduction and historical review. The earliest work was carried out in Great Britain and on the European Continent over a century ago, while the earliest work in the United States appears to be that reported by Platt in 1879. Following the unfavorable report by Platt there was a long period, lasting until about the time of World War I, during which little or no work seems to have been done on the manufacture of anthracite blend coke in the United States. Since then the trend has been toward the use of bituminous coal alone as the binder for agglomerating the anthracite particles, toward the use of less anthracite in the blending experiments and recently toward the use of only small amounts of anthracite fines carefully blended with regularly used coking coals, the mixture being carbonized in standard by-product ovens.

The technical aspects of blending anthracite with regularly used coking coals for the manufacture of coke are discussed in detail with emphasis on the several factors which may be expected to influence both quality and yield of the carbonization products. Among the more important considerations are: the effect upon yields of coke and by-products of the quantity of anthracite blended; the effect upon the quality of the coke and by-products of the quantity and quality of the anthracite blended; the effect upon the coking time of the quantity and quality of the anthracite blended; the effect upon the quality of the coke of the size of the anthracite and the relative size of the anthracite and bituminous coal; and the effect upon quality of coke of the degree of mixture or blending of the coals used in the blend. Laboratory- and plant-scale experimental data and plant operating results are presented and discussed.

Throughout the report, wherever possible, general equations are developed by means of which the effect of anthracite can be evaluated from readily available data, and specific examples are worked out for the effect of additions of anthracite to one particular bituminous coal blend that is used in considerable quantities in the anthracite marketing area.

A general equation is developed by means of which the probable yield of coke per ton of coal charged can be calculated for blends containing anthracite. For bituminous coals of the type normally used throughout the anthracite marketing area, the yield of coke increases approximately 0.1 per cent for each per cent of anthracite added to the blend.

For use in modern by-product ovens, the available evidence indicates that additions of anthracite in excess of about 10 per cent affect the size distribution and physical properties of the coke adversely. The maximum upgrading in shatter index of the coke is reached at about 10 per cent anthracite, while the tumbler test stability and hardness factors appear to show a slight but progressive decrease with increasing additions of anthracite. Up to at least 10 per cent anthracite additions, the properties of the coke appear to be entirely satisfactory for non-blast-furnace uses.

For use in modern blast-furnace operations in America, anthracite blend cokes are still in the experimental stage and insufficient factual information is available to formulate generalizations. Early trials in European furnaces apparently gave satisfactory performance.

Plant-scale operations using anthracite in the coking blend have demonstrated that in some cases the addition of small percentages of anthracite permit the use of shorter coking times which allow an increase of throughput conservatively estimated at 10 per cent. Additions of anthracite in excess of about 10 per cent appear not to effect a further reduction in coking time.

The yield and heating value of the gas from the carbonization of anthracite is less than that from an equal weight of bituminous coal. For low- and medium-volatile anthracites the yield and thermal value of the gas may be expected to average about 5.3 MCF and 1.8 million Btu., respectively, per ton of coal. Additions of anthracite to bituminous coal will, therefore, reduce both the yield and quality of the gas per unit weight of blend carbonized. The reduction in volume per unit weight of blend carbonized is about 0.5 per cent for each per cent of anthracite added, while the reduction in thermal value is about 0.6-0.7 per cent for each per cent of anthracite added. Because of increased throughput, however, the use of anthracite permits an increase in the daily gas production. Calculated to an equivalent heating value, the increased daily gas production may be as much as 5 to 6 per cent. Additions of anthracite greater than 11 per cent result in a decreased yield of gas on both the daily and the per ton of coal or coke basis.

Available data suggest that anthracite has no residual value for the production of by-products other than gas and may be considered as an inert diluent. The by-product yield per ton of blend carbonized is therefore inversely proportional to the percentage of anthracite used in the blend. As with gas yield, however, the increased throughput counteracts the decrease in yield per unit weight, and increases in the daily by-product yield up to about 5 per cent should be possible with small percentages of anthracite. Addition of anthracite in excess of 8 per cent will probably result in a decrease in daily yield as well as the yield per ton of coal or coke.

The necessity for giving attention to the nature and quality of the anthracite used for blending purposes is indicated. In many unsuccessful blending experiments, it has been found that part of the fault undoubtedly lies in the use of anthracites of a soft, friable and/or decrepitating nature. Part of the success attained in recent regular plant-scale operations is believed to be due to the careful selection of a hard anthracite, free from undesirable friability and decrepitation characteristics.

Although anthracite fines may contain a high percentage of ash, the preparation of No. 5 buckwheat size generally produces a product which is satisfactory for blending purposes, and where the percentage of anthracite in the blend does not exceed about 10 per cent, no marked increase in the ash content of the resultant coke is produced. Replacing a bituminous coal blend, which produces coke containing from 5 to 8 per cent ash, with

anthracite containing 83 per cent fixed carbon plus ash, will, for each per cent of anthracite replacing the bituminous coal blend, result in an increase in ash content of the anthracite blend coke equivalent to about 0.06 per cent with an anthracite of 10 per cent ash content, 0.14 per cent with an anthracite of 15 per cent ash content, and 0.20 per cent for an anthracite of 20 per cent ash content. A general equation has been developed for calculating the ash content of the coke made from a coal blend containing bituminous coal and anthracite.

Experimental evidence indicates that no difficulty should be experienced from the sulfur and phosphorus in anthracite because these elements are present in amounts smaller than those usually found in bituminous coking coals. Since the ash-fusion temperature of anthracite ash is generally high, no trouble is likely to be encountered in this connection.

In early work, very little attention was given to the effect of the screen size or the size consist of the anthracite used for blending. This was followed by a period, during which much emphasis was placed on the value of pulverizing the anthracite and even the bituminous coal to a fineness that would be impractical for regular by-product practice. Recently, however, it has been shown that anthracite fines of buckwheat No. 5 size (approximately 20- x 100-mesh), when blended with coking coal, will produce a coke of satisfactory quality for foundry use, and possibly for use in the blast furnace. It is essential that oversize anthracite particles be absent as they tend to cause points of weakness in the coke.

One of the principal causes of poor results in the carbonization of mixtures of anthracite fines and coking coals is the failure to mix the various components satisfactorily. The anthracite particles must be thoroughly dispersed throughout the bituminous coal if satisfactory agglomeration of the mass is to be obtained. Segregation of the anthracite, resulting from inadequate mixing, frequently produces an unsatisfactory coke due to localized weakness in the coke caused by poor agglomeration of a group of anthracite particles.

Information describing the recent and current use of No. 5 buckwheat anthracite in the manufacture of by-product coke is presented; at least four different plants are known to be using about 5 per cent of anthracite in their coking blends with apparent satisfaction.

The economic feasibility of blending less than 20 per cent of anthracite with coking coals in regular by-product practice and the effect of up to 20 per cent of anthracite on the returns from the carbonization products are discussed. It is possible to obtain a net increase in the daily returns from the carbonization products by virtue of the fact that in blending less than 10 per cent of anthracite the decrease in yields per ton of coal or coke is offset by the increased throughput.

The market value of anthracite at the coke plant and at the colliery is estimated for two different cases, with the coke plants located within the anthracite marketing area and contiguous to the metropolitan areas of Southeastern Pennsylvania and New York-New Jersey. In the first case, con-

ditions as of April, 1943 are used, and it appears that No. 5 buckwheat size anthracite for blending purposes may be worth roughly \$4.20 per net ton at the coke plant and roughly \$2.00 per net ton at the colliery. The results suggest that under the present conditions the blending of anthracite will be economically feasible for the coke plant operator and also show a fair return for the anthracite producer. In the second case, where conditions such as may be expected in more "normal" times prevail, the cost of the bituminous coal may be expected to be somewhat lower and as a result, the value of the anthracite is correspondingly less. The variety of factors that enter into the final determination of the value of the anthracite for blending purposes are too complex to permit generalizations; therefore, a general equation has been developed by which the value of anthracite can be calculated for conditions prevailing at any time and at any specific coke plant, providing the necessary data on cost of coal and value of products are available. Two other equations have been included, which permit the anthracite producer to determine the value of the No. 5 buckwheat in terms of moisture content, and to estimate the possible advantages and disadvantages of drying the coal prior to shipments. Under present conditions reducing the moisture content of the anthracite from 12 to 4 per cent would increase its value by 38 cents per ton for delivery in the Southeastern Pennsylvania area.

The potential markets for No. 5 buckwheat anthracite as a blending agent in coke production are discussed. Available information indicates that for the immediate future a potential nonfurnace coke production market of about  $\frac{1}{2}$  million tons exists throughout the anthracite marketing area. About 100,000 tons of this market is in the Eastern Pennsylvania area. Assuming a coke could be produced as a result of further investigation which would be suitable for blast-furnace use, the potential markets in the anthracite marketing area would be increased by 1 to  $1\frac{1}{2}$  million tons per year.

## CONCLUSIONS

An analysis of technical and economic data available from published and private sources leads to the following conclusions concerning the use of anthracite as a blending agent in the by-product coking process.

- (1) For carbonization in regular by-product ovens the use of more than 20 per cent anthracite in the blend has not proved feasible for the production of coke. Much of the evidence indicates that 10 per cent anthracite is about the practical limit.
- (2) The cokes produced from blends containing up to 10 per cent anthracite have been found entirely satisfactory for use in foundries and a number of foundries are now operating on such cokes.
- (3) The cokes produced from blends containing anthracite should be satisfactory for other non-blast-furnace uses, such as for water-gas generator and domestic fuel, but such cokes would be directly competitive with the prepared sizes of anthracite.
- (4) The cokes produced from blends containing small percentages of anthracite fines are not, as yet, generally acceptable for modern blast-furnace use. It is claimed by some operators that anthracite blend cokes possess a deficiency in certain desirable strength characteristics which is reflected in a disturbance of the blast-furnace operating cycle. Recently, however, at least one blast furnace plant has reported favorably on the use of 5 per cent anthracite in their coking blend, and several other plants are reported to be trying the use of  $2\frac{1}{2}$  to 3 per cent.
- (5) In the manufacture of anthracite blend coke, the adequate mixing of the anthracite and the bituminous coals is essential. Complete dispersal of the anthracite particles throughout the bituminous coal prevents localized weaknesses which may result from segregation of the anthracite.
- (6) Available evidence indicates that anthracite fines of buckwheat No. 5 size need not be pulverized in order to obtain satisfactory anthracite blend cokes.
- (7) The use of several per cent of anthracite will permit a reduction in the coking time and consequently an increase in throughput conservatively estimated to amount to at least 10 per cent. The increased throughput will vary with particular conditions and there is no evidence which indicates that increasing the percentage of anthracite will permit further reductions in the coking time.
- (8) The yield of coke per ton of coal increases with increasing percentage of anthracite in the anthracite-bituminous coal blend. The yield of tar, light oil, and ammonia per ton of coal decreases as the percentage of anthracite in the anthracite-bituminous blend is increased.

ed. The gas yield also decreases with increasing percentage of anthracite, but because the anthracite yields some gas the decrease is less rapid than for the other by-products.

- (9) A net daily increase in the yields of all products is possible due to increased throughput if not more than about 8 per cent of anthracite is used.
- (10) The thermal yield of the gas resulting from the carbonization of an anthracite-bituminous blend decreases with increasing additions of anthracite.
- (11) The value of anthracite for blending purposes at the coke plant decreases as the value of the bituminous coal at the coke plant decreases.
- (12) The value of anthracite for blending purposes at the coke plant decreases as the value of the gas increases.
- (13) The increase in value of buckwheat No. 5 anthracite as a result of drying to a lower moisture content is directly proportional to the value of the wet anthracite fines at the coke plant.
- (14) The value of the anthracite appears not to be affected by changes in the average value of the coke.
- (15) The increased throughput made possible by the blending of several per cent of anthracite fines with bituminous coal in regular by-product coking practice results in a decrease in conversion costs.
- (16) The immediate potential market for buckwheat No. 5 anthracite as a blending agent in by-product coking is approximately  $\frac{1}{2}$  million tons per year in the normal anthracite marketing area.
- (17) If a coke suitable for blast-furnace use can be developed using up to 10 per cent anthracite in the coking blend, the additional potential market would be about  $1\frac{1}{2}$  million tons per year.

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# CHAPTER I

## INTRODUCTION AND HISTORICAL REVIEW

The problem of economic utilization of anthracite fines, culm, or small sizes is by no means new and has troubled anthracite producers both here and abroad since the earliest days of the industry. Several methods of utilization have been suggested, some of which have operated on an industrial scale, but for the purposes of this report discussion is confined exclusively to the problem of utilizing anthracite fines in the manufacture of coke.

The desirability of blending bituminous coals with each other, with coke, or with anthracite has been recognized for many years. Over 100 years ago, Cruickshank clearly described, in British Patent 8141 (1839), the advantages of blending strongly coking coals with noncoking coal in order to improve the quality of coke. Reports are to be found in the literature of the actual use of anthracite blended in admixture with coking coals, pitch, or mixtures of coking coal and pitch in both Great Britain and on the Continent prior to 1850. Not until a quarter of a century later, however, is there any record of such attempts being made in America.

Cazin<sup>1</sup> claims to have experimented with an anthracite coke in Germany as early as 1855, using only bituminous coking coal as binder. Foley<sup>2</sup> in 1875 stated that he was associated with experiments on the manufacture of anthracite coke begun in 1859 by the Bonvilles Court (Coal) Company of South Wales, and that anthracite coke had been manufactured as needed since that time. The anthracite coke contained from 60-70 per cent anthracite, with bituminous coal and pitch as binders. Coking had been carried out in different types of ovens, but principally in the ordinary "beehive" oven. The coke was claimed to produce "superior anthracite finished iron" and to have been used in the blast-furnaces of the company for many years. About 1862 Riley<sup>3</sup> conducted experiments on the manufacture of anthracite coke in the south of France, using anthracite and pitch, and claimed to have made "some very good coke."

In 1875 Siemens<sup>4</sup> pointed out that the process of making artificial coke from anthracite and binding material was, of course, not new—that he had first seen it in operation many years before at the Creuzot Works and had then formed a very favorable opinion of the coke produced. Samuelson<sup>5</sup> remarked in reference to Siemens' comments on experiments at Creuzot that the "practice was continued up to the present day (1875)." The proportions of "exceedingly dry coal" (semianthracite) and bituminous coal were about half and half, ground together and coked in Appolt ovens. The yield of coke was 70-72 per cent and the ash content was high; despite this the coke gave "a most excellent yield" in a blast furnace.

The process of Penrose and Richards of Swansea, Wales, for the manufacture of anthracite coke was described by Hackney<sup>6</sup> in 1875. In this process 60 per cent anthracite, 35 per cent bituminous or binding coal, and 5 per cent pitch were mixed and crushed by passage through a "Carr's disin-

tegrator" and then coked in the ovens (15 feet long; 5 feet, 7 inches and 6 feet, 2 inches wide; and 4 feet, 4 inches to the underside of the arch; charge about 4 tons) employed at that time in South Wales. It was claimed that the resultant coke was "so hard, indeed, that it scratches glass with comparative ease." The yield of coke was 80 per cent of the weight of the charge and the density of the coke about 23 per cent greater than coke made from the best Welsh bituminous coal. In addition, the coke was observed to burn away in a fire or under blast without showing any tendency to crumble or decrepitate, while, so far as it had been tried at the time, both in the cupola and in the blast furnace, the anthracite coke had given "remarkably good results," presumably when compared with Welsh cokes. It was claimed that in a small foundry cupola, in which 1 pound of good Welsh coke melts 10 pounds of iron, 1 pound of anthracite coke melts 16 pounds and the metal is hotter when tapped out. In a trial at the Italian Government Arsenal at Turin, the anthracite coke had been tested in a foundry cupola against the best Durham coke and the saving in fuel per ton of pig iron melted was reported to have amounted to 20 per cent, and as much iron had been melted with the anthracite coke in 20 hours as with Durham coke in 24 hours. A test in a blast furnace of the Landore Siemens' Steel Company showed an improvement in the quality of the pig iron produced when the furnace was operated on the anthracite coke as contrasted with operations using good ordinary coke of the district, but Siemens was inclined not to place too much weight on the results because he doubted whether the results with anthracite coke would show a similar improvement when compared with Durham coke.

The work described by Platt<sup>7</sup> in 1879 appears to have been the first reported on the manufacture of anthracite coke in the United States. This work was instituted as a result of that reported by Hackney in 1875 and, except for some analytical work in the laboratories of the Pennsylvania Geological Survey, all of the work, full-scale as well as laboratory experiments, was conducted at the Cambria Iron Works, Johnstown, Pennsylvania, between 1875 and 1879. The work reported by Platt gives more detailed quantitative information about procedures and results than any reported previously. Experiments are reported in which the effect of the size of the anthracite used is considered, but unfortunately there are no quantitative data concerning the actual screen size. It was found that fine anthracite or "dust" produced a stronger coke than "mingled dust and small coal," that a 50-50 blend or mixture of anthracite fines and bituminous coal "made a firm, tough, silvery, strong coke" and that increasing percentages of anthracite produced a progressively weaker coke, with coke containing more than two-thirds anthracite (presumably only bituminous coal supplying the binding material) being entirely worthless for purposes requiring the carrying of any burden. Platt further observed that "the decrease in strength in the coke was not directly proportional to the decrease in the percentage of bituminous coal, but it fell off sharply and with marked changes in strength

when the bituminous coal percentage had been only slightly diminished." Fifty years later Marson, according to Mendelsohn<sup>8</sup>, demonstrated that the shatter indices of coke produced from blends of coal are nonadditive in nature.

The full-scale coking experiments at Johnstown were conducted in 30-inch Belgian ovens, and it was stated that "in examining the cokes made it is clearly shown that complete coking extends inwards only about 8 to 10 inches from the sides, the middle of the mass in every case being much less perfectly coked. These well-coked sides are much stronger and better coke than any taken for testing, and the best of it is what would be yielded by coking the mixture in long narrow ovens." Platt believed that pitch was not necessary to produce an anthracite coke; at least the laboratory tests and Belgian oven tests at Johnstown so indicated. Two series of full-scale oven tests were made at Johnstown. The first was made with anthracite slack from the Cameron Colliery, the second with slack from Williamstown. The bituminous coals used were from the Pittsburgh seam at Latrobe and Connellsville, respectively. The yield of anthracite coke ranged from about 72 to 76 per cent (approximately 4-ton charges of coal). Four trial runs in a cupola at the foundry of the Cambria Iron Works, using a 48-hour anthracite coke from a 50-50 anthracite mixture made from Williamstown anthracite and Connellsville coal, gave results which, when compared with Connellsville coke, led to the following conclusions: (1) Anthracite coke has a lower melting capacity. (2) It requires more time to do the same work; however, this does not prove that better results may not be obtained by further tests. (3) Anthracite coke crumbles badly in handling, "also seems to leave a cinder in cupola very hard to separate from brick when cleaning."

Platt concludes his report on anthracite coke with the following statements:

"In view of the results it is not necessary to enter into calculations to show the cost at which 'anthracite coke' could be produced in large quantities. If the material as made at the Johnstown ovens be a fair sample of what might be expected as the average product—and the record of the charges as given . . . is evidence that much care was exercised—the conglomerate fuel could not compete at present (1879) either with coke or anthracite coal."

Evidently the highly unfavorable results obtained in these early tests at Johnstown effectively inhibited much experimentation with anthracite coke in the United States for a considerable number of years, because no work on the subject appears to have been reported for about the next 35 years. Then, about 1918, experimental work was initiated by Markle<sup>9</sup> who, after extensive laboratory and full-scale oven tests, was granted two U. S. Patents, 1,287,382 (1918) and 1,407,700 (1922) on a "Process of Forming Fuel." In the first, anthracite culm and hard pitch were mixed in proportions of about 83 to 17, respectively, and the volatile matter driven off by carbonization.

In 1921<sup>10</sup> Markle described the process and the resultant product which was called "Anthracol" or "Anthrac." "Anthracol," according to Markle, "is a mixture of small particles of anthracite coal and a matrix of practically pure carbon formed from the distillation of coal-tar pitch or other suitable bitumen. It is a hard, dense, homogeneous mass with a silvery luster and in color varies from silvery to grayish black." The "Anthracol" yield was 87 per cent when using 17 per cent pitch with 83 per cent anthracite culm. In the second patent Markle claimed that he could obtain substantially the same results as reported in the first patent by substituting coking bituminous coal for pitch, using not less than 60 per cent anthracite slack nor more than 40 per cent coking bituminous coal. The desirability of fine grinding and intimate mixing of the constituents was stressed if a good product were to be obtained. Most of the early workers had also observed the value of thorough mixing and noticed the detrimental effect of coarse sizes in the mixture.

One curious observation by Lawrence<sup>11</sup> in a report on results with a mixture of 10 per cent pitch, 15 per cent soft coal, and 75 per cent culm stands out and suggests that the work on anthracite coke conducted before 1900 had fallen into complete obscurity. Lawrence in 1919 made the following observation: "The product obtained had very little strength, scaled easily, and in every respect was an inferior product. In fact, it was not as good as the product obtained with 10 per cent pitch alone, showing that the addition of the soft coal had a detrimental effect. The reason was that the soft coal apparently coked independently of the rest of the mixture and thus did not give a uniform result. Past experience in trying to coke mixtures of hard and soft coal verify this result also so that further work along this line has been discontinued."

Curiously enough, Markle's second patent, cited above, on using bituminous coal as the binding material in the manufacture of "Anthracol," was granted only three years after this rather pessimistic statement was written.

Markle<sup>11</sup> appears to have been one of the first to give attention to the yields of gas and by-products in the manufacture of anthracite coke, with a record of tests as early as 1920. In 1923 a series of tests showed yields of gas, "Anthracol," and breeze as well as qualitative observations on the physical characteristics of the "Anthracol" from mixtures of 70-30, 65-35, and 60-40, anthracite and bituminous coals, respectively.

Knowles, in personal correspondence with Markle<sup>11</sup> in 1925, described experiments on coking mixtures of anthracite and high-volatile coking coals, presumably in the Knowles oven, and reported:

"Coking anthracite was merely an incident and done in small quantities along with other noncoking coals. The largest charge of anthracite which I coked was about 8 square feet, or 300 pounds, just to see what it would do in mixtures of 30-70, 40-60, 50-50, and 60-40, anthracite and coking coal, respectively—the latter West Virginia (Fairmount) coking slack. . . . The coke was an excellent domestic

fuel—hard, fairly dense, blocky, and burned readily from the open grate to the basement furnace."

The reader will note that in most of the work already outlined the emphasis generally has been on using 50 per cent or more of anthracite fines in the manufacture of anthracite coke. In the work described subsequently, the emphasis tends toward the use of less than 50 per cent anthracite.

In 1930 Mott and Wheeler<sup>12</sup> reported new work on the manufacture of anthracite coke in Great Britain. This work had been carried out as part of the work on the blending of coals for the manufacture of coke conducted under the auspices of the Midland Coke Research Committee and the Iron and Steel Industrial Research Council. The initial experiments were made by means of 300-pound "box tests" in which the sheet iron boxes containing about 300 pounds of coal mixture were charged into a full-size, 21-inch oven along with the regular charge. The boxes were charged with different percentages (0 to 40) of anthracite fines (duff) of less than 1/8-inch size in admixture with a South Yorkshire high-volatile coking coal blend (Parkgate and Silkstone slack) in order to determine the optimum amount of anthracite to use in further full-scale tests. By means of the shatter indices of the resultant cokes it was believed that 20 to 30 per cent anthracite was the optimum range, at least for the particular coking coal and the size of anthracite used. On the basis of this preliminary experiment, full-scale tests were conducted in 14- and 21-inch ovens to study the effect of coking time or rate of coking on the physical characteristics of the cokes made from a 70-30 blend of a South Yorkshire (67 per cent Parkgate—33 per cent Silkstone) coking slack and minus 1/8-inch anthracite duff, respectively. Such characteristics as size analysis, shatter indices, specific gravity and porosity, reactivity toward oxygen, and temperature of combustion were studied. As a result of all the blending work, for several grades of coking coal and various inerts, the following general inferences were drawn: (1) Increasing the rate of heating an oven tends to reduce the size of the coke produced. This applies more particularly to the plus 4-inch and plus 3-inch sizes and less to the proportion of "useful sizes." (2) As in regular coking practice, faster rates of heating tend to give stronger coke. However, it appears from the shatter indices of the anthracite coke that the rate cannot be very much in excess of 1 inch per hour. (3) Increased rate of heating appears to produce a slight increase in the apparent specific gravity of anthracite coke, while the true specific gravity remains practically unchanged. (4) In general, the influence of the rate of heating the oven on the reactivity and temperature of combustion is small and unimportant in comparison with the influence on the size and hardness of the coke. According to Mott and Wheeler, Häusser and Besthorn arrived at the same conclusion as a result of their work with German cokes.

In 1938 Lane and Cobb<sup>13</sup> described experiments on blends of a Welsh anthracite and a Welsh highly caking bituminous coal (Black Vein seam

from Monmouthshire) carbonized at 800°C (1472°F). The proportion of anthracite used was varied from 50 to 80 per cent, the 50-50 coke was the strongest, the 80-20 being only feebly coherent. These investigators reported that the physical properties of the anthracite coke were "very far from being an average of those of its constituents carbonized at the same temperature."

Again in 1939 Mott and Wheeler<sup>14</sup> reported on some work conducted in an attempt to find a substitute for fusain. Anthracite, wood charcoal, electrode carbon, and high- and low-temperature cokes were ground to pass through 200 mesh and coked in box tests in admixture (0 to 7½ per cent) with a South Yorkshire (Parkgate) coking coal. Anthracite was noticeably inferior to fusain and was not as good a substitute as high-temperature coke but was about on a par with electrode carbon and slightly better than K.S.G. low-temperature coke.

The Archbald "Pipestem" Low-Temperature Carbonization Process<sup>15</sup> developed in Pennsylvania during the early 1930's is unique in that it is a continuous process in which a mixture of coking coal and inert carbon, such as anthracite, is wetted with tar and the mixture extruded at a pressure of less than 10 pounds per square inch into tubes installed in a furnace operating at temperatures between 1200°F and 1400°F. The proportions of constituents vary with the volatile matter of the coking coal, a typical mixture containing 60 per cent anthracite and 40 per cent of a low-volatile coking coal. It is stated that operation is better and the coke is stronger if the coal mixture is not ground too fine; however, grinding to minus 10-mesh is the usual practice. The resultant anthracite coke or "Pipestem Coal" is fairly hard and for comparable size it was found to have a lower size degradation than chestnut anthracite. Combustion characteristics and resistance to decrepitation and disintegration upon heating were satisfactory.

Recently various coke oven operators have experimented with coking blends containing up to 20 per cent anthracite fines and have carbonized these blends in modern by-product ovens. Most of the reports on such operations are in the form of private communications and very little detail regarding the coals used, the nature of the blending, or the quality of product is available. In general, the conclusion has been reached, whether entirely justified or not, that addition of anthracite is detrimental for the production of blast furnace coke and advantageous for the production of foundry coke. Few reports have been received concerning the advantages or disadvantages for domestic coke production. The only detailed report on the recent use of anthracite in this country is that of Roberts<sup>16</sup> who describes plant-scale operation using up to 10 per cent anthracite in Piette ovens and states that 4 per cent anthracite is now being used regularly in both Piette and Koppers ovens at The Laclede Gas Light Company in St. Louis. It is noteworthy that, under the prevailing conditions, new experiments on the use of anthracite blend coke in the blast furnace are being conducted.

The foregoing historical review has been presented with the view to show-

ing that the use of anthracite in coking operations is by no means new and is, in fact, as old as the coking process itself. Despite the extensive historical background, however, surprisingly little is really known about the process or why in some cases excellent results are attained, while in other cases dismal failure has resulted. In subsequent sections of this report an attempt is made to analyze the various factors that enter into the use of anthracite in coking blends and to point out where possible the causes for success or failure, the factors of major importance, and the economic possibilities of anthracite as a blending agent.

## CHAPTER II

### TECHNICAL ASPECTS

From the technical viewpoint there are two distinct processes by which anthracite may be utilized in the manufacture of coke. In one the anthracite is blended in relatively small amounts with the bituminous coals normally used for coke manufacture and the resulting blend coked in existing by-product ovens with a view to using more readily available coal supplies, lowering the cost of production, changing the properties of the coke, or increasing the throughput in existing equipment. In the other the object is to produce from anthracite, by addition of pitch, bituminous coal or other suitable binding material a marketable product, called anthracoke throughout this report, by carbonizing the mixture either in existing equipment or in such redesigned equipment as deemed necessary.

For the purposes of this report only the first of these two possibilities will be considered in detail, because under existing war conditions construction materials would not be available for new enterprises unless a special demand existed for the product. Up to the present it has not been fully demonstrated that anthracoke is economic in competition with other fuels nor that the product has special properties that make it more suitable for particular uses. The possible use of existing ovens for anthracoke production does not appear feasible under present conditions because all existing facilities are reported to be operating at or near capacity, producing coke for vital war industries.

The possible use of anthracite as a blending agent in the bituminous coal mixtures normally used at by-product ovens throughout the anthracite marketing area may, however, have especial significance as a war measure because of the transportation difficulties involved in bringing the bituminous coals long distances to the ovens, the increased cost of bituminous coking coals, or the desire for increased coke capacity per oven. In the following sections the various technical factors involved in the use of anthracite fines are discussed in detail.

#### EFFECT OF ANTHRACITE ON YIELDS OF COKE AND BY-PRODUCTS

##### COKE YIELD

The probable yield of coke from actual plant operation, especially when coal blends are used, can be determined exactly only by full-scale oven tests, but considerable information has accumulated in recent years which indicates that in most cases reasonably close approximations of plant yields may be predicted on the basis of analytical data for the coals, or on the basis of small-scale bomb or box tests.

Lowry, Landau, and Naugle<sup>17</sup> have published a statistical analysis of the U. S. Bureau of Mines-American Gas Association carbonization assay data (coals 1 to 55 inclusive) and report that within the limits of experimental

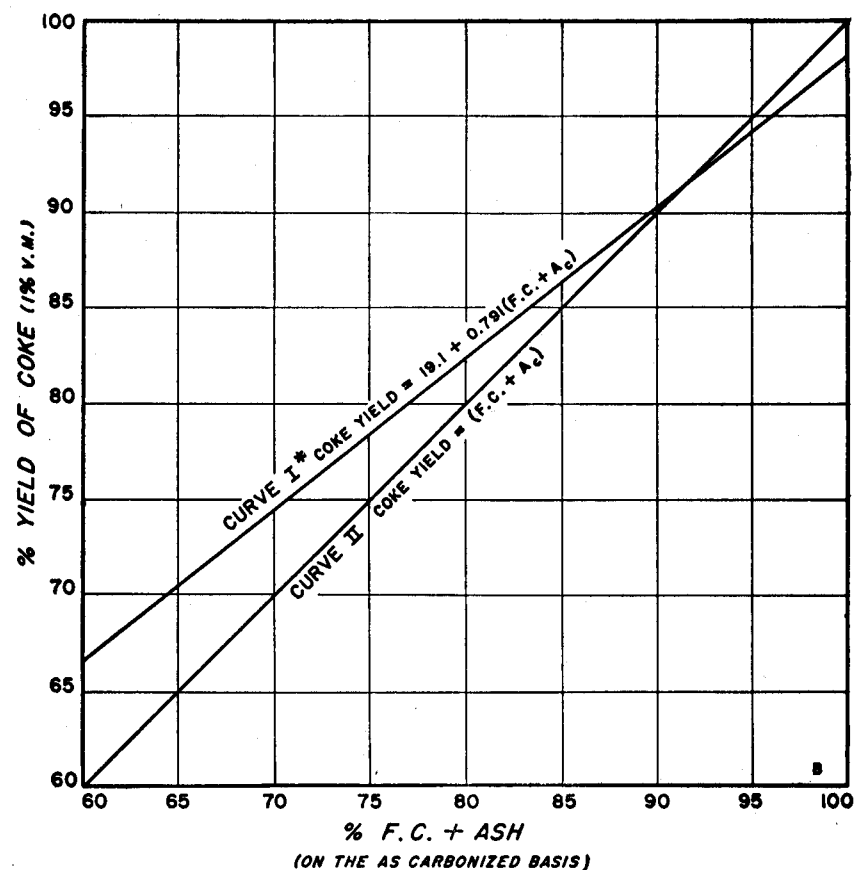
error the yield of coke (K) may be calculated from the fixed carbon (FC) and ash ( $A_c$ ) contents of the coals using Equation 1:

$$\text{Equation 1. } K = a + b (FC + A_c),$$

where "a" and "b" are constants depending upon the apparatus and conditions for coking. For the U. S. Bureau of Mines-American Gas Association apparatus, which carbonizes a charge of 85 to 200 pounds of coal, the con-

FIGURE 1

#### RELATIONSHIP OF FIXED CARBON PLUS ASH AND COKE YIELD IN BM-AGA CARBONIZATION ASSAY TEST



\* BASED PRINCIPALLY ON COALS OF LESS THAN 3% MOISTURE

stant "a" equals 19.2 at 900°C and 19.1 at 1000°C, while the constant "b" equals 0.791 at both temperatures. Calculations for thirty-five coking coal blends were also made and according to the authors "... the data for blends appeared generally to be additive based on the original coals. . ." The data from which Equation 1 was derived were for cokes containing an average of about 1 per cent volatile matter, and the coking coals and blends in all but a few cases contained less than 3 per cent moisture.

Figure 1 shows a plot of the Lowry equation<sup>17</sup>, as Curve I, a straight line, together with another straight line, Curve II, drawn on the assumption that the coke yield will be equal to the fixed carbon plus ash content of the coal. It will be observed that the two curves cross in the vicinity of 92 per cent fixed carbon plus ash and that the divergence between the two curves is greater the lower the fixed carbon plus ash content of the coal. Thus at 60 per cent fixed carbon plus ash the coke yield is almost 7 per cent greater than the fixed carbon plus ash content of the coal. In the range from 83 to 95 per cent fixed carbon plus ash (the range normally found with No. 5 buckwheat anthracite) the maximum deviation between the two curves is only 1.7 per cent. In view of the fact that the amount of anthracite in the final blend will usually be less than 20 per cent, a maximum probable error of 0.3 per cent would be introduced by assuming that for anthracite the coke yield and the fixed carbon plus ash content are equivalent.

On the basis of tests in which 100-pound samples were carbonized in a horizontal steel retort, Mendelsohn<sup>8</sup> reports that the yield of coke resulting from the blending of bituminous coals may be predicted from Equation 2. The agreement between this equation and actual test results published by the Bureau of Mines for bituminous coal blends is excellent.

$$\text{Equation 2. } \% \text{ Coke} = 1/100 (ax + (100-a)y)$$

In this equation, "a" equals per cent of coal X in blend, "x" equals per cent of coke produced from coal X, and "y" equals per cent of coke produced from coal Y.

Although the numerical relationship between coke yield and fixed carbon plus ash will change with the type of oven and the conditions of coking, the Bureau of Mines-American Gas Association test appears to give a reasonably accurate means of predicting actual plant operation results for coke yield. Where actual plant data are lacking, therefore, the use of the foregoing equations should prove useful.

Calculation of the coke yield from a blend of two or more constituents such as will be encountered in all operations where anthracite is employed is a relatively simple operation. If data for the fixed carbon (FC) plus ash ( $A_c$ ) on the as-charged basis are available, Equation 3 may be used to determine the average fixed carbon plus ash content of the blend  $(FC + A_c)_X$

$$\text{Equation 3. } \left(\frac{\%A}{100}\right)(FC + A_c)_A + \left(\frac{\%B}{100}\right)(FC + A_c)_B + \left(\frac{\%C}{100}\right)(FC + A_c)_C = \%(FC + A_c)_X,$$

where A, B, and C refer to components A, B, and C of the blend and X is the resultant blend. Using Fig. 1, it is then possible to determine the probable coke yield for laboratory tests similar to the U. S. Bureau of Mines-American Gas Association test. Experience at any given plant on the relationship between laboratory test data and actual operation will permit a reasonably accurate prediction of actual coke yield. In general, it has been found that these tests are reasonably reliable indications of actual plant yields.

If actual laboratory test or plant-scale data are available for the several coals involved, the individual coke yields may be substituted in Equation 3 in place of  $(FC + A_c)$  and the calculation will give directly the yield of coke from the blend. When anthracite is one of the coals, the coke yield for the anthracite alone may be taken as equal to the fixed carbon plus ash on the as-carbonized basis.

In order to demonstrate more clearly the specific effect of anthracite additions upon coke yields a chart, Fig. 2, has been prepared showing the effect of 0 to 20 per cent anthracite additions to a standard coking coal blend normally used in one large Eastern by-product plant. These specific data are applicable only to this particular plant or to plants using the same blend, but the chart illustrates clearly the trend that will be obtained in any plant using anthracite, and the effect on coke yield of changes in the fixed carbon plus ash content of the anthracite as charged. The data upon which this chart is based are: a moisture content of 1.4 per cent for the bituminous coal blend as charged, the production of a coke containing 1 per cent volatile matter, and a coke yield from the bituminous coal blend as given in data published by the U. S. Bureau of Mines<sup>18</sup>. Detailed data on analyses of the coals and yields of coke and by-products are shown in Tables I and II of Appendix I.

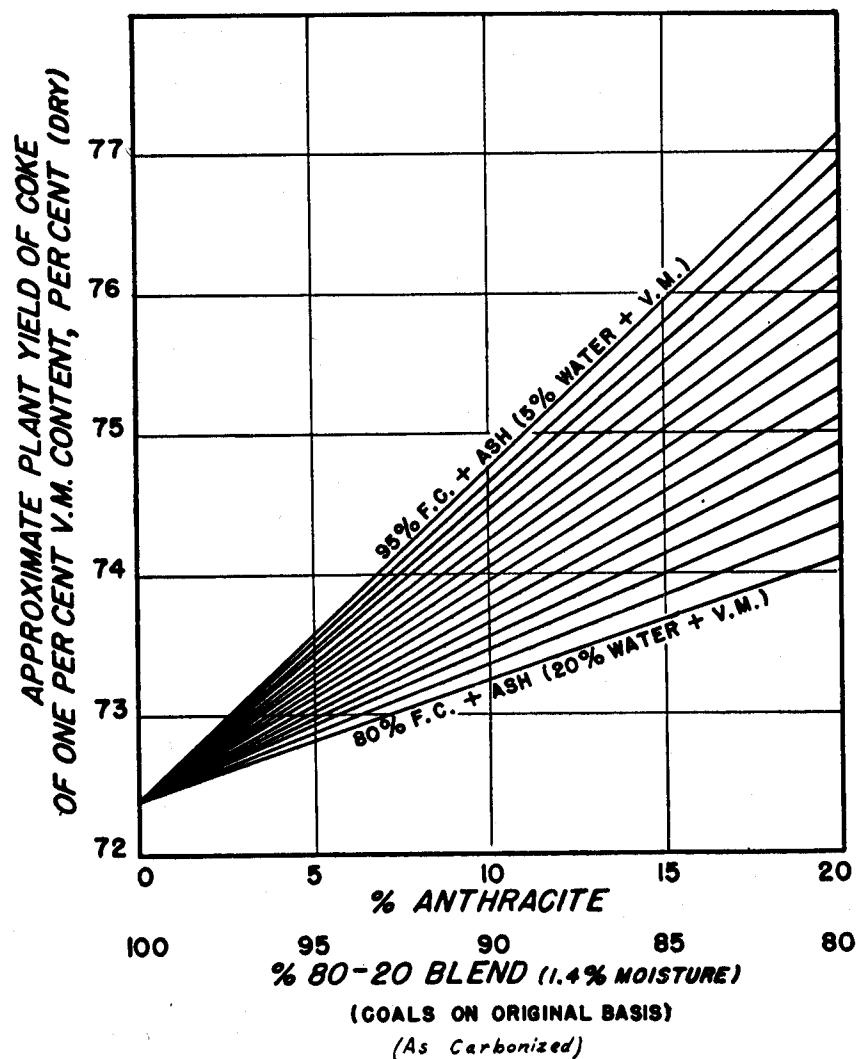
It is unfortunate that so few quantitative data are reported for the effect of anthracite additions on coke yields in plant-scale operations. Although some data are given in the work reported prior to 1900, their applicability is limited because the method of carbonization then employed consumed 5 or more per cent of the fixed carbon of the coal, giving a coke yield lower than the fixed carbon plus ash. Much of the later work is of limited value because the yield of coke from the coking coal carbonized alone is not reported.

The only quantitative plant-scale results on the change in coke yields resulting from the addition of different percentages of anthracite to a specific coking blend are those described by Roberts<sup>16</sup>. In one series of tests 0, 3, 5, and 10 per cent of anthracite was added to blends of the same bituminous coals, and the resultant blends coked under constant conditions. The data are



FIGURE 2

**YIELD OF COKE FROM ORIGINAL COALS FOR  
DIFFERENT PERCENTAGES OF ANTHRACITE  
REPLACING THE 80% POWELLTON,  
20% POCAHONTAS No. 4 BLEND**



reproduced in Table 1 and show a small but definite increase in coke yield with increase in the percentage of anthracite. In these particular tests, high moisture anthracite was used, and the fixed carbon plus ash of the anthracite was only 82.5 per cent as charged, which was not sufficiently greater than the fixed carbon plus ash content of the coking coal blend to produce an appreciable change. However, the addition of 10 per cent of anthracite shows an average apparent, although not necessarily real, increase in coke yield of about one-tenth of 1 per cent for each 1 per cent of anthracite added to a particular coal blend. This general observation is of limited value and will be brought to mind again as a result of deductions in a later chapter.

TABLE 1

EFFECT OF DIFFERENT PERCENTAGES OF ANTHRACITE ON THE YIELD OF COKE FROM COAL CARBONIZED FOR 21.5 HOURS IN 19-3/4-INCH PIETTE OVENS.

| Coal, Per Cent |          |            | Coke (dry), Per Cent |                            |
|----------------|----------|------------|----------------------|----------------------------|
| Bituminous     |          |            |                      |                            |
| High Vol.      | Low Vol. | Anthracite | Total                | Foundry (over 3" x 3-1/2") |
| 50             | 50       | 0          | 77.4                 | 28.0                       |
| 53             | 44       | 3          | 77.6                 | 38.3                       |
| 58             | 39       | 3          | 76.6                 | 35.5                       |
| 48.5           | 48.5     | 3          | 77.0                 | 40.7                       |
| Avg. 53.2      | 43.8     | 3          | 77.1                 | 38.2                       |
| 52             | 43       | 5          | 77.2                 | 44.3                       |
| 57             | 38       | 5          | 76.8                 | 51.8                       |
| 47.5           | 47.5     | 5          | 78.4                 | 47.2                       |
| Avg. 52.2      | 42.8     | 5          | 77.5                 | 47.8                       |
| 40             | 50       | 10         | 79.1                 | 58.7                       |
| 50             | 40       | 10         | 77.9                 | 63.8                       |
| Avg. 45        | 45       | 10         | 78.5                 | 61.3                       |

#### GAS

Because of the lack of plant scale data, the effect of anthracite additions upon the yield of gas in by-product coking is a problem, the solution of which, as in the case of coke yields, must be based upon laboratory scale tests. Although anthracite acts as a diluent in the coking blend, thus decreasing the gas yield therefrom, it is by no means an inert. Laboratory-scale tests by several investigators have shown that anthracite, despite its relatively low-volatile matter content, will yield upon carbonization a large volume of low specific gravity gas of high hydrogen content.

Turner and Keene<sup>19</sup> obtained the data shown in Table 2 upon carbonization of a number of anthracites from various sections of the anthracite producing region. Carbonization was carried out at a temperature of 1036°C. (1900°F.) in a silica tube and the products removed rapidly by suction.

Scott and Jones<sup>20</sup> have reported the data shown in Table 3 for the carbonization of two anthracites. Carbonization was carried out at a maximum temperature of 1000°C. (1832°F.) in a silica tube at atmospheric pressure.

Although the experimental technique was different in the two investigations, the results are in substantial agreement. Both indicate that the probable yield of gas from low- and medium-volatile anthracites may be expected to range from about 4500 to 7500 cubic feet per ton of dry anthracite carbonized.

TABLE 2

YIELD, ANALYSIS, SPECIFIC GRAVITY, AND CALORIFIC  
VALUE OF THE GAS FROM ANTHRACITE

| Class of Anthracite  | High Vol. | Medium Vol. | Low Vol. |
|--|-----------|-------------|----------|
| No. of Samples Tested  | 5         | 16          | 15       |
| Avg. Volatile Matter (dry basis), %                                | 7.6       | 5.6         | 3.8      |
| Avg. Gas Yield <sup>1</sup> up to 1900°F (1036°C)<br>cu. ft./ton   | 7800      | 6750        | 4850     |
| Avg. Composition, %:   |           |             |          |
| CO <sub>2</sub>  | 2.2       | 2.0         | 1.8      |
| O <sub>2</sub>   | 1.0       | 1.1         | 2.3      |
| H <sub>2</sub>   | 83.6      | 84.2        | 83.2     |
| N <sub>2</sub>   | 2.0       | 2.6         | 4.8      |
| CO   | 4.1       | 4.1         | 4.2      |
| CH <sub>4</sub>  | 7.1       | 6.0         | 3.7      |
| Avg. Specific Gravity <sup>2</sup> (dry)                           | 0.204     | 0.200       | 0.219    |
| Avg. Calorific Value of Gas <sup>1</sup> ,<br>Btu. (gross)/cu. ft. | 351       | 342         | 316      |
| Thermal Value, Btu./lb. of Coal                                    | 1370      | 1152        | 768      |

<sup>1</sup>Saturated with water vapor at 60°F and 30 inches Hg.

<sup>2</sup>At 60°F, 30 inches Hg.

TABLE 3

YIELD, ANALYSIS, SPECIFIC GRAVITY, AND CALORIFIC  
VALUE OF GAS FROM TWO ANTHRACITES.

| Sample   | A     | B     |
|--|-------|-------|
| Volatile Matter (dry basis), %                             | 4.6   | 6.7   |
| Avg. Gas Yield <sup>1</sup> (up to 1000°C) cu. ft./ton     | 7350  | 8600  |
| Composition, %:  |       |       |
| CO <sub>2</sub>  | 2.6   | 2.8   |
| Illuminants  | 0.1   | 0.1   |
| H <sub>2</sub>   | 78.9  | 77.7  |
| CO   | 3.7   | 7.2   |
| CH <sub>4</sub>  | 13.9  | 10.7  |
| C <sub>2</sub> H <sub>6</sub>                              | 0.1   | 0.0   |
| N <sub>2</sub>   | 0.3   | 1.2   |
| Specific Gravity <sup>2</sup> (dry)                        | 0.216 | 0.241 |
| Calorific Value of Gas <sup>1</sup> , Btu. (gross)/cu. ft. | 405   | 379   |
| Thermal Value, Btu./lb. of Coal                            | 1490  | 1630  |

<sup>1</sup>Saturated with water vapor at 60°F and 30 inches Hg.

<sup>2</sup>At 60°F, 30 inches Hg.

Roberts<sup>16</sup> has reported the results of a "bomb test" made on a Pennsylvania anthracite (see Table I, Appendix I for proximate analysis) containing 5.37 per cent volatile matter on the dry basis. Despite the fact that the exact conditions of temperature and pressure of the gas are not given, the yield of 5100 cubic feet per ton of coal (dry basis) and the calorific value of 320 Btu. per cubic foot are of the same order of magnitude as the corresponding values for anthracites of similar volatile matter content reported in the foregoing tables. Although not specifically stated, it appears probable that the coal was carbonized at about 900°C (1652°F). Roberts also stated that the anthracite used had only about one-third the "gas value" (a term also known as "thermal value" which is defined as the cubic feet of gas per pound or per ton of coal times the calorific value of the gas in Btu. per cubic foot) of a West Virginia low-volatile coal, which agrees with the data of both Turner and Keene, and Scott and Jones.

With the foregoing information on the yield and thermal or gas value of the gaseous carbonization products from anthracite alone, there remains only the need for specific evidence of the effect of blending prior to carbonization in order to arrive at a reasonably accurate conclusion concerning the effect of anthracite additions on the gas yield from such blends.

Lowry, Landau, and Naugle<sup>17</sup> have shown that for ninety bituminous coals and coal blends carbonized in the U. S. Bureau of Mines-American Gas Association carbonization assay test, the specific gravity ( $G_r$ ) of the gas is a linear function of the volatile matter (VM) and moisture content ( $H_2O$ ) of the coals or coal blends according to Equation 4,

$$\text{Equation 4. } G_r = a + b(\text{VM}) + c(\text{H}_2\text{O})$$

where  $a$ ,  $b$ , and  $c$  are constants depending upon the carbonization apparatus and test conditions. For carbonization in the U. S. Bureau of Mines-American Gas Association apparatus at 900°C. (1652°F.),  $a = 0.1860$ ,  $b = 0.00552$ , and  $c = 0.00559$ ; at 1000°C. (1832°F.),  $a = 0.1633$ ,  $b = 0.00560$ , and  $c = 0.00582$ . On the basis of the same tests Lowry, et al, likewise show that the weight percentage of gas ( $G_w$ ) is a linear function of volatile matter and moisture content of the coals or coal blends carbonized, according to Equation 5,

$$\text{Equation 5. } G_w = a + b(\text{VM}) + c(\text{H}_2\text{O})$$

where, for carbonization in the U. S. Bureau of Mines-American Gas Association assay apparatus at 900°C.,  $a = 6.52$ ,  $b = 0.247$ , and  $c = 0.149$ .

Similarly, Mendelsohn<sup>8</sup> has shown that the weight yields of gas from bituminous coal blends are additive functions of the gas yields from the individual coals. Bennett<sup>21</sup>, however, has recently published a report, not yet available in this country, which states that the yield of gas from a blend of coals may be greater or less than that of simple proportionality. The value of the "gas coefficients of digestive carbonization" has to be found by tests on the coals singly and their blends in any known ratios.

Because details of the Bennett gas coefficients are not yet available and detailed information on gas yields from the individual coals and of anthracite blends are likewise lacking, it is impossible at present to check this apparent contradiction of the Lowry equation. In the range of anthracite blends under consideration, where the probable limit of anthracite will not exceed 20 per cent of the blend, it appears reasonable, however, to assume that Equations 4 and 5 are applicable within the limits of estimation possible from analytical data. Likewise, it appears reasonable to assume that the calorific value of the gas is an additive function of the calorific values of the gases from the individual components of the blend. Throughout subsequent calculations these two assumptions have been followed.

On the basis of considerations presented elsewhere in this report, it appears probable that most of the anthracite applicable for blending purposes will come principally from the producing areas mining low- or medium-volatile coals and that the fixed carbon plus ash content of these coals will not be less than 83 per cent. For such coals, the following should represent a reasonably conservative estimate of the gas yield and quality.

|                                   |   |      |
|-----------------------------------|---|------|
| Yield*—Per Cent by weight         | — | 4.3  |
| Cu. ft./ton of coal               | — | 5300 |
| Specific Gravity**                | — | 0.21 |
| Gross Heating Value, Btu./cu. ft. | — | 340  |
| Gas Value, Btu./lb. of coal       | — | 900  |

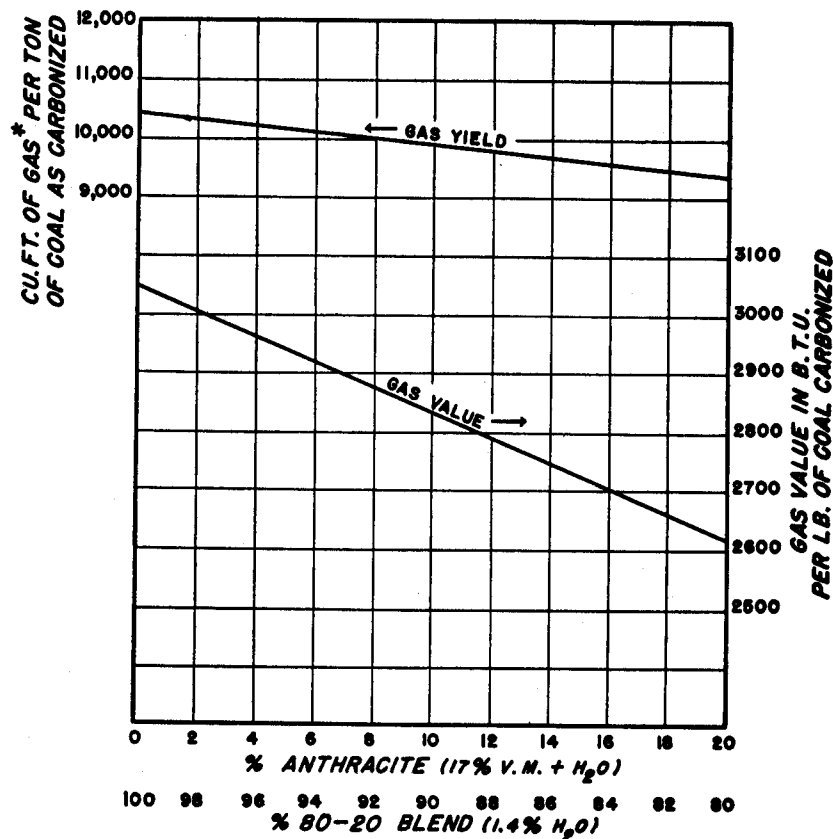
Using these data, the effect of anthracite additions upon the gas yield from anthracite-bituminous coal blends has been calculated for the same bituminous coal blend used previously for illustrating the effect of anthracite additions upon the coke yield. These data are shown in Fig. 3 in the form of a graph. It is apparent from this graph that the addition of anthracite up to an amount not exceeding 20 per cent of the total blend reduces the gas yield a maximum of only about 1000 cubic feet, or approximately 10 per cent, while the thermal value, as Btu. yield in gas per pound of coal carbonized, falls rapidly with increasing anthracite content, and is 14 per cent lower for the addition of 20 per cent anthracite.

Unfortunately no plant-scale data are available which can be used as a check upon the validity of the foregoing assumptions and calculations, but in view of the evidence herein presented, the conclusions appear justified.

Although Fig. 3 illustrates well the effect of anthracite additions to a specific bituminous coal blend, it is of interest to examine the effect of anthracite additions to bituminous coal blends which produce different gas yields upon coking. For the general case, the gas yield is expressed by Equation 6.

FIGURE 3

**EFFECT ON GAS YIELD AND GAS VALUE  
OF 0 TO 20 PER CENT OF ANTHRACITE IN A  
BLEND OF 80 PER CENT POWELLTON AND  
20 PER CENT POCAHONTAS No. 4 COAL**



ALL COALS ON AN AS CARBONIZED BASIS

\* SATURATED WITH WATER VAPOR AT 60°F. AND 30" Hg.

\*Saturated with water vapor at 60°F. and 30" Hg; coal as carbonized.

\*\*Dry gas at 60°, 30" Hg (the value for saturated gas at 60°F. and 30" Hg is practically the same).

Equation 6. Actual Gas Yield (MCF) per Ton Coal =

$$y \frac{b}{100} + x \frac{a}{100}$$

where "y" is the actual yield (MCF) of gas from 1 ton of the bituminous coal coked alone; "x" is the actual yield (MCF) of gas from 1 ton of anthracite, and where specific data are lacking may be taken as 5.3 for most medium- and low-volatile anthracites; "b" is the percentage of bituminous coal; and "a" is the percentage of anthracite in the blend as coked.

Using the equation, the effect of additions of 0 to 20 per cent anthracite to bituminous coal blends producing from 10 to 14 MCF per ton have been calculated and the data are shown graphically in Fig. 4.

The effect of anthracite additions upon the thermal value is also of interest and may be calculated for the general case by use of Equation 7.

$$\text{Equation 7. Gas Yield (MCF) of Standard Btu.} = \frac{byv + axu}{\text{Equivalent Gas per Ton Coal} \quad 100w}$$

where a, b, y, and x are the same as in Equation 6, v is the actual heating value in Btu./cu. ft. of the gas from the bituminous coal, u is the actual heating value in Btu./cu. ft. of the gas from the anthracite coal, and w is the standard heating value in Btu./cu. ft. of the gas for any plant (in Pennsylvania this is usually 530 Btu./cu. ft.). In the example used throughout this report, y = 10.4, x = 5.3, v = 586, and u = 340. For medium- and low-volatile Buckwheat No. 5 anthracite, where specific data are not available, the use of 5.3 MCF of gas per ton of anthracite as a gas yield, and 340 Btu./cu. ft. as the heating value for gas from anthracite will probably be satisfactory for general use.

#### TAR, LIGHT OIL, AND AMMONIA

By definition, anthracite is that rank of coal which upon distillation or carbonization will yield no tar. This definition is substantiated by extensive experimental evidence which also indicates that little or no light oil is to be expected as a result of anthracite carbonization. Turner and Keene<sup>19</sup>, as a result of tests on thirty-six different samples of anthracite representing all the major mining districts of the anthracite region, found no tar or hydrocarbons higher than methane. No ammonia was reported in the volatile products. Scott and Jones<sup>20</sup> carbonized a low- and a medium-volatile anthracite and reported 0.1 to 0.2 per cent illuminants and 0.0 to 0.1 per cent ethane in the volatile products. No ammonia was reported.

Roberts<sup>16</sup> carbonized a sample of anthracite in "bomb tests" and reports slight yields of tar and ammonia, but states in summarizing the plant-scale work at Laclede that . . . "anthracite has no residual value such as tar, ammonia, and light oil."

FIGURE 4

EFFECT OF ANTHRACITE ADDITIONS ON GAS YIELD FROM BITUMINOUS COALS; PER CENT DECREASE IN GAS YIELDS DUE TO ANTHRACITE ADDITIONS

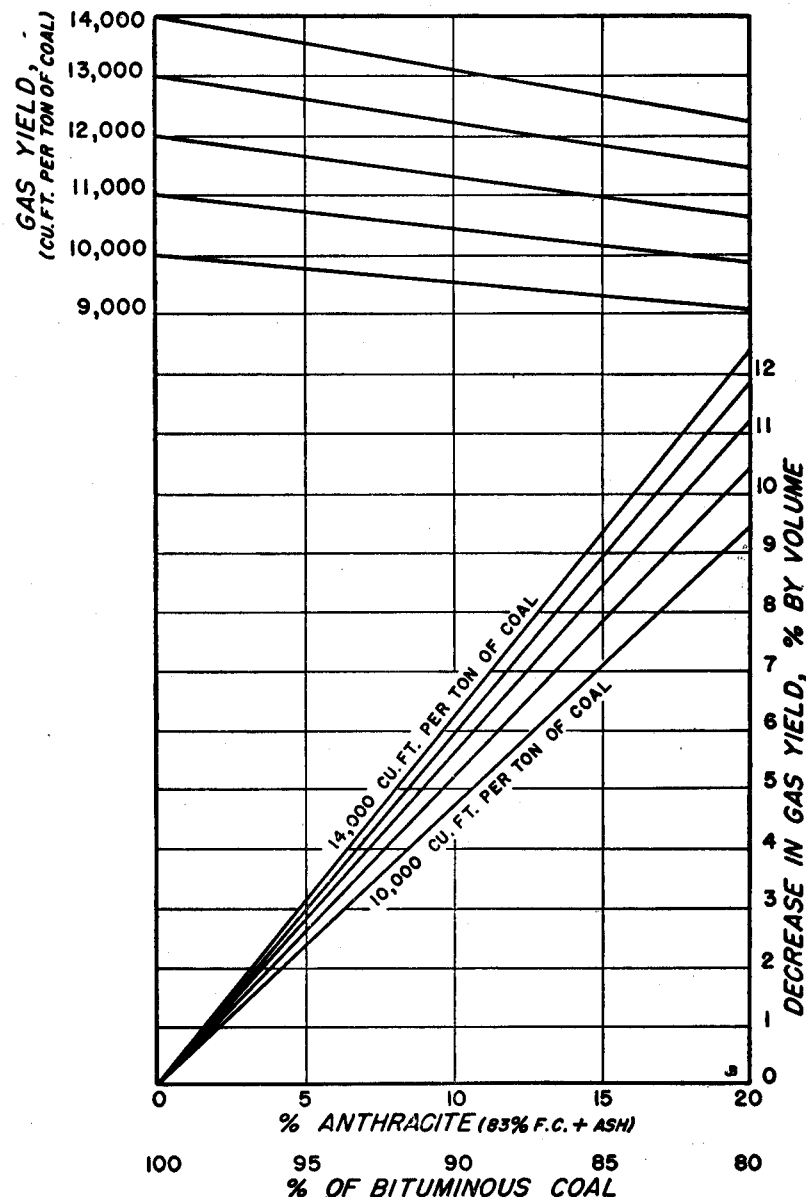
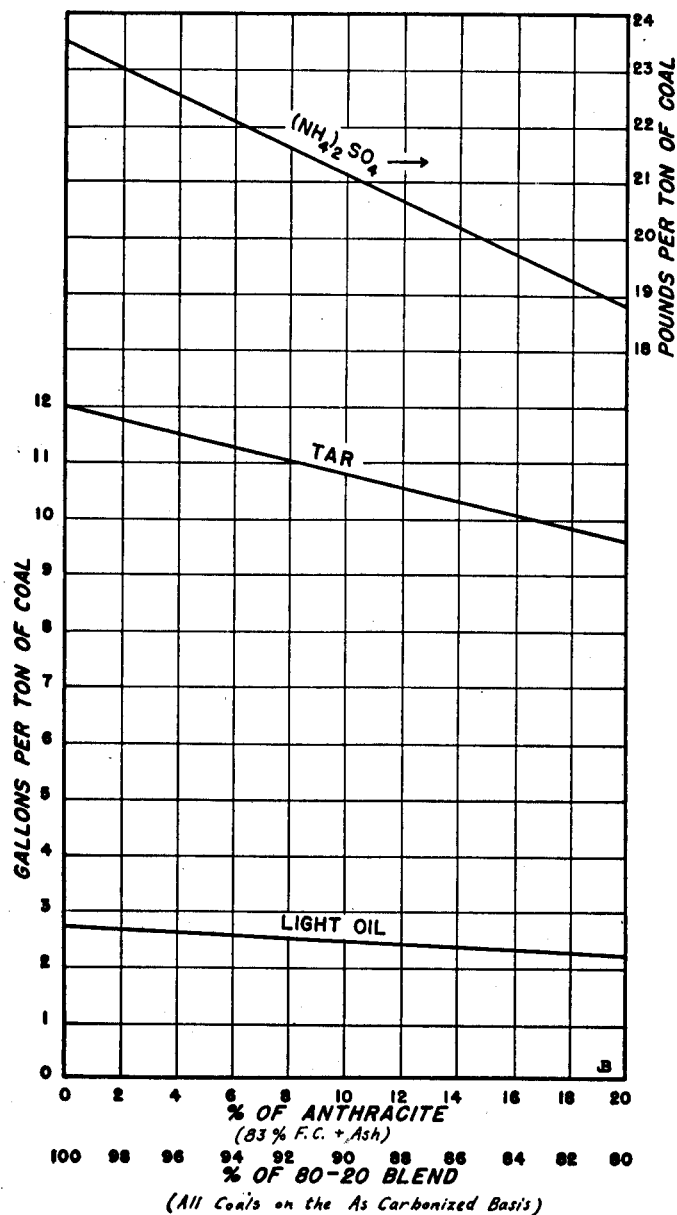


FIGURE 5

# EFFECT OF ANTHRACITE ON YIELDS OF BY-PRODUCTS FROM A BLEND OF 80% POWELLTON AND 20% POCAHONTAS No. 4



There appears to be no evidence in the technical literature which would indicate that anthracite will act other than as an inert diluent on the production of tar, light oil, or ammonia from coking operations. The determination of the effect of the anthracite upon the yields of these three by-products is, therefore, much simpler than for similar determinations of the effect of anthracite on the yield of gas and coke. For all subsequent calculations it is assumed that the yields of tar, light oil, and ammonia from bituminous coal blends containing anthracite are directly proportional to the percentage of bituminous coal present in the blend.

On the basis of the foregoing assumption, a chart, Fig. 5, has been prepared which shows the effect of 0 to 20 per cent anthracite additions to the previously used coking blend of 80 per cent Powellton-20 per cent Pocahontas No. 4 bituminous coals. The yields of tar, light oil, and ammonia used for the 100 per cent coking coal blend are those published by the U. S. Bureau of Mines<sup>18</sup>, see Table II, Appendix I.

## EFFECT OF ANTHRACITE ON QUALITY OF COKE AND BY-PRODUCTS

### THE SIZE OF COKE

The most significant effects on the quality of the coke produced by the addition of anthracite to coking blends are a general upgrading in the size of the coke and its blocky character. This is illustrated by reproductions of photographs made by Mott and Wheeler<sup>12</sup> of actual cokes produced in full-scale oven tests using a standard South Yorkshire blend with and without addition of anthracite. Fig. 6A shows the typical fingered coke produced from the bituminous coal, while Fig. 6D shows the typical blocky structure of the coke produced from the 20 per cent anthracite, 80 per cent coking coal blend.

Accurate information concerning the manner in which additions of anthracite to coking coal blends affect the screen analysis of the coke produced is limited to work reported in 1930 by Mott and Wheeler<sup>12</sup> and that reported in 1942 by Roberts<sup>16</sup>. The data of Mott and Wheeler are less satisfactory for comparative purposes because of variations in coking time, but despite this the effect of the anthracite is clearly discernable.

Mott and Wheeler report the data shown in Table 4 when using a coking coal blend consisting of 67 per cent Parkgate and 33 per cent Silkstone coal, both from South Yorkshire. Detailed analyses of the coals used are shown in Table III, Appendix I. Additions of 30 per cent anthracite were chosen because preliminary box tests had indicated that 20 to 30 per cent anthracite should give optimum results. The anthracite used was of minus 1/8-inch size.

In the case of the tests conducted in the 21-inch oven, the effect of the addition of 30 per cent anthracite is quite evident despite the three different coking times. At both the low and high rate of coking in the 21-inch oven, the percentage of plus 4-inch size is increased. The cumulative percentage on 2-inch is slightly better at the lower coking rate and poorer at the faster coking rate, while the percentage of minus 1-inch breeze shows the same relationship. In the case of the tests in the 14-inch oven, very poor results

COKE PRODUCED FROM A SOUTH YORKSHIRE COKING COAL;  
ROSE SECTION OF COKES, 6A AND 6D

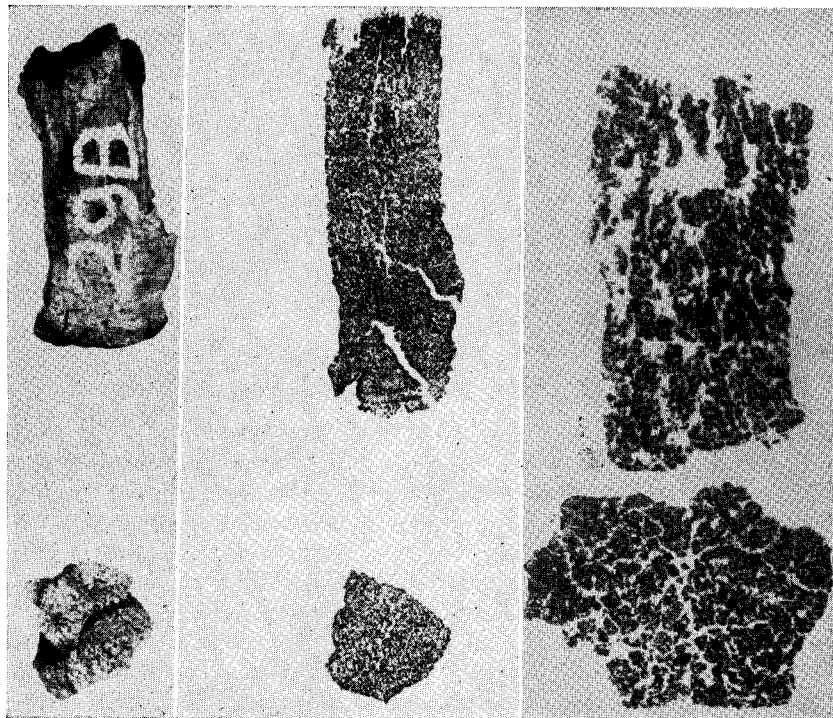


FIGURE 6A

FIGURE 6B

FIGURE 6C

FIGURE 6A IS A FINGERY COKE PRODUCED FROM A SOUTH YORKSHIRE COKING COAL. FIGURE 6B IS A ROSE SECTION OF THE COKE IN FIGURE 6A.

FIGURE 6C IS A ROSE SECTION OF THE ANTHRACITE COKE IN FIGURE 6D

BLOCKY COKE PRODUCED BY BLENDING 20 PER CENT ANTHRACITE FINES WITH A SOUTH YORKSHIRE COKING COAL

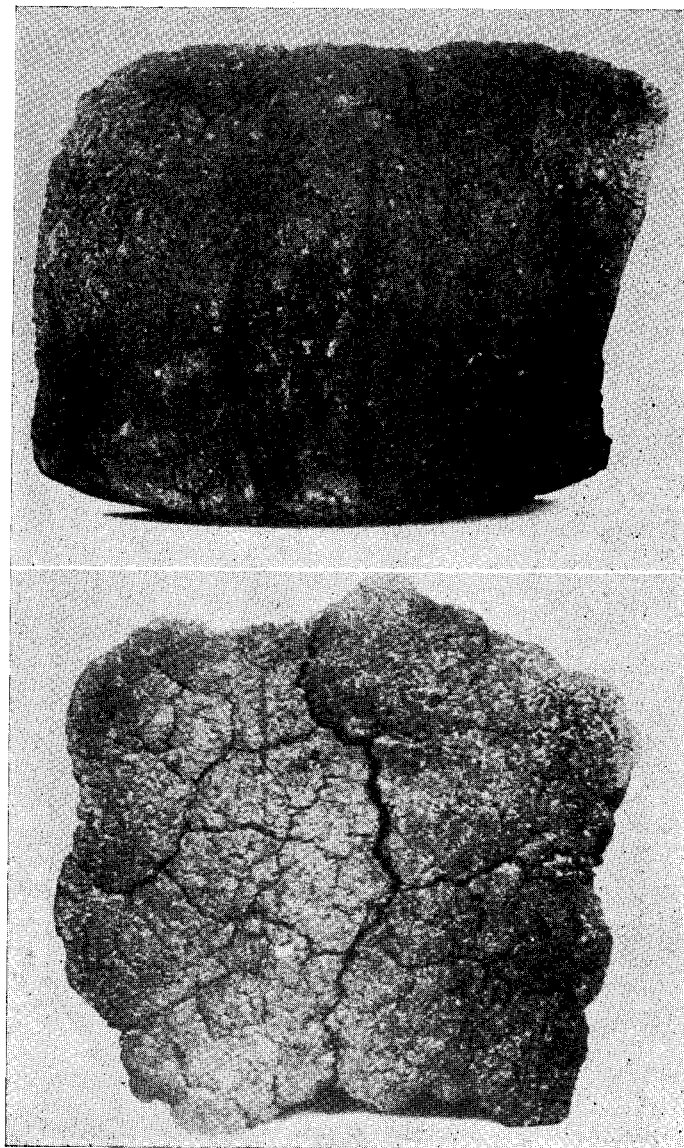


FIGURE 6D

TABLE 4  
EFFECT OF ANTHRACITE ON THE SIZE ANALYSIS OF THE COKE  
(Run-of-Oven Coke)

| Coal — Per Cent<br>Bituminous Anthracite | Width<br>of Oven<br>(in.) | Coking<br>Time<br>(hr.) | Rate of<br>Coking<br>(in./hr.) | Size Analysis of Coke — Per Cent |        |        |           |         |               |
|--|---------------------------|-------------------------|--------------------------------|----------------------------------|--------|--------|-----------|---------|---------------|
|  |                           |                         |                                | +4in.                            | 4x3in. | 3x2in. | Cum. 2in. | 2x1½in. | 1½x1in. —1in. |
| 100                                      | 21                        | 22½                     | 0.95                           | 13.7                             | 28.3   | 36.5   | 78.5      | 10.5    | 6.2           |
| 70                                       | 21                        | 24¼                     | 0.86                           | 20.2                             | 26.0   | 33.3   | 79.5      | 11.5    | 4.6           |
| 70                                       | 21                        | 20                      | 1.05                           | 22.7                             | 21.1   | 29.8   | 73.6      | 13.2    | 8.0           |
| 100                                      | 14                        | 12                      | 1.17                           | 6.5                              | 25.4   | 50.3   | 82.2      | 11.3    | 3.8           |
| 70                                       | 14                        | 9½                      | 1.47                           | 1.0                              | 14.6   | 34.3   | 49.9      | 22.6    | 18.5          |

were obtained with anthracite in the blend, but this is probably due to the unusually high coking rate employed. On the whole, the data of Mott and Wheeler suggest that the percentage of anthracite used in this particular blend of coking coals is too great to produce a satisfactory product.

Roberts, on the other hand, clearly demonstrates the advantages to be gained by smaller additions of anthracite. In full-scale oven tests the percentage of anthracite added to the standard low- and high-volatile West Virginia coking coal blend was varied from 0 to 10 per cent with the results shown in Table 5. The original test work was carried out in 19-¾-inch Piette ovens and was later extended to 19-¾-inch Koppers ovens. The anthracite used in the test was No. 5 buckwheat size from the Hazelton district, blended directly in as-received condition. Coking time was held constant at 21-½ hours or at a coking rate of 0.92 ins. per hour.

An examination of these data shows that a very marked upgrading of size was produced which increased progressively with increase in percentage of anthracite used. Cumulative percentage on 2-inch similarly increased, while the percentage of minus 1-inch breeze remained substantially constant. It is significant to note that the upgrading as determined by percentage of plus 4-inch, cumulative percentage on 2-inch, or percentage of minus 1-inch breeze is very much better for the Roberts tests with 3, 5, or 10 per cent anthracite than for the Mott and Wheeler tests with 30 per cent anthracite despite the fact that the original coking coal blends coked at about the same rate gave rather similar results. The Roberts' bituminous coal blend gave slightly more plus 4-inch, less cumulative on 2-in, and less minus 1-inch breeze. These are further evidence that the 30 per cent additions of anthracite are probably excessive.

In order to demonstrate the effect of coking time upon the size consist of the coke produced when using anthracite additions, a second series of tests were made with the same coals in both the 19-¾-inch Piette ovens and the 19-¾-inch Koppers ovens used for regular plant operation. Because of the high freight rate on the anthracite shipped to St. Louis, 4 to 5 per cent anthracite was chosen as the economic limit and, therefore, the tests on the effect of coking time were not made with the 10 per cent anthracite blend. Data for the 0, 4, and 5 per cent blends are shown in Table 6. Unfortunately, the range of coking time investigated is rather limited, nevertheless, it is sufficient to show the marked upgrading that can be obtained even at a fast coking rate when anthracite is used. In the Piette ovens the 19-hour coking time with the anthracite blend gave appreciably better percentages of plus 4-inch and cumulative on 2-inch but more minus 1-inch breeze. In the Koppers ovens the 19-hour test with the anthracite blend showed a similar trend.

In subsequent plant operation the standard coking time has been reduced to 18.6 hours when using the 4 per cent anthracite blend and Roberts reports that comparable upgrading in size is obtained with but a slight increase in the percentage of breeze over that previously obtained with the bituminous coal blend alone.

TABLE 5  
EFFECT OF DIFFERENT PERCENTAGES OF ANTHRACITE ON THE  
SIZE ANALYSIS OF THE COKE  
(Run-of-Oven Coke)

| Coal — Per Cent |          |                 | Size Analysis of Run-of-Oven Coke — Per Cent |        |        |            |         |         |        |      |       |
|-----------------|----------|-----------------|--|--------|--------|------------|---------|---------|--------|------|-------|
| Bituminous      |          | Anthra-<br>cite | +4in.  | 4x3in. | 3x2in. | Cum. +2in. | 2x1½in. | 1½x1in. | 1x¾in. | ¾in. | —1in. |
| High-Vol.       | Low-Vol. |                 |  |        |        |            |         |         |        |      |       |
| 50              | 50       | 0               | 19.0   | 21.1   | 33.6   | 73.7       | 15.6    | 7.5     | 0.8    | 1.2  | 3.3   |
| 53              | 44       | 3               | 38.1   | 22.4   | 22.6   | 83.1       | 8.5     | 5.2     | 0.6    | 1.6  | 3.2   |
| 58              | 39       | 3               | 31.4   | 20.6   | 30.6   | 82.6       | 8.8     | 5.6     | 0.7    | 1.3  | 3.0   |
| 48.5            | 48.5     | 3               | 37.2   | 20.3   | 26.4   | 83.9       | 8.9     | 3.5     | 0.9    | 1.6  | 3.7   |
| Avg. 53.2       | 43.8     | 3               | 35.6   | 21.1   | 26.5   | 83.2       | 8.7     | 4.8     | 0.7    | 1.5  | 3.3   |
| 52              | 43       | 5               | 54.3   | 19.0   | 15.8   | 89.1       | 4.7     | 3.0     | 0.8    | 1.3  | 3.2   |
| 57              | 38       | 5               | 51.3   | 20.2   | 17.9   | 89.4       | 5.1     | 2.3     | 0.5    | 1.6  | 3.2   |
| 47.5            | 47.5     | 5               | 50.8   | 18.7   | 17.1   | 86.6       | 6.5     | 3.5     | 0.5    | 1.7  | 3.4   |
| Avg. 52.2       | 42.8     | 5               | 52.1   | 19.3   | 16.9   | 88.4       | 5.8     | 2.9     | 0.6    | 1.5  | 3.3   |
| 40              | 50       | 10              | 63.0   | 17.5   | 11.6   | 92.1       | 2.7     | 2.1     | 0.6    | 1.3  | 3.1   |
| 50              | 40       | 10              | 63.8   | 16.9   | 11.9   | 92.6       | 2.6     | 1.8     | 0.5    | 1.4  | 3.0   |
| Avg. 45         | 45       | 10              | 63.4   | 17.2   | 11.8   | 92.4       | 2.65    | 1.95    | 0.55   | 1.35 | 3.05  |

TABLE 6  
EFFECT OF COKING TIME ON THE SIZE ANALYSIS OF THE COKE  
(Run-of-Oven Coke)

| Coal — Per Cent |          |                 | Coking<br>Time<br>(hr.) | Size Analysis of Run-of-Oven Coke — Per Cent |        |        |            |         |         |        |       |       |
|-----------------|----------|-----------------|-------------------------|--|--------|--------|------------|---------|---------|--------|-------|-------|
| Bituminous      |          | Anthra-<br>cite |                         | +4in.  | 4x3in. | 3x2in. | Cum. +2in. | 2x1½in. | 1½x1in. | 1x¾in. | —¼in. | —1in. |
| High-Vol.       | Low-Vol. |                 |                         |  |        |        |            |         |         |        |       |       |
| 60              | 40       | 0               | 19 <sup>1</sup>         | 31.7   | 21.4   | 25.4   | 78.5       | 12.1    | 5.3     | 0.9    | 1.9   | 4.1   |
| 60              | 40       | 0               | 20 <sup>1</sup>         | 21.7   | 25.9   | 31.8   | 79.4       | 11.4    | 5.1     | 0.6    | 2.0   | 4.1   |
| 57              | 38       | 5               | 19 <sup>1</sup>         | 42.7   | 23.0   | 22.6   | 88.3       | 3.8     | 2.5     | 1.5    | 1.9   | 5.4   |
| 57              | 38       | 5               | 20 <sup>1</sup>         | 59.1   | 18.3   | 13.7   | 91.1       | 3.8     | 2.1     | 0.5    | 1.4   | 3.0   |
| 57              | 38       | 5               | 21.5 <sup>1</sup>       | 51.3   | 20.2   | 17.9   | 89.4       | 5.1     | 2.3     | 0.5    | 1.6   | 3.2   |
| 60              | 40       | 0               | 19.0 <sup>2</sup>       | 18.1   | 16.5   | 34.9   | 68.4       | 18.9    | 9.6     | 0.9    | 1.3   | 3.1   |
| 60              | 40       | 0               | 19.5 <sup>2</sup>       | 18.0   | 21.1   | 31.2   | 70.4       | 16.5    | 8.6     | 1.2    | 1.9   | 4.5   |
| 55              | 45       | 0               | 21.5 <sup>2</sup>       | 23.7   | 22.8   | 31.2   | 77.7       | 12.5    | 6.1     | 0.8    | 1.5   | 3.6   |
| 60              | 36       | 4               | 19.0 <sup>2</sup>       | 32.6   | 20.0   | 26.0   | 78.6       | 9.4     | 6.0     | 1.3    | 2.5   | 6.0   |
| 60              | 36       | 4               | 19.5 <sup>2</sup>       | 46.1   | 19.9   | 20.6   | 86.6       | 5.5     | 3.1     | 0.7    | 2.4   | 4.8   |

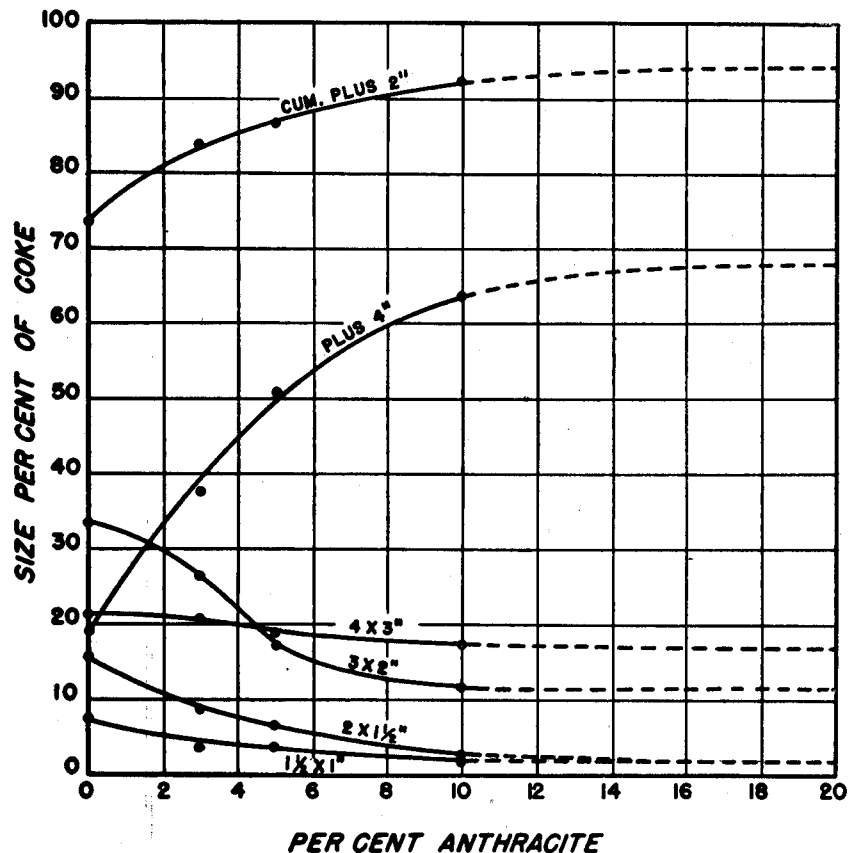
<sup>1</sup>Carbonized in Piette ovens, average width 19¾ inches.

<sup>2</sup>Regular plant operation results with Koppers ovens, average width 19¾ inches.



FIGURE 7

### SIZE DISTRIBUTION OF RUN-OF-OVEN COKE vs. PER CENT ANTHRACITE



Part of the data of Table 5 has been plotted to show the effect of anthracite additions when the composition of the bituminous coal portion of the blend is maintained constant at equal proportions of high- and low-volatile coal. This graph, Fig. 7, demonstrates more clearly than the tabular material the result attainable. The size distributions reported in Tables 5 and 6, when using a constant 60-40 proportion of high- and low-volatile coals show similar trends, but the data are too limited to permit construction of a similar graph. However, the difference in the proportions of the bituminous coals and especially the change in coking time have a noticeable effect upon the increase or decrease of the percentage of larger sizes. For example, the use

of 4 per cent anthracite in the 21.5-hour coke, made from equal proportions of high- and low-volatile coals, produces a 137 per cent increase in the percentage of plus 4-inch coke and a 17 per cent increase in the cumulative per cent of plus 2-inch size coke, while 4 per cent anthracite in a 19-hour coke, made from high- and low-volatile coal in proportions of about 60-40, produces only about an 80 per cent increase in the amount of plus 4-inch size and a 15 per cent increase in the cumulative per cent of plus 2-inch size. As with the other so-called inerts, there is generally a decrease of the "in between" sizes with the addition of anthracite; it is curious that the 4 x 3-inch size is not greatly affected.

Regarding the yield of breeze from anthracite blend cokes, it appears from the data of Table 5, that with long coking times, e.g., 21.5 hours, the addition of anthracite has very little effect on the amount of minus 1-inch size coke initially produced. On the other hand, reference to Table 6 shows that, initially, the cokes made on shorter coking times, e.g., 19 hours, tend to produce about one per cent more of the minus 1-inch size coke. From these results the use of 6 per cent as the figure for the yield of breeze in subsequent market analyses seems to be reasonable.

A re-examination of Table 4, which shows the size analysis results reported by Mott and Wheeler for plant-scale tests on anthracite blend cokes, emphasizes the difficulty of arriving at any satisfactory conclusions regarding size distribution because of the different coking times. It is clear, however, that decreasing the coking time when using anthracite results in an increasing quantity of minus 1-inch size coke. None of the size analysis results of Mott and Wheeler's 300 lb. box tests with anthracite blends have been reproduced in this report because the size of coke from box tests is not generally representative of oven coke, and because the data were generally too erratic, especially in the cumulative percentage of plus 2-inch size.

In Table 7 are shown some quantitative approximations, deduced partly from Figure 7 and partly from other data of Roberts, which demonstrate the effect of different percentages of anthracite on the size distribution of run-of-oven anthracite blend cokes. The fact that these data are compiled for cokes made from certain bituminous coals, using certain carbonizing conditions, must not be overlooked because other coals and other carbonizing conditions will probably give quite different results.

#### PHYSICAL PROPERTIES OF COKE

Although there is considerable question as to the true significance of the commonly determined physical properties of coke, such as shatter index, stability factor, abrasion index, hardness index, apparent and true specific gravities, porosity, reactivity or combustibility, nevertheless, these data are helpful to the coke-oven operator and the users of coke as control tests or as a means of tentatively evaluating a product that has not yet been tried for a specific purpose. It has been pointed out, however, by Russell and Perch<sup>22</sup>

TABLE 7

EFFECT OF DIFFERENT PERCENTAGES OF ANTHRACITE  
ON THE SIZE DISTRIBUTION OF RUN-OF-OVEN  
ANTHRACITE BLEND COKES

| Per Cent Anthracite | Approximate Percentage Increase or Decrease of Per Cent |         |         |            |          |          |
|---------------------|---|---------|---------|------------|----------|----------|
|                     | Plus 4 in.  | 4x3 in. | 3x2 in. | Cum. 2 in. | 2x1½ in. | 1½x1 in. |
| 0                   | 0   | 0       | 0       | 0          | 0        | 0        |
| 3                   | +100  | ± 5     | -20     | +10 to 15  | -45      | -45      |
| 4                   | +140  | ± 5     | -35     | +15 to 20  | -50      | -45      |
| 5                   | +160  | ± 5     | -50     | +15 to 20  | -55      | -50      |
| 10                  | +230  | ± 5     | -60     | +20 to 30  | -80      | -65      |

"... that there is no general scheme by which blast furnace operation can be predicted accurately from the physical properties of the cokes. Undoubtedly the most important justification for thorough and frequent testing is the knowledge of changes that occur..." Any discussion of the effect of anthracite additions upon the quality of the coke produced would, however, be incomplete without some discussion of the physical properties of the product obtained.

**Shatter Test**—The shatter test is generally employed as a means of quantitatively evaluating the impact hardness of coke. Moreover, it should be stressed that the results attained are only relative and that the precision is limited. The test code<sup>23</sup> states: "Since the average probable error of a single shatter test determination is approximately two per cent, it is advisable to make several tests and report average results..." Mott and Wheeler have shown that for 116 cokes with shatter indices ranging from under 50 to over 80, the general average deviation of each result of a shatter test from the mean of three tests was 2.3 for the 2-inch index and 1.4 for the 1½-inch index. It has also been observed by Mott and Wheeler that the percentage of coke remaining on the ½-inch screen after shattering a coke is of little value as an index of hardness of the coke because the ½-inch index rarely falls below 97, except when the coke is very readily abraded. It is, therefore, a rough measure of the abrasability of the coke, because cokes liable to loss by abrasion have not the same coherence as normal cokes, and small fragments are readily knocked off the pieces by impact.

In many tests on cokes made in fast-coking, narrow ovens, it has been found that the two-inch shatter index is abnormally low in comparison with the 1½-inch index. An example of this anomaly is shown in Table 8. The same South Yorkshire high-volatile coking coal blend used by Mott and Wheeler in the anthracite coke tests was used in these tests.

TABLE 8

COMPARISON OF SHATTER INDICES OF COKES MADE  
FROM THE SAME COAL

| Width of Oven | Shatter Indices, Per Cent |         |        |
|---------------|---------------------------|---------|--------|
|               | 2-inch                    | 1½-inch | 1-inch |
| 14-inch       | 65.6                      | 85.2    | 95.2   |
| 21-inch       | 74.1                      | 86.7    | 94.1   |

The 1½-inch and 1-inch indices are nearly the same for the two cokes, while the 2-inch index for the coke made in the 14-inch oven is abnormally low. Mott and Wheeler have explained the anomaly as follows:

"The reason for this has been traced to the small cross-sectional area of the coke produced in modern narrow ovens, a condition leading to the formation of much 1½-inch to 2-inch coke on shattering. Since the coke made in modern narrow ovens in America and Germany has not been found in practice to be inferior to that made in the older types of wide ovens, but rather the reverse, it can reasonably be concluded that the 1½-inch shatter index more fairly represents the blast-furnace value of such cokes than does the 2-inch index."

It was observed that prismatic cokes, in general, yield a higher proportion of 1½-inch to 2-inch sizes on shattering than do the blockier cokes.

Since "box tests" are useful for gauging the quality of the coke made from various coal blends, it is helpful to know what correlation, if any, exists between the characteristics of coke made in box tests and coke from full-scale ovens. The size of the coke made in a box test does not normally compare satisfactorily with that of coke made in a large-scale oven, being usually larger. A comparison of shatter test results for cokes made from the same coal in full-scale oven charges and in 300-lb. box tests is shown in Table 9.

TABLE 9

COMPARISON OF BOX TESTS AND FULL-SCALE OVEN TESTS

| Coke Made From:  | Coking Conditions            | Shatter Indices, Per Cent |         |
|--|------------------------------|---------------------------|---------|
|  |                              | 2-inch                    | 1½-inch |
| S. Yorkshire Coking Blend<br>67% Parkgate<br>33% Silkstone | Full-scale oven <sup>1</sup> | 74                        | 87      |
|  | Box test <sup>3</sup>        | 70                        | 87      |
| 70% S. Yorkshire Blend<br>30% Anthracite Fines             | Full-scale oven <sup>2</sup> | 72                        | 90      |
|  | Box test <sup>3</sup>        | 85                        | 90      |

<sup>1</sup>21-inch oven, 22½ hr. coking time.

<sup>2</sup>21-inch oven, 24½ hr. coking time.

<sup>3</sup>Box of coal placed 2 feet from oven sole, coking time 24 hr.

There is close agreement with regard to the 1½-inch index for cokes from the same coal blends. The 2-inch indices are abnormal, presumably due to the fact that the boxes used for the tests were sometimes only 14 inches wide, and thus the coking conditions would be similar to those in 14-inch ovens which yield cokes of abnormal 2-inch shatter indices. Despite all attempts to correlate box coking tests with full-scale results, however, the final judgment on the quality of the coke from a blend of coals can only be passed on the coke made in full-scale ovens.

Mott and Wheeler, in a series of 300 pound box tests with a coking time of 24 hours, tested the effect of 0 to 40 per cent of anthracite fines of less than ⅛-inch size in admixture with the South Yorkshire high-volatile coking blend which has been mentioned previously. The 2-inch and 1½-inch shatter indices of the cokes were the sole measure of the quality of the coke, and served to indicate the optimum amount of anthracite to be mixed with the coking coal. The results of the series of tests are shown in Table 10.

TABLE 10  
EFFECT ON SHATTER INDICES OF COKE MADE WITH  
DIFFERENT PERCENTAGES OF ANTHRACITE

| Coal, Per Cent |            | Shatter Indices, Per Cent |         |
|----------------|------------|---------------------------|---------|
| Coking Blend   | Anthracite | 2-inch                    | 1½-inch |
| 100            | 0          | 70                        | 87      |
| 90             | 10         | 69                        | 85      |
| 80             | 20         | 75                        | 88      |
| 70             | 30         | 85                        | 90      |
| 60             | 40         | 73                        | 86      |

Ostensibly, it appears from these tests that 30 per cent of anthracite is the optimum amount to mix with this particular South Yorkshire coking blend. On the other hand, full-scale oven tests, in which 30 per cent of anthracite is used, indicate that the optimum deduced on the basis of the box tests alone is certainly too high. The results of these full-scale tests are compiled in Table 11. The effect of rate of coking on the hardness and strength of the coke is also evident.

TABLE 11  
EFFECT OF RATE OF COKING ON COKES MADE IN  
FULL-SCALE OVEN TESTS

| Coal, Per Cent<br>Coking Blend | Anthracite | Width of<br>Oven<br>(in.) | Coking<br>Time<br>(hrs.) | Rate of<br>Coking<br>(in./hr.) | Shatter Indices Per Cent |        |       |       |
|--------------------------------|------------|---------------------------|--------------------------|--------------------------------|--------------------------|--------|-------|-------|
|                                |            |                           |                          |                                | 2-in.                    | 1½-in. | 1-in. | ½-in. |
| 100                            | 0          | 14                        | 12*                      | 1.17                           | 65.6                     | 85.2   | 95.2  | 97.7  |
| 70                             | 30         | 14                        | 9½                       | 1.47                           | 52.6                     | 73.9   | 91.1  | 97.4  |
| 100                            | 0          | 21                        | 22½*                     | 0.95                           | 74.1                     | 86.7   | 94.1  | 97.4  |
| 70                             | 30         | 21                        | 24¼                      | 0.86                           | 72.3                     | 90.1   | 96.4  | 98.1  |
| 70                             | 30         | 21                        | 20                       | 1.05                           | 66.9                     | 84.5   | 94.7  | 97.3  |

The anthracite cokes made on fast or only moderately fast coking rates are not as satisfactory on the basis of shatter indices as the cokes made from the original coals. It appears probable, therefore, that if a coking time of 24¼ hours for the anthracite blend coke is necessary to obtain a satisfactory coke as contrasted with 22½ hours for the regular coke, the use of 30 per cent of anthracite is certainly not practical.

Mott and Wheeler report a test with the South Yorkshire high-volatile coking blend in which the addition of 20 per cent of anthracite fines of minus ⅛-inch size produced a coke which was discharged from the ovens in large pieces, rarely less than a 9-inch cube (See Figure 6D). It appears that in this case also, 20 per cent of anthracite, at least of the size and with the particular coking blend used, was excessive, for although the outer shell of these coke lumps was very hard, the inside crumbled rather readily once the outer shell had been broken. The shatter indices of this coke were: 2-inch 86, 1½-inch 89, 1-inch 93. With a normal coke having the same 2-inch index, the shatter indices are: 2-inch 86, 1½-inch 93, and 1-inch about 97.

The abrasion index (amount of coke remaining on 1½-inch screen in "The Sheffield Coke Abrasion Test") of the anthracite blend coke explains its inferiority, being 83.2, with 6.0 per cent of dust through 1/16-inch. For a normal coke having a 2-inch shatter index of 86, the abrasion index would be about 97, with about 1.0 per cent of dust through 1/16 inch. Examination of the photographic reproduction shown in Figure 6 indicates the reason for the higher friability of the anthracite coke. Figure 6C is a coke section prepared according to the Rose method<sup>24</sup> and shows the relatively open and fissured structure of the coke prepared from the anthracite blend. The original appearance of this coke is shown in Figure 6D. For comparison, Figure 6A shows the appearance of the regular coke made from the bituminous coals alone, and Figure 6B is a Rose section of this coke.

\*Yorkshire cokes of fair to good reputation.

The work reported by Roberts is confined to the use of 0 to 10 per cent of anthracite fines of Buckwheat No. 5 size in admixture with high- and low-volatile coals from West Virginia. All of the cokes were made in full-scale ovens, either in a battery of Piette ovens, average width 19¾ ins., used for experimental work, or in regular plant operation with Koppers ovens, also of 19¾ ins. average width. The results reported by Roberts are of especial significance for this reason if for no other. In Table 12 the beneficial effect of the anthracite additions to the original coal is unmistakable when the various shatter indices are compared; even the ½-inch index is improved. Evidently the original coal blend used here produces a coke (rate of coking 0.92 in./hr.) which is superior to that from the blend used by Mott and Wheeler in Table 11 where the coke is produced under similar conditions (rate of coking 0.95 in./hr.). However, such a comparison is of extremely limited value because Roberts' tests are based only on the foundry-size fraction of the coke (plus 3" x 3½"), while Mott and Wheeler's tests follow ASTM specifications, (plus 2").

Roberts also investigated the effect of rate of coking on the shatter indices of coke. In this work, of which Table 13 is a compilation, the effect of coking time is not so pronounced as in Table 11, because the rates do not differ greatly. It can be seen that the shatter indices of the coke from the 19-hour test in the Piette ovens, using the 60-40 blend of bituminous coals, compare very favorably with those for the 19-hour coke made from the

TABLE 12

EFFECT OF DIFFERENT PERCENTAGES OF ANTHRACITE ON THE SHATTER INDICES OF COKE

(All cokes made in Piette ovens, coking time 21.5 hrs., rate of coking 0.92 in./hr.)

| Coal, Per Cent          |                        |            | Shatter Indices of Foundry-size Coke<br>(plus 3" x 3½"), Per Cent Cumulative |       |       |        |       |       |
|-------------------------|------------------------|------------|--|-------|-------|--------|-------|-------|
| Bituminous<br>High-Vol. | Bituminous<br>Low-Vol. | Anthracite | 4-in.  | 3-in. | 2-in. | 1½-in. | 1-in. | ½-in. |
| 50                      | 50                     | 0          | 39.0   | 58.0  | 85.8  | 93.2   | 96.2  | 97.6  |
| 53                      | 44                     | 3          | 38.0   | 63.4  | 87.9  | 94.2   | 97.8  | 99.0  |
| 58                      | 39                     | 3          | 26.0   | 63.0  | 87.9  | 94.9   | 98.0  | 99.0  |
| 48.5                    | 48.5                   | 3          | 62.0   | 76.1  | 91.5  | 94.6   | 96.4  | 97.5  |
| Avg. 53.2               | 43.8                   | 3          | 42.0   | 67.5  | 89.1  | 94.6   | 97.4  | 98.5  |
| 52                      | 43                     | 5          | 47.1   | 63.6  | 90.1  | 94.3   | 96.7  | 97.6  |
| 57                      | 38                     | 5          | 63.5   | 79.0  | 91.6  | 95.6   | 97.4  | 98.3  |
| 47.5                    | 47.5                   | 5          | 58.0   | 75.0  | 92.4  | 95.8   | 97.9  | 98.5  |
| Avg. 52.2               | 42.8                   | 5          | 56.2   | 72.5  | 91.3  | 95.2   | 97.3  | 98.1  |
| 40                      | 50                     | 10         | 76.6   | 87.1  | 95.1  | 96.7   | 97.7  | 98.4  |
| 50                      | 40                     | 10         | 63.5   | 85.0  | 94.0  | 96.4   | 97.4  | 98.2  |
| Avg. 45                 | 45                     | 10         | 70.1   | 86.1  | 94.6  | 96.6   | 97.6  | 98.3  |

same blend in the regular Koppers ovens. It, therefore, follows that the improvement evident in the shatter indices of the 19-hour coke made in the Koppers ovens from the 60-36-4, bituminous-anthracite blend is real when compared with those for the 20-hour coke made in the Piette ovens from the 60-40 blend of bituminous coals alone. Thus, although the individual groups of cokes shown in the table show a slight indication in favor of longer coking times for improved cokes, a comparison such as that just made for the 19-hour 60-36-4 coke and the 20-hour 60-40 coke demonstrates clearly that the use of a small percentage of anthracite in the blend will produce as good and even better coke on shorter coking time than regular practice admits. Figure 8A shows the external appearance of the coke produced with this 60-36-4 blend, while Figure 8B is a typical view of this coke as discharged on the wharf.

*Abrasion and Tumbler Tests.*—One of the principal criticisms usually levelled at anthracite blend cokes, in fact at most cokes containing noncoking forms of carbon, is that such cokes are more friable and more abradable than regular cokes. In most cases the criticism has been correct, at least in part, but too often, the blame has been fixed on the anthracite or inert, per se, with no consideration being given to the effect of such factors as the screen size of the anthracite or inert, the nature and quality of these materials, the intimacy of mixing or thoroughness of blending, etc.

Quantitative information on the friability and abradability of anthracite blend coke is almost non-existent. The results of an abrasion test reported by Mott and Wheeler on a 20 per cent anthracite blend coke were described in the foregoing pages and Roberts has reported the results of a series of tumbler tests on anthracite blend cokes containing 0 to 10 per cent of anthracite. A compilation of Roberts' results using 0 to 10 per cent of anthracite

TABLE 13

EFFECT OF COKING TIME ON THE SHATTER INDICES OF COKE

| Coal, Per Cent          |                        |                 | Coking<br>Time<br>Hours | Rate of<br>Coking<br>in./hr. | Shatter Indices of Foundry-size Coke<br>(over 3"x3½"), Per Cent Cumulative |       |       |        |       |       |
|-------------------------|------------------------|-----------------|-------------------------|------------------------------|--|-------|-------|--------|-------|-------|
| Bituminous<br>High-Vol. | Bituminous<br>Low-Vol. | Anthra-<br>cite |                         |                              | 4-in.  | 3-in. | 2-in. | 1½-in. | 1-in. | ½-in. |
| 60                      | 40                     | 0               | 191                     | 1.04                         | 29.6   | 49.5  | 79.3  | 90.2   | 95.8  | 97.9  |
| 60                      | 40                     | 0               | 201                     | 0.99                         | 45.0   | 59.5  | 84.0  | 91.0   | 95.6  | 97.2  |
| 57                      | 38                     | 5               | 191                     | 1.04                         | 51.4   | 77.5  | 89.5  | 94.3   | 97.4  | 98.5  |
| 57                      | 38                     | 5               | 201                     | 0.99                         | 51.0   | 65.5  | 87.3  | 93.3   | 96.9  | 98.5  |
| 57                      | 38                     | 5               | 21.5 <sup>1</sup>       | 0.92                         | 63.5   | 79.0  | 91.6  | 95.6   | 97.4  | 98.3  |
| 60                      | 40                     | 0               | 19.0 <sup>2</sup>       | 1.04                         | 31.3   | 49.5  | 78.7  | 89.2   | 95.9  | 98.1  |
| 55                      | 45                     | 0               | 21.5 <sup>2</sup>       | 0.92                         | 26.2   | 51.7  | 84.7  | 93.1   | 96.7  | 98.3  |
| 60                      | 36                     | 4               | 19.0 <sup>2</sup>       | 1.04                         | 57.9   | 75.0  | 90.3  | 94.7   | 97.3  | 98.7  |
| 60                      | 36                     | 4               | 19.5 <sup>2</sup>       | 1.01                         | 59.7   | 78.4  | 91.2  | 93.9   | 96.6  | 97.0  |

<sup>1</sup>Carbonized in Piette ovens, average width 19¾ inches.

<sup>2</sup>Regular Plant Operation results with Koppers ovens, average width 19¾ inches.

ANTHRACITE BLEND COKES PRODUCED FROM 60 PER CENT HIGH-VOLATILE AND  
36 PER CENT LOW-VOLATILE BITUMINOUS COALS AND  
4 PER CENT ANTHRACITE FINES



FIGURE 8A



FIGURE 8B

in blends coked in Piette ovens for 21.5 hours is shown in Table 14. The effect of coking time on the tumbler test results can be seen from an examination of Table 15.

An examination of the data of Table 14 fails to reveal any conclusive relationship between the percentage of anthracite added to the coking blend and either the "stability factor" (the cumulative percentage retained on the 1-inch screen) or the "hardness factor" (the cumulative percentage retained on the 1/4-inch screen). For the three blends in which the relative proportions of the high- and low-volatile bituminous coals are maintained constant and equal, increasing additions of anthracite appear to cause a decrease in both stability factor and in hardness factor. However, the data shown in Table 15 for addition of anthracite to the same bituminous coals, in the proportions of 60-40 high- and low-volatile, when coked on a 19-hour cycle show a definite improvement in stability factor and substantially the same hardness index. On a 20-hour coking cycle the stability index shows a decrease upon addition of anthracite but the hardness index is again substantially the same as for the coke from the bituminous coals alone.

From these data, therefore, it would seem probable that either the reproducibility of tumbler test data on cokes from plant scale operation is not precise enough to detect changes of two or three per cent in stability factor, or that factors other than the addition of anthracite are more significant in establishing the stability factor of the coke produced. In this connection Russell and Perch<sup>22</sup> have reported that the stability factor from representative

TABLE 14  
EFFECT OF DIFFERENT PERCENTAGES OF ANTHRACITE ON THE  
TUMBLER TEST OF COKE

(Piette ovens, coking times 21.5 hours, rate of coking 0.92 in./hr.)

| Coal, Per Cent |          |            | Tumbler Test on 2 to 3 inch coke from Run-of-Oven Coke, Per Cent Cumulative |           |       |         |         |
|----------------|----------|------------|---|-----------|-------|---------|---------|
| High-Vol.      | Low-Vol. | Anthracite | 2-in.   | 1 1/2-in. | 1-in. | 1/2-in. | 1/4-in. |
| 50             | 50       | 0          | 25.2  | 42.2      | 64.7  | 71.7    | 72.3    |
| 53             | 44       | 3          | 12.8  | 34.5      | 60.7  | 69.9    | 70.8    |
| 58             | 39       | 3          | 11.4  | 32.8      | 61.5  | 71.8    | 72.7    |
| 48.5           | 48.5     | 3          | 17.2  | 37.5      | 62.3  | 69.1    | 70.0    |
| Avg. 53.2      | 43.8     | 3          | 13.8  | 34.9      | 61.5  | 70.3    | 71.2    |
| 52             | 43       | 5          | 14.8  | 34.5      | 58.0  | 70.0    | 71.1    |
| 57             | 38       | 5          | 22.3  | 43.6      | 63.1  | 71.5    | 72.6    |
| 47.5           | 47.5     | 5          | 16.5  | 22.5      | 60.4  | 68.1    | 68.7    |
| Avg. 52.2      | 42.8     | 5          | 17.9  | 33.5      | 60.5  | 69.9    | 70.8    |
| 40             | 50       | 10         | 32.2  | 49.8      | 60.1  | 63.4    | 64.0    |
| 50             | 40       | 10         | 37.3  | 53.0      | 64.4  | 69.1    | 69.7    |
| Avg. 45        | 45       | 10         | 34.8  | 51.4      | 62.3  | 61.3    | 66.9    |

samples may agree within 1.4 per cent. They report, however, that blast furnace men prefer to maintain a uniform stability factor rather than aim for some particular value.

It is of interest to note, that although shatter test data of the cokes from the same blend coked in Piette and Koppers ovens show almost quantitative agreement (Table 13), tumbler test data for the same cokes (Table 15) show a difference comparable to the difference between the results for the original bituminous blend and the anthracite blend. This would suggest that probably the reproducibility of tumbler test data was the cause of the apparent difference between the several tumbler test results. Russell and Perch have also pointed out that in a total of 69 tests, the Tumbler stability factor of the coke from an 80-20 blend of Powellton-Pocahontas No. 3 coals is not appreciably affected by changes in coking time ranging from 15.31 hours to 18.41 hours.

*Apparent and True Specific Gravities, Porosity and Combustion Characteristics.*—The apparent specific gravity is a measure of the amount of carbon per unit volume of coke, the higher the apparent specific gravity for a given ash content the greater the carbon content per unit volume. Within certain limits increased apparent specific gravity is, therefore, advantageous but if the coke is too dense, it may lack the necessary cell structure and be insufficiently porous. Mott and Wheeler<sup>12</sup> have also shown that in general very dense cokes of high apparent specific gravity are often brittle and hence deficient in impact hardness.

Data on the physical properties of several anthracite cokes have been reported by Mott and Wheeler<sup>12</sup> and by Roberts<sup>16</sup>. The former are reproduced in Table 16 and the latter in Tables 17 and 18. The data of Table 16

TABLE 15

EFFECT OF COKING TIME ON THE TUMBLER TEST OF COKE

| Coal, Per Cent          |                     |      | Coking<br>Time<br>Hours | Rate of<br>Coking<br>in./hr. | Tumbler Test on 2 to 3 inch Coke<br>from Run-of-Oven, % Cumulative |        |       |       |       |
|-------------------------|---------------------|------|-------------------------|------------------------------|--|--------|-------|-------|-------|
| Bituminous<br>High-Vol. | Anthra-<br>Low-Vol. | cite |                         |                              | 2-in.  | 1½-in. | 1-in. | ½-in. | ¼-in. |
| 60                      | 40                  | 0    | 19 <sup>1</sup>         | 1.04                         | 11.8   | 29.6   | 58.1  | 68.8  | 69.9  |
| 60                      | 40                  | 0    | 20 <sup>1</sup>         | 0.99                         | 13.4   | 35.3   | 61.3  | 67.7  | 58.8  |
| 57                      | 38                  | 5    | 19 <sup>1</sup>         | 1.04                         | 18.8   | 37.9   | 60.2  | 67.7  | 69.0  |
| 57                      | 38                  | 5    | 20 <sup>1</sup>         | 0.99                         | 11.6   | 37.4   | 58.2  | 67.7  | 58.3  |
| 57                      | 38                  | 5    | 21.5 <sup>1</sup>       | 0.92                         | 22.3   | 43.6   | 63.1  | 71.5  | 72.6  |
| 60                      | 40                  | 0    | 19.0 <sup>2</sup>       | 1.04                         | 20.0   | 37.1   | 60.5  | 67.9  | 68.8  |
| 55                      | 45                  | 0    | 21.5 <sup>2</sup>       | 0.92                         | 23.1   | 42.4   | 64.6  | 71.3  | 72.2  |
| 60                      | 36                  | 4    | 19.0 <sup>2</sup>       | 1.04                         | 19.8   | 39.9   | 58.3  | 67.6  | 68.6  |
| 60                      | 36                  | 4    | 19.5 <sup>2</sup>       | 1.01                         | 21.4   | 41.6   | 58.5  | 66.4  | 67.4  |

<sup>1</sup>Carbonized in Piette ovens, average width 19¾ inches.

<sup>2</sup>Regular plant operation results in Koppers ovens, average width 19¾ inches.

for cokes made with 30 per cent anthracite show a marked increase in apparent specific gravity, a slight decrease in true specific gravity, and a marked decrease in porosity. Shatter test data on these same cokes (Table 11) substantiate Mott and Wheeler's claim that such cokes are deficient in impact hardness. The data of Roberts, Table 17, however, show a slight decrease in apparent specific gravity with increasing additions of anthracite, while the data of Table 18 show a slight increase in apparent specific gravity. In both sets of Roberts' data, true specific gravity remains substantially constant while porosity increases slightly for blends of equal parts of the two bituminous coals and decreases slightly for the 60-40 ratio of high- to low-volatile coal.

These data suggest that it is not so much the anthracite additions as the correct blending of the several coals used that produces the changes in physical properties of the coke. Thus, using the same bituminous coals with 10 per cent anthracite, coked under the same conditions, a blend of 40 high-volatile, 50 low-volatile, and 10 anthracite gave a coke almost identical with an original 50-50 bituminous coal blend, while a 50 high-volatile, 40 low-volatile, 10 anthracite blend gave a coke with lower apparent specific gravity and higher porosity.

Unfortunately the data of the foregoing tables are limited in scope but since the average error in specific gravity and porosity data should not exceed 2 to 3 per cent the trends observed appear to be real, rather than apparent.

Mott and Wheeler report the true specific gravity of each of their cokes on the ash-free basis in order that changes in specific gravity are not masked or exaggerated by variations in ash content. Assuming a specific gravity of 2.5 for the coke ash, the ash-free values were calculated by use of Equation 8(14).

$$\text{Equation 8. True Specific Gravity (Ash-free Basis)} = \frac{2.5 d (100 - a)}{250 - ad}$$

where "a" is the per cent ash in the coke and "d" is the true specific gravity as determined. For the Roberts' data these corrections have not been made because data on ash content of the cokes are lacking. Since comparisons are made only between blends where the ash content is virtually constant, especially in Table 18, no error is introduced due to ash variations.

Mott and Wheeler<sup>14</sup> have observed that "... Cokes made from good coking coals are of higher true specific gravity, up to about 2.0, than those made from inferior coking coals, which average about 1.7. Cokes made by blending a coking coal with a noncoking material, such as anthracite, are usually of low true specific gravity. The true specific gravity can serve as a rough guide to the reactivity of a coke for those of low specific gravity are the most reactive."

TABLE 16  
EFFECT OF ANTHRACITE AND RATE OF COKING ON THE  
SPECIFIC GRAVITY AND POROSITY OF COKE

| Coal, Per Cent               |            | Width<br>of Oven<br>(in.) | Coking<br>Time<br>(hrs.) | Rate of<br>Coking<br>(in./hr.) | Specific Gravity |                             | Porosity, Per Cent |       |
|------------------------------|------------|---------------------------|--------------------------|--------------------------------|------------------|-----------------------------|--------------------|-------|
| S. Yorkshire<br>Coking Blend | Anthracite |                           |                          |                                | Apparent         | True<br>(Ash-free<br>Basis) | Apparent           | Total |
| 100                          | 0          | 21                        | 22½                      | 0.95                           | 0.85             | 1.80                        | 45.3               | 54.2  |
| 70                           | 30         | 21                        | 24½                      | 0.86                           | 1.03             | 1.78                        | 36.0               | 43.7  |
| 100                          | 0          | 14                        | 12                       | 1.17                           | 0.85             | 1.83                        | 37.5               | 55.0  |
| 70                           | 30         | 14                        | 9½                       | 1.47                           | 1.11             | 1.76                        | 31.2               | 39.0  |

The data of Table 19 are the only results found pertaining to reactivity of anthracite cokes and these are for cokes which have been shown in other sections of this report to be relatively poor. The data are of interest, however, as an indication of the apparent correlation between reactivity and porosity. From these results a decrease in porosity appears to increase reactivity to O<sub>2</sub> quite markedly and to increase reactivity to CO<sub>2</sub>, although to a lesser extent. But, Mott and Wheeler<sup>12</sup> have also observed that highly reactive cokes have frequently been found among those of either abnormally low or abnormally high apparent and total porosities. In summarizing a considerable amount of work on the correlation between reactivity and combustion characteristics, Mott and Wheeler<sup>14</sup> state, ". . . Except when a coke is used in such a manner that a high combustion temperature is not produced (i.e., in an open grate) it is doubtful whether measurement of its specific reactivity provides information of much value as to its probable behavior. The conditions of burning a high temperature coke usually lead to high combustion temperatures when the most important factor affecting its general reactivity is its size . . ." This same conclusion has been reached by Gauger and Wright<sup>25,26</sup>, as a result of water gas and cupola studies using anthracite as fuel.

It may be concluded from what experimental evidence is available, therefore, that the apparent and true specific gravity and the porosity of cokes produced from blending anthracite with bituminous coals can be regulated

TABLE 17

EFFECT OF DIFFERENT PERCENTAGES OF ANTHRACITE ON THE  
SPECIFIC GRAVITY AND POROSITY OF COKE

(All cokes made in Piette ovens, coking time 21.5 hrs., rate of coking 0.92 in./hr.)

| Coal, Per Cent |          |            | Specific Gravity |      | Porosity,<br>Per Cent |      |
|----------------|----------|------------|------------------|------|-----------------------|------|
| Bituminous     |          | Anthracite | Apparent         | True | Total                 |      |
| High-Vol.      | Low-Vol. |            |                  |      |                       |      |
|                | 50       | 50         | 0                | 0.95 | 1.94                  | 51.3 |
|                | 53       | 44         | 3                | 0.90 | 1.94                  | 51.2 |
|                | 58       | 39         | 3                | 0.95 | 1.93                  | 51.1 |
|                | 48.5     | 48.5       | 3                | 0.90 | 1.92                  | 53.1 |
| Avg.           | 53.2     | 43.8       | 3                | 0.92 | 1.93                  | 51.8 |
|                | 52       | 43         | 5                | 0.91 | 1.94                  | 52.9 |
|                | 57       | 38         | 5                | 0.94 | 1.92                  | 51.2 |
|                | 47.5     | 47.5       | 5                | 0.89 | 1.93                  | 54.3 |
| Avg.           | 52.2     | 42.8       | 5                | 0.91 | 1.93                  | 52.8 |
|                | 50       | 40         | 10               | 0.92 | 1.93                  | 52.6 |
|                | 40       | 50         | 10               | 0.94 | 1.94                  | 51.5 |
| Avg.           | 45       | 45         | 10               | 0.93 | 1.935                 | 52.1 |

to give the same or different values, depending upon the ratios in which the several coals are blended and that these data or data on reactivity are not directly related to performance in the blast furnace.

#### BY-PRODUCTS

The effect of anthracite additions upon the yields of by-products resulting from carbonization of bituminous coal blends has been discussed in a previous section of this report. The effect of anthracite additions upon the quality of the by-products was not, however, specifically mentioned.

TABLE 18  
EFFECT OF ANTHRACITE AND RATE OF COKING ON SPECIFIC  
GRAVITY AND POROSITY OF COKE  
(All cokes made in Piette ovens of 19¾ in. average width.)

| Coal, Per Cent          |                        | Coking<br>Time<br>(hrs.) | Rate of<br>Coking<br>(in./hr.) | Specific Gravity |      | Porosity<br>Per Cent<br>Total |
|-------------------------|------------------------|--------------------------|--------------------------------|------------------|------|-------------------------------|
| Bituminous<br>High-Vol. | Low-Vol.<br>Anthracite |                          |                                | Apparent         | True |                               |
| 60                      | 40                     | 0                        | 1.04                           | 0.90             | 1.91 | 52.8                          |
| 60                      | 40                     | 0                        | 0.99                           | 0.91             | 1.91 | 52.4                          |
| 57                      | 38                     | 5                        | 1.04                           | 0.93             | 1.88 | 50.5                          |
| 57                      | 38                     | 5                        | 0.99                           | 0.94             | 1.88 | 50.0                          |
| 57                      | 38                     | 5                        | 0.92                           | 0.94             | 1.92 | 51.2                          |

TABLE 19  
EFFECT OF ANTHRACITE AND RATE OF COKING ON THE REACTIVITY AND  
TEMPERATURE OF COMBUSTION OF COKE

| Coal, Per Cent               |            | Width<br>of Oven<br>(in.) | Coking<br>Time<br>(hrs.) | Rate of<br>Coking<br>(in./hr.) | Reactivity*  |                           | Temperature of<br>Combustion, °C. |         |
|------------------------------|------------|---------------------------|--------------------------|--------------------------------|--|---------------------------|-----------------------------------|---------|
| S. Yorkshire<br>Coking Blend | Anthracite |                           |                          |                                | O <sub>2</sub> Disap-<br>pears from<br>Blast (in.) | 20% CO<br>in Gas<br>(in.) | Maximum                           | Average |
| 100                          | 0          | 21                        | 22½                      | 0.95                           | 5  | 11                        | 1670                              | 1540    |
| 70                           | 30         | 21                        | 24½                      | 0.86                           | 4  | 10                        | 1740                              | 1600    |
| 100                          | 0          | 14                        | 12                       | 1.17                           | 4½   | 11                        | 1650                              | 1510    |
| 70                           | 30         | 14                        | 9½                       | 1.47                           | 3  | 10½                       | 1660                              | 1520    |

\*Using a furnace of 1 square foot grate area, originally described by Kreisinger, Ovtz, and Augustine (U.S.B.M.T.P. 137, 1916), but with a modified procedure the Midland Coke Research Committee's method of test expressed the "reactivity with oxygen" of the coke by the distance above the grate at which oxygen no longer appears in any quantity in the gas sample, and the "reactivity with carbon dioxide" by the distance at which the gases contain 20 per cent or more of carbon monoxide. Essentially, the test method consisted of a fuel bed of arbitrary depth made up of standard size coke and furnished with a standard rate of supply of air. The distances which express the "reactivity with oxygen of the coke are computed from graphs of the oxygen content of the gases at different levels in the fuel bed. In arriving at an expression for the "reactivity with carbon dioxide" of the coke it was found that a fuel bed 12 inches deep of 1 to 1½ inch coke was insufficient to reduce to carbon monoxide all the carbon dioxide formed in the lower part of the bed. However, a satisfactory measure of the rate of reaction between the coke and the carbon dioxide was obtained from the distance above the grate at which an arbitrary quantity of carbon monoxide—say 20 per cent—appeared in the gas samples.



No experimental evidence has been found for carbonization at temperatures of 900-1000°C. (1652-1832°F.) which suggests that anthracite may exert any catalytic effect upon the reactions occurring during carbonization and thus alter the nature or the properties of the by-products. It is assumed, therefore, that the nature and properties of the by-products are additive functions of the nature and properties of the by-products from the constituent coals.

In Table 20 are shown analyses and properties of the gas obtained from the carbonization of two typical bituminous coal blends and average data for the analyses and properties of the gas from anthracite. It is readily apparent that the effect of anthracite additions to a bituminous coal blend will be to increase the hydrogen content of the gas and decrease the illuminant, methane, and ethane content. The resultant gas from the anthracite-bituminous coal blend will tend to have a lower specific gravity, lower heating value, lower sulphur content, and lower gas value.

Since it has already been shown that anthracite will act as an inert diluent on the production of other by-products, it is highly unlikely that anthracite additions will affect the quality of the tar, light oil, or ammonia normally obtained from the bituminous coal blends.

#### EFFECT OF QUALITY OF ANTHRACITE ON QUALITY OF CARBONIZATION PRODUCTS

Despite the extensive work done upon the use of anthracite in the manufacture of coke, surprisingly little specific data have been published concerning the physical and chemical properties of the anthracites which are desirable or undesirable. Most attempts have been limited to one or two coals, and anthracites as a group condemned or praised on the basis of these results, with no account taken of the fact that the anthracites vary almost as widely in properties as do bituminous coals. In view of the care taken in the selection of bituminous coals for coke manufacture, it is remarkable that such indiscriminate selection of anthracites has yielded even the limited success that has been attained.

Among the physical and chemical properties that would be expected to influence the final product from the coking of anthracite and bituminous coal blends are the following: ash, ash fusion temperature, moisture, volatile matter, sulphur, phosphorus, and hardness or decrepitation characteristics of anthracites. In the following paragraphs the probable significance of each of these factors is discussed in the light of available information.

#### ASH

One of the most important considerations in the use of anthracite as a blending agent in coke production is the effect it will have upon the ash content of the resultant product. Number 5 buckwheat anthracite, unless cleaned

TABLE 20  
COMPOSITION AND PROPERTIES OF THE GAS DISTILLED FROM  
BITUMINOUS COALS AND FROM ANTHRACITE

|  | 80% Powellton,<br>20% Pocahontas No. 41<br>(Carbonized at 900°C.) | 60% Pittsburgh<br>(W. Va.), 40%<br>Pocahontas No. 42<br>(Carbonized at 1000°C.) | 100% Anthracite <sup>3</sup><br>(Coal Distilled<br>up to 1000°C.) |
|--|---|---|---|
| V.M. in coal (dry basis)   | 29.9  | 28.7  | 4.7   |
| Composition of gas:  |   |   |   |
| CO <sub>2</sub>  | 1.5   | 1.3   | 1.9   |
| O <sub>2</sub>   | 4.6   | 3.2   | 0.0   |
| H <sub>2</sub>   | 0.5   | 0.3   | 1.6   |
| CO   | 56.3  | 59.7  | 83.6  |
| CH <sub>4</sub>  | 4.9   | 6.9   | 4.1   |
| C <sub>2</sub> H <sub>6</sub>  | 30.1  | 25.4  | 5.2   |
| N <sub>2</sub>   | 1.0   | 1.8   | 0.0   |
|  | 1.1   | 1.4   | 3.6   |
| H <sub>2</sub> S, grains/100 cu. ft.                                   | 250   | 130   |   |
| Small amounts of H <sub>2</sub> S<br>reported in all<br>samples tested |   |   | 0.212**   |
| Specific gravity of gas  | 0.346*  | 0.348*  | 340   |
| Gross Btu./cu. ft.*  | 586   | 546   | 5,900   |
| Cu. ft./ton as carbonized  | 10,400  | 12,000  | 1,000   |
| Gas value, Btu./lb. coal   | 3,050   | 3,280   | 1.6   |
| Moisture in coal as carbonized   | 1.4   | 1.4   |   |

\*Saturated with H<sub>2</sub>O vapor at 60°F. and 30" Hg.

\*\*60°F. and 30" Hg. dry.

1Coal. 62C. See Tables I and II, Appendix I for partial data. U. S. Bur. Mines T. P. 630 (1941).

2Coal 25, U. S. Bur. Mines Mono. 5 (1934).

3Compiled from data of Turner and Keene<sup>19</sup> and Scott and Jones<sup>20</sup>.

to a degree generally considered uneconomic at the present time, will contain from about 9 to 15 per cent ash depending upon the source of the coal and the degree of cleaning to which it is subjected. Specifications<sup>27</sup> for blast furnace coke usually limit the ash content to from 7 to 9 per cent. For foundry purposes an upper limit of 12 per cent is specified<sup>28</sup>, but in general the trade objects to ash contents in excess of 10 per cent. No fixed specification for domestic coke appears to have been published but the trade definitely prefers a low ash coke.

It is generally accepted that the weight of ash in a coke from a given blend will be the same as that obtained if equal weights of the coals used for producing the coke were coked separately; hence, the weight of ash in the coke may be regarded as additive. But, the prediction of the percentage of ash in a coke resulting from the blending of two or more coals is a more difficult problem because different coals yield different amounts of coke. However, the relationship between yield of coke and proximate analyses of the individual constituents of the blend has been discussed thoroughly in a previous section of this report and the equations and methods of calculation therein described are directly applicable here.

Where data are available for the yields of coke from the individual coals coked separately, the ash content of the coke resulting from the blend may be calculated from Equation 9.

Equation 9. % Ash in Coke =

$$\frac{100 [(A) (a) + (B) (b) + (C) (c)]}{(A) (d) + (B) (e) + (C) (f)},$$

where A, B, and C refer to the percentages of the component coals used in the coking blend, d, e, and f refer to the percentages of coke from the component coals when coked individually and a, b, and c refer to the ash contents of the original coals.

Where only proximate analyses of the coals are available, the ash content of the resultant coke can still be predicted with reasonable accuracy by calculating the coke yields from the individual coals by the use of Equation 1 or by reading the coke yields directly from Curve I of Figure 1, and substituting these data in Equation 9. Experimental data from the U. S. Bureau of Mines-American Gas Association assay test results suggest that the value obtained by the foregoing calculations may tend to be slightly (0 to 0.4 per cent) higher than experimental results. For the purposes for which such calculations are used, however, this relatively small error appears to be negligible.

For the general case of a three-component blend in which the relative proportions of the components are varied, the calculations are rather involved. However, examples are shown of the specific effect of the addition of anthra-

FIGURE 9

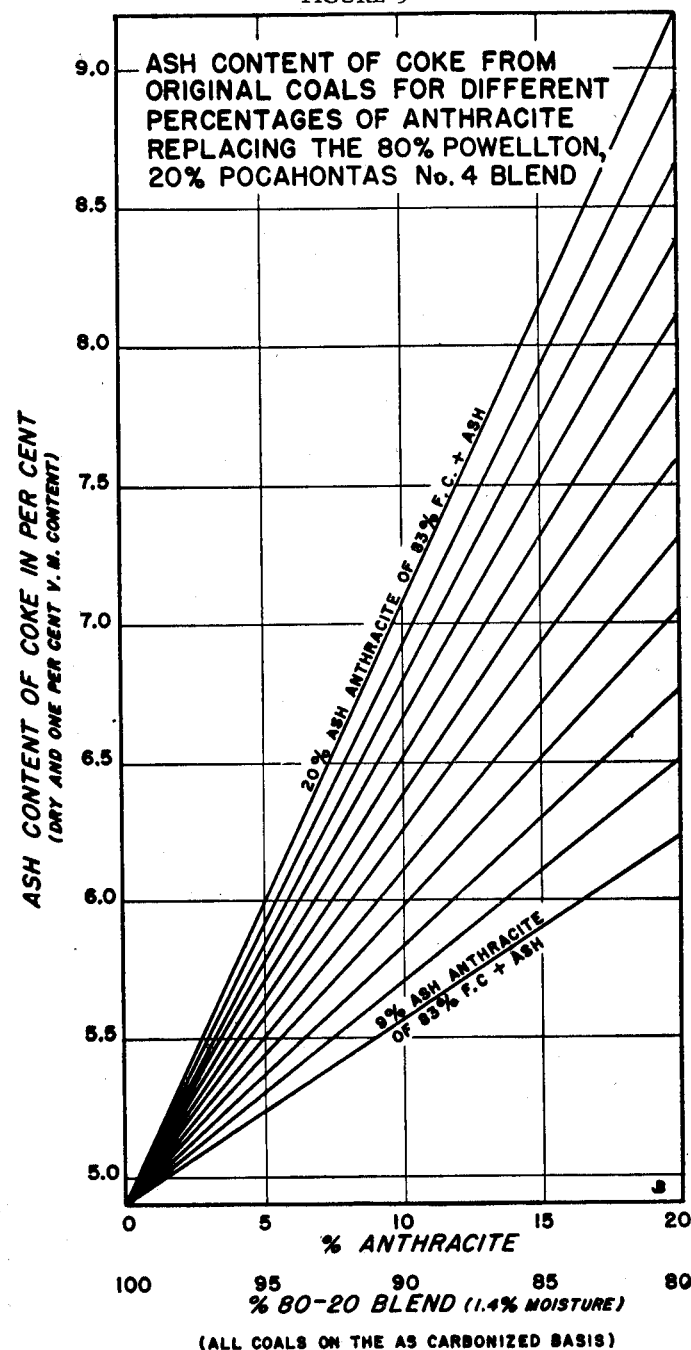
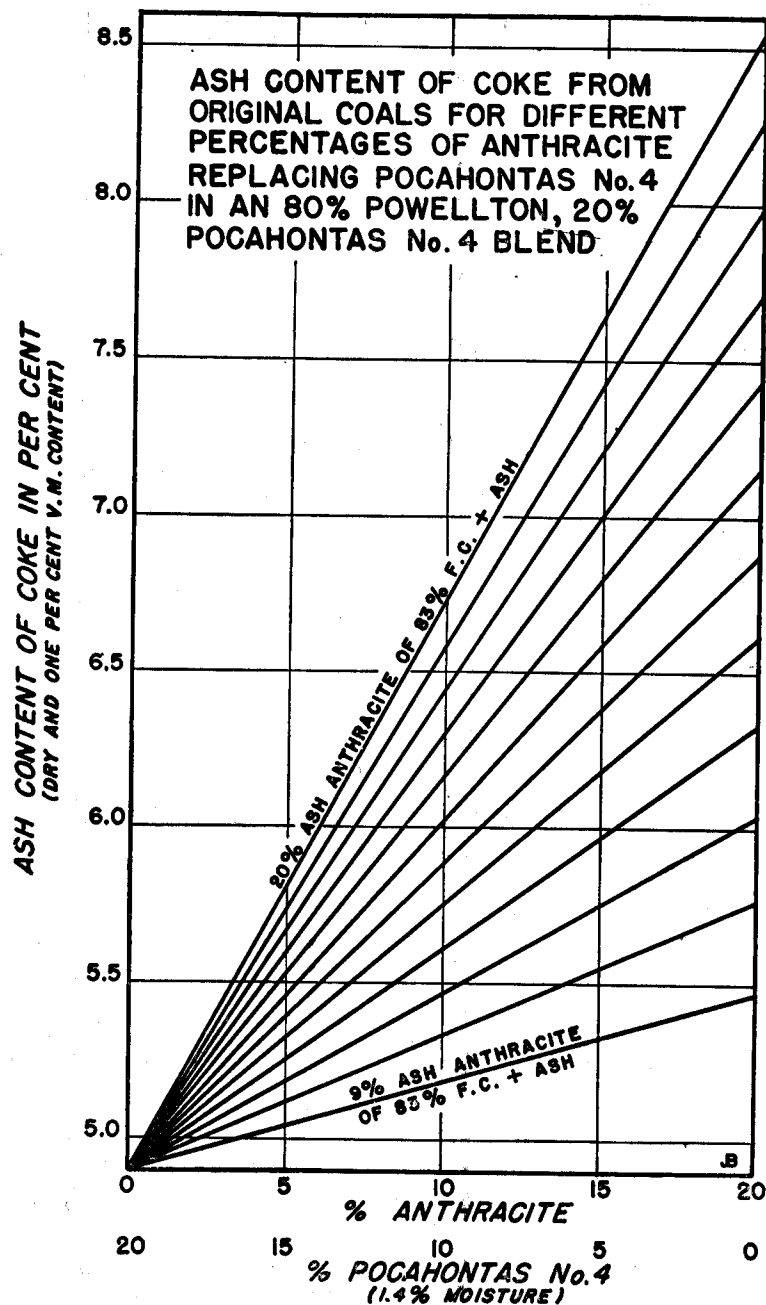
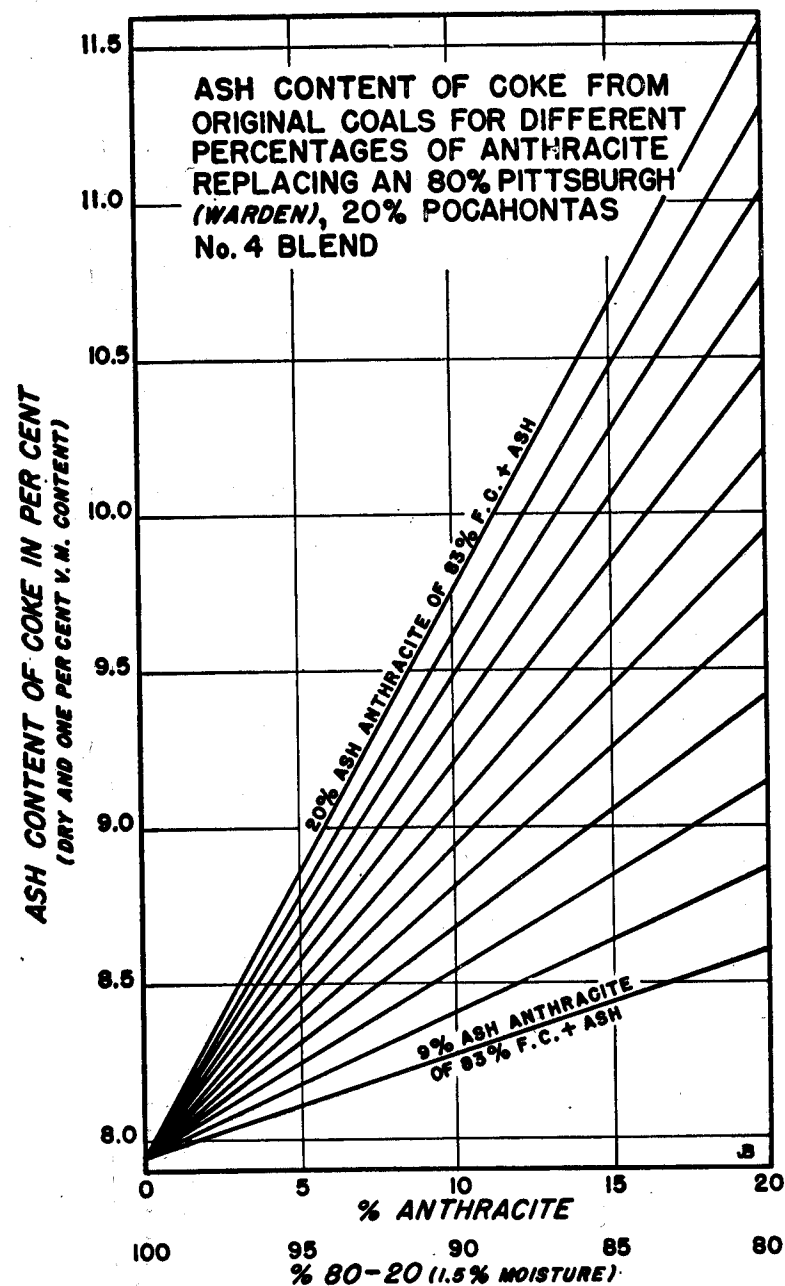


FIGURE 10



(ALL COALS ON THE AS CARBONIZED BASIS)

FIGURE 11



(ALL COALS ON THE AS CARBONIZED BASIS)

cites of varying ash content to three specific coking blends. Figure 9 shows the change in ash content of the coke for varying additions of anthracite to the standard coking blend previously used for an example. Similarly, Figure 10 shows the change in ash content if varying percentages of anthracite are substituted for equal amounts of the low-volatile coal normally used in this standard blend (the probable procedure if anthracite were used). Figure 11 shows the effect of anthracite substitutions for varying percentages of another commonly used coking blend.

With the aid of such graphs it is possible to read directly the limiting percentage of ash in the anthracite which it is possible to use and still produce an acceptable coke. The graphs can similarly be used to determine the maximum percentage of anthracite of a given ash content that it is possible to use.

Only one check is available on the validity of these equations and calculations when anthracite is used in the coking blend, and this is from the data of Roberts<sup>16</sup> who reports that the addition of 4 per cent anthracite containing 11.9 per cent ash, increased the ash content of the coke 0.3 to 0.4 per cent. Data on the ash contents of each of the original coals are not available but from Figures 9, 10, and 11 it is apparent that the increase in ash content of the coke resulting from this addition of anthracite is 0.2 to 0.3 per cent for cokes in the normal range of 5 to 8 per cent ash content.

#### ASH FUSION TEMPERATURE

Quantitative data on the composition of anthracite ash are rather limited. Jones and Buller<sup>29</sup> have reported analyses of ash from the prepared sizes of a number of Northern Field anthracites obtained from various localities. The data shown in Table 21 indicate the range in composition found by these investigators.

TABLE 21  
ASH ANALYSES AND SOFTENING TEMPERATURES OF  
NORTHERN FIELD ANTHRACITE

| Constituent                          | % Range     |
|--------------------------------------|-------------|
| SiO <sub>2</sub>                     | 55.0 - 55.6 |
| Al <sub>2</sub> O <sub>3</sub>       | 30.8 - 38.1 |
| Fe <sub>2</sub> O <sub>3</sub>       | 1.2 - 10.1  |
| TiO <sub>2</sub>                     | 1.0 - 1.8   |
| CaO                                  | 0.3 - 1.4   |
| MgO                                  | 0.0 - 0.8   |
| Na <sub>2</sub> O & K <sub>2</sub> O | 0.4 - 1.3   |
| P <sub>2</sub> O <sub>5</sub>        | 0.08 - 0.14 |
| SO <sub>3</sub>                      | 0.0 - 0.8   |
| Ash Softening Temperature, °F.       | 2660-3000   |

Analyses of ash from two Eastern Middle Field steam size anthracites<sup>30</sup> showed slightly lower SiO<sub>2</sub> but all other constituents fell within the range given for the Northern Field coals.

Data for ash fusion temperature of anthracites from all the anthracite fields show substantially the same range as shown in Table 21, with the ash fusion temperatures for the majority of the coals falling in the range from 2800 to 3000°F. These high fusion temperatures are indicative of the low content of fluxing constituents (Fe<sub>2</sub>O<sub>3</sub>, CaO, MgO, and alkalis in the ash).

Where specific data are available for the ash analyses of the individual coals used in a given blend, it is possible to calculate with a high degree of accuracy the ash fusion temperature of the ash in the resultant coke but the effect of the different ash constituents is such that generalizations cannot usually be made. In view of the low content of fluxing materials usually present in anthracite ash, however, it is reasonably safe to predict that in general additions of anthracite will tend to raise the ash fusion temperature of the coke.

#### VOLATILE MATTER

The normal range of volatile matter for Pennsylvania anthracites is from about 3 to 9 per cent on the dry coal basis. Obviously such a variation in volatile matter content can influence both the yield and character of the carbonization products produced from blending anthracite with coking coals.

**COKE.**—As previously shown, the coke yield from a blend is an additive function of the coke yields of the individual constituents of the blend and the coke yield from anthracite is approximately equal to the fixed carbon plus ash content of the anthracite as carbonized. For the same moisture content, therefore, the yield of coke from a given anthracite is inversely proportional to its volatile matter content, and the yield of coke from the blend will, therefore, change accordingly. Where the percentage of anthracite in the blend is relatively low, the effect of changes in the volatile matter content of the anthracite will not be significant, but as the percentage of anthracite increases the volatile content becomes more significant.

**GAS.**—An examination of Tables 2 and 3, presented in a previous section, shows that the composition of the gaseous products of anthracite carbonization changes with change in volatile matter content. The change, however, is not large enough to be of significance in cases where the amount of anthracite in the blend does not exceed about 20 per cent. A fact that is of considerable significance, however, is that the thermal value of the gas of the lower volatile anthracites averages only 768 Btu. per pound, while the thermal value of the gas of the high volatile anthracites averages 1370 Btu. per pound of anthracite carbonized. This is almost an 80 per cent increase and where gas sales are a significant item in the final balance sheet, as is the case at many coke ovens, this change in the thermal value of the gas may become

important. Obviously, however, the problem is one of economic balance because increased gas yield is only obtained at the expense of a decrease in coke yield.

**TAR, LIGHT OIL, AND AMMONIA.**—As previously shown, the anthracite appears to have no residual value for tar, light oil, or ammonia, and as far as can be determined from available data, change in volatile content will not, therefore, have any effect upon the yield or quality of these by-products.

#### MOISTURE

It is well known that the moisture content of a coking blend as charged to the oven has a definite influence upon the properties of the resultant coke. Fuchs<sup>31</sup> and Mott and Wheeler<sup>12</sup> have attributed this largely to the change in the bulk density of the charge, while Mott and Wheeler<sup>12</sup> have also shown that the moisture content materially affects the time of coking. In a modern 18-inch oven, approximately 3 hours of the coking time was used in the removal of the 10 per cent water carried by the charge. Since both bulk density and coking time are factors in establishing the properties of the coke, it is readily apparent that the moisture content of the blend is one of the determining factors in the control of coke properties.

In America, however, it is not generally the practice to control the moisture content of the blend, because the drying of either the individual coals or the blend is not considered economic. In general, the coals are blended in the as-received condition and when the coals are of substantially the same moisture content no problem is encountered in obtaining a satisfactorily uniform mixture. Mott and Wheeler<sup>14</sup> have reported difficulty in blending fine sizes of dry inert material with the normal 10-12 per cent moisture content coking blends used in England, but no data are available on the blending of relatively wet fine sized inerts with a coking coal that is relatively dry.

Anthracite in No. 5 buckwheat size normally carries a moisture content of 12-14 per cent which is appreciably higher than most coking blends as charged to the oven. Because of the relatively close sizing of the anthracite and the absence of very fine (minus 100-mesh) material, however, no difficulty is anticipated in obtaining satisfactory mixing of the high moisture content anthracite with the bituminous coal. Roberts<sup>16</sup> reports using No. 5 buckwheat anthracite with a 12 per cent moisture content and states:

"This, of course, was very objectionable in view of the high freight rate and the increased difficulty of handling, and also in that it raised the moisture content of the coal mixture. Wetting the coal mixture tends to increase the porosity of the resultant coke. However, the percentage of anthracite was not expected to be over 6 per cent, so the objections to its presence were largely those of paying freight on water shipped over long distances and the difficulty of handling the wet material."

In actual plant operation, 4 per cent anthracite was found to be the economic optimum with this particular blend of coals, and judged by the marked upgrading of the coke that was obtained, no serious difficulty could have been experienced in producing satisfactory mixing.

The increase in moisture content of the blend as a result of additions of high moisture content anthracite cannot be specifically stated because no two plants use bituminous coals of exactly the same moisture content. By the use of Equation 10, however, the moisture content of the blend can be determined readily for different percentages of anthracite of varying moisture content when using bituminous coals of different moisture content.

$$\text{Equation 10. } \% \text{ H}_2\text{O in Blend} = \frac{1}{100} \left[ (\% \text{H}_2\text{O in A})(\% \text{A}) + (\% \text{H}_2\text{O in B})(\% \text{B}) + (\% \text{H}_2\text{O in C})(\% \text{C}) \right], \text{ where A, B,}$$

and C refer to the components of the blend.

#### SULPHUR AND PHOSPHOROUS

To the coke manufacturer, data on sulphur and phosphorous content of the coals used for coking purposes are of definite interest because in many instances coke is sold on the basis of sulphur and phosphorous content. For blast furnace and foundry operations an upper limit of 1.0 for sulphur content is usually specified, although some contracts may call for substantially lower sulphur contents. The general specification for phosphorous is less than 0.01 per cent although again a lower limit is sometimes specified in individual purchase contracts.

Published data <sup>19,32,33</sup> on the sulphur content of anthracites (ash- and moisture-free basis) indicate a normal range of about 0.6 to 1.2 per cent for face samples of anthracites from various sections of the anthracite region. The sulphur content of the so-called prepared sizes pea and larger, will generally range from 0.5 to 1.0 per cent. No specific data have been published regarding the sulphur content of No. 5 buckwheat, the size under consideration for coke oven use, but in general it may be expected to average about the same as that reported for the prepared sizes.

The published data on phosphorus content of anthracite is extremely meager, but Jones and Buller<sup>29</sup> have presented data from which the approximate range of phosphorous contents of typical Northern Field anthracite may be calculated. These data indicate phosphorous contents ranging from .004 to .007 per cent. No specific data for the other anthracite fields have been reported, but a few limited analyses indicate that the coals from the other fields have phosphorous contents of the same order of magnitude.

In view of the foregoing information, it appears reasonably certain that the use of anthracite in coke blends will have no tendency to increase either

the sulphur or phosphorous content of the coke and that in many cases anthracite additions may even be beneficial in reducing sulphur and phosphorous contents.

#### FRIABILITY

The information concerning the effect of friability or decrepitation characteristics of the anthracite upon the quality of coke produced is extremely limited. The only specific data on this subject, reported by Roberts<sup>16</sup>, are for a few anthracites and semianthracites. Box test data indicated a definite upgrading of the coke with all the coals (anthracites and semianthracites), but, in actual plant tests it was found that only two anthracites—one from the Hazleton district and one from the Pittston district—produced a satisfactory upgrading of the coke. Unfortunately the exact source of the coals which proved unsatisfactory was unobtainable from the broker who furnished the coals, and quantitative friability or decrepitation data were not secured. It was observed, however, that the satisfactory coals were definitely less friable than those which proved unsatisfactory.

Although the foregoing results represent a very limited range of anthracites and the data are not quantitative, nevertheless, the observations are of definite significance and may indicate a possible explanation for some of the variable results reported by different investigators. Thus, the extensive tests by Platt<sup>7</sup>, which indicated that anthracite additions were detrimental to coke quality, were all made with two of the most friable and highly decrepitating coals in the anthracite region.

The source of the coal is not given in other reports of the use of Pennsylvania anthracite, but in lieu of more specific plant scale information it would appear desirable for the anthracite industry to confine promotion of anthracite fines as a blending agent in coke production to those anthracites of known high mechanical strength.

#### EFFECT OF SIZE OF ANTHRACITE UPON COKE PRODUCED

There appears to be general agreement between various investigators that the size consist of the inert material that is blended with coking coals is a definite factor in establishing the properties of the resultant product, but some disagreement exists as to what the exact size range should be. From an analysis of the various data presented, it would appear probable that the disagreement between results is attributable to two factors, both of which appear to be of as much significance as the size of the inert material itself. These factors are the size consist of the coking coals with which the inert is blended and the adequacy of the mixing in the blend of inert and coking coal. Russell and Perch<sup>22</sup>, for example, have shown that for some bituminous coals the stability factor (Tumbler Test) of the resultant coke is a straight line function of the degree of pulverization, expressed as total percentage through  $\frac{1}{8}$ -inch, up to at least 90 per cent through  $\frac{1}{8}$ -inch.

Most of the quantitative data upon the effect of size of inert material pertains to the use of coke breeze. Thus, Cole<sup>34</sup> reports that minus  $\frac{1}{8}$ -inch coke breeze containing some oversize particles, produced a noticeable upgrading of size. Upon subsequent crushing to desired sizes, however, the percentage of breeze produced was greater than that originally blended. Roberts<sup>16</sup> reports that coarse coke breeze was of no value for upgrading. Kuhlwein<sup>35</sup> claims that both the blending coal and coke breeze must be ground to 2 mm. (equivalent to approximately  $\frac{1}{12}$ -inch) to give satisfactory upgrading. Pfluke<sup>36</sup>, as a result of tests with various sizes of coke breeze, concludes that optimum results are obtained with 5 per cent of minus  $\frac{1}{32}$ -inch breeze when blended with a single high-volatile coal ground to 100 per cent through 2- $\frac{1}{2}$ -inch and 85 per cent through 1- $\frac{3}{16}$ -inch. Sedlachek<sup>37</sup>, in similar oven-scale tests, reported optimum results with 5 per cent of minus  $\frac{1}{32}$ -inch coke breeze when blended with a coking blend sized to 90 per cent through  $\frac{1}{4}$ -inch. Huyck<sup>38</sup> similarly reports optimum results with 3 per cent of minus  $\frac{1}{32}$ -inch coke breeze blended with coking coals ground to 80 per cent through  $\frac{1}{8}$ -inch. The Midland Coke Research Committee<sup>39</sup> has found that grinding the coke to 14-mesh (about  $\frac{1}{32}$ -inch) is necessary in order to obtain satisfactory upgrading in plant-scale operation. Haskell<sup>34</sup> reports that the yield of larger sizes of coke and of breeze increases as the percentage of coke breeze dust (size not specifically stated but minus 100-mesh material mentioned) is increased.

Most of the data on the sizes of anthracite used in coking blends are less specific, but the following are of interest. Roberts<sup>16</sup> reports that No. 5 buckwheat, which actually screened 20-x 100-mesh ( $\frac{1}{32}$ -inch x  $\frac{1}{170}$ -inch), was the ideal size according to oven-scale operating results. Actual screen analysis of Buckwheat No. 5 as reported by Roberts is shown in Table V, Appendix I. Minus 100-mesh anthracite was tried in box tests and the results indicated no advantage over the regular bituminous coal blend operation and poorer results than with No. 5 buckwheat size. Mott and Wheeler<sup>14</sup> used 5 and 7- $\frac{1}{2}$  per cent Welsh anthracite of minus 200-mesh size very carefully blended with coking coal blends and coked in box tests. The results indicate that the anthracite produced a definite upgrading but was not as effective as coke breeze or fusain in similar quantities. Mott and Wheeler<sup>12</sup> also report extensive oven-scale tests using 30 per cent of minus  $\frac{1}{8}$ -inch Welsh anthracite blended with a standard coking blend and obtaining satisfactory cokes. Markle<sup>11</sup> has reported that satisfactory cokes can be obtained with as little as 25 per cent bituminous coal if the anthracite and bituminous coal are pulverized to 95 per cent through 20-mesh ( $\frac{1}{32}$ -inch) and 85 per cent through 40-mesh ( $\frac{1}{64}$ -inch). Later statements by Markle<sup>11</sup> suggest that the anthracite should be ground to at least 80 per cent through 60-mesh ( $\frac{1}{100}$ -inch). Lane and Cobb<sup>13</sup> report that excellent coke may be produced with as much as 50 per cent anthracite, but only if both components are powdered (no specific size stated). If either component is

coarse grained, a deterioration of coke properties occurs. Rose<sup>40</sup> reports that in laboratory experiments the addition of inerts, including anthracite, in sizes below 60-mesh, to coking coals may produce an insulating effect upon the bituminous coal and prevent agglomeration of the plastic particles. Box tests with No. 4 (3/32-inch x 3/16-inch) and with No. 5 buckwheat, however, were reported to produce satisfactory cokes with 50-50 blends of anthracite and bituminous coal. It is of interest to note that for the blending of bituminous coals, Mott and Wheeler<sup>12</sup> have found that fine grinding may be helpful in some cases, while in other cases it was definitely detrimental to the properties of the resultant coke. This suggests that some of the contradictory results reported in the literature may be due to the use of different coals and that actual tests should be made using various size consists in order to determine the one producing optimum results.

On the basis of existing evidence on the use of both coke breeze and anthracite, it would appear that the optimum top size for anthracite was in the vicinity of 1/32-inch and that sizes larger than 1/8-inch may be definitely detrimental. It appears unlikely, therefore, that further grinding of No. 5 buckwheat, which has a top size of 3/64-inch, offers any advantage. The evidence indicates that fine grinding of the anthracite has no special advantage and may even be detrimental to the properties of the coke. Fine grinding of the anthracite would have another distinct disadvantage not previously discussed, namely, the greater the variation in size consist of the coals blended, the greater the difficulty of securing a uniform blend. For satisfactory blending of finely ground anthracite similar fine grinding of the bituminous coal would be necessary, but such a procedure is neither practical from the cost viewpoint, nor desirable from the use standpoint because of alterations in the bulk density of the charge and, therefore, in the properties of the resultant coke; hence, fine grinding of the anthracite appears undesirable.

#### EFFECT OF ANTHRACITE ADDITIONS UPON TIME REQUIRED FOR COKING

Unfortunately most of the data available on the actual use of anthracite in coking blends fail to show quantitative results concerning the effect of anthracite upon the time required for coking. The following summarizes what little information appears to be available.

Roberts<sup>41</sup> reports that the Laclede plant *normally* operates on a coking rate of not less than 26 hours to produce good foundry coke, and that 21-1/2 hours was found to be the very minimum that would produce an acceptable foundry coke from the bituminous coal blend in use. However, using 4 per cent of No. 5 buckwheat anthracite substituted for an equal amount of the low-volatile coal normally used in the bituminous coal blend, the coking time was successfully reduced to 18-2/3 hours and a *better* foundry coke produced than that previously obtained on the 26-hour cycle. The coal was coked in both Piette and Koppers ovens of 19 3/4 inches average width. These

results indicate a possible reduction of 12 to 28 per cent in the coking time, depending upon whether the 21 1/2 or 26-hour cycle is taken as standard; and Roberts suggests that a further reduction could be made and still obtain a substantial yield of the foundry sizes. For the past year\* this plant has been operating with 4 per cent anthracite in the blend, using the 18 2/3-hour cycle, and has been obtaining a yield of foundry coke greater than 50 per cent as compared to the normal 25 per cent yield previously obtained with original bituminous coal blend.

Mott and Wheeler<sup>12</sup>, however, report the data shown in Table 22 for two series of plant-scale tests using appreciably higher percentages of anthracite and conclude that the addition of anthracite fines tends to increase the time required for coking. Other data reported by these authors<sup>12,14</sup> indicate that in general anthracite is as effective as low-temperature coke in upgrading the size and shatter index of the coke, so it appears probable that a lower percentage of anthracite in the blend would have shown a reduction in coking time comparable to that obtained using the low-temperature coke breeze.

Markle<sup>11</sup> has reported full-scale tests in Semet-Solvay ovens using a blend of 18 per cent pitch and 82 per cent anthracite in which the average coking time was 20 hours as compared to 21.6 hours for the bituminous coal blend used in the other ovens of the battery. Although not strictly comparable with other work reported these data also indicate a substantial reduction in coking time.

From the foregoing experiences in actual coke plant operation, it appears probable that a reduction of at least 10 to 20 per cent in coking time is possible when the amount of anthracite used in the blend does not exceed about 20 per cent.

\*As of June, 1943.

TABLE 22  
EFFECT OF WELSH ANTHRACITE ON COKING TIME

| Width of Oven | % Anthracite in Blend | Coking Time Hours | Rate of Coking in./hr. | Shatter Index 2 in. | Shatter Index 1-1/2 in. |
|---------------|-----------------------|-------------------|------------------------|---------------------|-------------------------|
| 21            | 0                     | 22-1/2            | 0.95                   | 74                  | 87                      |
| 21            | 30                    | 24-1/2            | 0.85                   | 72                  | 90                      |
| 21            | 30                    | 20-1/2            | 1.00                   | 67                  | 84                      |
| 21            | 20*                   | 14-1/2            | 1.49                   | 80                  | 89                      |
| 14            | 0                     | 12                | 1.15                   | 66                  | 85                      |
| 14            | 30                    | 9-1/2             | 1.45                   | 53                  | 74                      |
| 14            | 20*                   | 10                | 1.40                   | 79                  | 88                      |

\*Low-temperature coke breeze used in place of anthracite.

## EFFECT OF MIXING AND BLENDING

It is generally agreed by those familiar with coal blending for coke production that intimate mixing of the various coals is essential to the production of a satisfactory and uniform product. If inerts are to be added to the blend, it is not surprising, therefore, that the properties of the product will depend largely upon the intimacy with which the inert and coking blend are mixed.

At a meeting of the British Iron and Steel Institute as early as 1875 this subject was discussed thoroughly and some of the statements are still of interest. Hackney<sup>6</sup> reported that plant-scale experience in the blending of anthracite with coking coals showed that the resultant coke was harder and denser the finer the materials were crushed and the more intimately they were mixed. Martin<sup>4,2</sup> reported that his experience had been that when the coking coal and anthracite were simply mixed and carbonized no coherent coke was produced, but that when the two were ground together in the same proportions a very hard and satisfactory coke resulted. Foley<sup>2</sup> reported that in their plant it was the practice to grind the anthracite and coking coal together using rolls for crushing and pulverization.

Markle<sup>11</sup> has reported that in the preparation of anthracoke from anthracite and pitch, the lack of intimate mixing leads to poor or unsatisfactory results. Similarly, in the patent<sup>9</sup> specifications for anthracoke production using bituminous coal as binding material, the following statement is made: . . . "in order to produce a relatively dense fuel without cell structure, which is the object of my improvements, it is necessary that both the anthracite and bituminous elements be finely ground and intimately mingled so as to form a uniform mixture in which the particles of both are in contact throughout the mass."

Mott and Wheeler<sup>14</sup> have found that, in the case of blending very finely ground inert materials (minus 200-mesh) with coking coals, it is necessary to mix the inert with about twice its weight of dry coking coal as a carrier before blending with the regular coking mixture in order to ensure satisfactory and adequate mixing. Even using this procedure their results suggest that adequate mixing was not obtained. These results substantiate a statement made by Rose<sup>40</sup> that in certain cases fine grinding of the inert material appeared to be detrimental because the fine particles of inert material tended to form a film around the coarser coking coal particles, thus effectively preventing their agglomeration into a coherent and uniform mass.

It is significant to note that in all cases where a good product was obtained with combinations of anthracite and bituminous coal, or with the blending of other inerts, intimate mixing of the material was practiced, whereas, in most cases where the resultant product was unsatisfactory, the description of the procedure used states or implies that little attention was given to the securing of intimate mixing.

Operators of modern coke ovens, where blending of various coals is generally practiced, are cognizant of the necessity for careful blending of the coking mixture and have available equipment which performs this function. The blending of anthracite material smaller in size than the normal size consist of the coking coal mixture may present some new problems, but it is believed that a satisfactory solution can be developed.



# CHAPTER III

## COMMERCIAL ASPECTS

### PLANT SCALE USE OF ANTHRACITE OR OTHER INERTS IN COKE MANUFACTURE

The various reports extant concerning the use of anthracite or other inert in the manufacture of by-product coke have been mentioned briefly in Chapter I and several of the more detailed and earlier studies have been discussed in the appropriate sections of Chapter II. By the way of recapitulation, however, it is of interest to examine more in detail those cases where actual plant-scale use has been tried or is now practiced. Furthermore, it is desirable and convenient to present in this section some very recent information on the plant-scale use of anthracite fines which has come to the attention of the writers.

Although prior to 1900 numerous reports indicate that quantities of anthracite, up to 50 per cent of the blend, were being used successfully in the production of blast-furnace coke, none of this work was in the modern type of by-product oven and very little factual information is available regarding the quality of the coke, or the operation of the blast furnaces in which it was used. Little work on actual use appears to have been done between 1900 and 1930, but since then a number of by-product plants have operated for varying lengths of time using either anthracite or other inert, and several of the reports are of definite interest, in particular the most recent reports because they are the most factual.

The data and results of Roberts<sup>16</sup> and Mott and Wheeler<sup>12</sup> on plant-scale operation with anthracite have already been discussed in considerable detail. Roberts obtained and was obtaining, as of October, 1942, very excellent results with 4 per cent of anthracite (No. 5 buckwheat). He also reported<sup>50</sup> that the use of anthracite fines in the coal blend from which foundry coke was to be recovered permitted Laclede to retain old customers and attract new ones, which otherwise would have been impossible except for the additional throughput made possible as a result of the anthracite blending.

It has been reported<sup>43</sup> also that the Bethlehem Steel Company has experimented at its Bethlehem Plant with from 5 to 20 per cent of anthracite (No. 5 buckwheat size) in the coal charge and as of November, 1942 was operating with 10 per cent. It was reported that, using 20 per cent anthracite, the cost of coke was reduced from \$6.60 to \$5.66 per ton. Blast furnace engineers reported, however, that the inclusion of the anthracite in the coke retarded the normal operating cycle, and for the production of blast furnace coke the practice was discontinued, while for foundry coke 10 per cent of anthracite was claimed to give satisfactory results.

The results of several more recent reports on plant-scale use of anthracite fines suggest that Roberts' experience is not unique.

At one merchant plant it was reported<sup>51</sup> that 5 to 6 per cent of anthracite fines seems to be the optimum for the foundry coke blend, and a suitable foundry coke can be produced in 18½ hours. Regarding the satisfactory operation of a cupola with anthracite blend coke, this plant operator reported as follows:

"... At the ... meeting of the American Foundrymen's Association, one of our customers asked what we were doing to our coke, stating that he had been able to increase his melting rate materially. Some customers have been using it (anthracite blend coke) since we began production and have never expressed an opinion one way or another so we let the matter rest.

"We are located in a district where excellent foundry cokes are produced ... from Eagle Seam coals and low-volatile coal at slow coking rates (27 to 30 hours). We do not claim that our product is equal to such cokes in size or structure, nor do we claim that it is as hard as that produced on slower coking rates from our regular coals without the addition of anthracite. However, it is a good, substantial coke, much better than I have seen at some of the Eastern by-product plants ..."

This operator also mentioned that the use of a small percentage of anthracite fines in the coking blend has enabled them "... to retain certain customers who use egg or mixed sizes of coke which we could not possibly have satisfied with the present coke from our domestic (100% coking coal) mixture." It is further reported that the difference between the coke from the regular bituminous coal blend and that from the anthracite-bituminous blend is "really surprising."

Another merchant plant operator recently reported<sup>52</sup> the use of 6 per cent of a Buckwheat No. 5 anthracite from the Western Middle Field of Pennsylvania, with the anthracite fines showing an average screen analysis as follows:

|                             |    |
|-----------------------------|----|
| on 10-mesh (U. S. Standard) | 2% |
| 10 x 20                     | 51 |
| 20 x 40                     | 33 |
| 40 x 100                    | 12 |
| through 100                 | 2  |

The 6 per cent of anthracite replaced 3 per cent of medium-volatile and 3 per cent of low-volatile coals used in the foundry coke blend. This blend of anthracite fines with medium- and low-volatile coals was chosen in order to produce more foundry coke possessing physical properties similar to those of the foundry coke made from straight coking coal.

Paralleling Roberts' experience, this operator stated that the use of anthracite fines has permitted a decrease of 5½ hours in the coking time, with 16-inch ovens, for the production of foundry coke with no loss of desirable

physical properties of the coke. The operating temperature of the ovens, taken on the air block five minutes after reversal, is 1300°C.

With respect to breeze production, this operator reported as follows:

"Breeze content of run-of-oven coke is just about the same as from coke without anthracite. Our limited experience in crushing the coke down to 3½" square and smaller indicates no increase in breeze production from anthracite bearing coke as against coke containing no anthracite."

In using anthracite at this plant only a few changes were necessary in the storage facilities. No additional problem was encountered in the mixing as it was stated that thorough mixing of any blend of coal was very necessary, and "anthracite is no exception." A paddle wheel mixer is employed at this plant for mixing the coals. It is significant to note in this connection that Roberts<sup>41</sup> and at least one other plant<sup>54</sup> using anthracite fines emphasize grinding the whole blend to as much as 90% minus ⅛" square mesh.

In regard to the use in the cupola of the anthracite blend foundry coke produced at this plant, the following remarks are of interest:

"We have had no complaints about foundry coke chargeable to the use of the anthracite fines . . . In our experience with many foundries, the coke made from the coal mix containing anthracite has been found to be interchangeable with the product previously produced."

One plant, which has been using 5 to 6 per cent of anthracite fines of buckwheat No. 5 size, apparently from the Northern Field, for some time in the manufacture of foundry coke, has presented<sup>53</sup> some interesting observations with reference to the production of breeze and the use of anthracite fines. It was stated that the blend used in producing domestic coke has not been changed since anthracite fines began to be used regularly and the domestic blend is practically the same as the foundry coke blend except for the anthracite. At the present time about 50 per cent of the ovens are charged with the foundry blend containing anthracite and the breeze production is substantially the same now as it was before the use of anthracite. Prior to the use of anthracite this plant was getting about 3.0 to 3.5 per cent breeze "as is," according to regular monthly plant data. It was pointed out, however, that at this plant little or no crushing of the coke has been necessary during the last few years, and furthermore, had crushing of the coke been necessary in normal (100% coking coal) operation, anthracite fines would probably not have been added, as the purpose of the addition is to produce large sized coke. In spite of this, the opinion was advanced that if it were necessary to crush the coke from the anthracite blend, the increase in breeze production would not be more than a few tenths of one per cent.

It is suggested that the reason for this is that the carefully selected anthracite, when present in small percentages, does not seem to act in the same

manner as like quantities of coke breeze or coke breeze and flue dust, etc. An examination of coke sections from the two types of inerts shows that the structure of those cokes containing coke breeze and/or flue dust bears no comparison with that from cokes containing a small quantity of suitable anthracite. The former have a checked structure . . . , while the latter, to one unfamiliar with anthracite blend cokes, would show no evidence of the inert when only small amounts of the anthracite are used.

Still another plant, which reports<sup>54</sup> satisfaction with anthracite blend coke, has been using up to 5 per cent of No. 5 buckwheat from the Eastern Middle Field in the production of blast furnace, foundry and domestic coke. The No. 5 buckwheat anthracite used was reported as having the following characteristics:

#### Size analysis:

|             |      |                       |         |
|-------------|------|-----------------------|---------|
| on 10-mesh  | 4.6% | True specific gravity | 1.64    |
| 10 x 20     | 48.6 | Volatile matter       | 4.0     |
| 20 x 40     | 36.3 | Ash                   | 13.9    |
| 40 x 100    | 9.0  | Sulphur               | 0.66    |
| through 100 | 1.5  | Fusion                | 2800°F. |

At this plant the anthracite fines replace from an equivalent amount to several times the amount of low-volatile coal. It was found possible to dispense with all of the low-volatile coal in the 75-25 blend of high- and low-volatile coking coals by using 5 per cent of No. 5 buckwheat anthracite with 95 per cent of high-volatile coal, but as a sufficient tonnage of high-volatile coal is not available, some low-volatile has to be used. The use of up to 5 per cent of anthracite was reported to increase the breeze production by one per cent.

The use of anthracite fines introduced no complication in the mixing and blending operations. It was reported to be possible to reduce coking time, the extent and flue temperatures used depending on the size of the coke desired and the blend used.

Improved performance was claimed, in both the cupola and blast furnace, when the anthracite blend coke was used; however, operating data have not yet been collected.

The addition of anthracite in small quantities shows up in the production of a larger, stronger and harder coke as demonstrated by the test results in Tables 23 and 24, which are a summary of test data reported by the plant under discussion. The coking time reported in each of these tests was 16.8 hours, in 17-inch ovens. All of the work has been conducted since September, 1943. In Table 23, the effect of anthracite on the screen size and shatter index of coke are shown. It is evident that the trends are similar to those reported by Roberts. In Table 24, the effect of anthracite on the physical and chemical properties of coke is shown. Again the results are similar to those reported by Roberts.

It will be noticed, however, that the on 2-inch shatter indices reported by Roberts in Tables 12 and 13 are noticeably higher than the corresponding indices for cokes of the same percentage of anthracite shown in Tables 23 and 24. This is attributable to at least two causes. Since it is evident that the rates of coking are practically the same and oven-widths do not differ greatly, the differences must be due to the different proportions of high- and low-volatile coals (cf. Tables cited) and probably to the use of high- and low-volatile coals from different sources. It is known that, in the case of the high-volatile coals used, one is from the Eagle Seam, which ranges from medium-volatile to high-volatile A in rank, while the other is from the Campbell Creek Seam, a high-volatile A coal.

The differences in the specific gravity and porosity data of Table 24 and Tables 17 and 18 are probably attributable also to the difference in the proportions and sources of the high- and low-volatile coals used in the tests.

At the plant under discussion<sup>54</sup> it was stated that the original purpose in undertaking the tests with anthracite fines was to supplement the coal supplies which are rapidly becoming difficult to obtain, and as a result of the gratifying nature of the tests it was reported that 40,000 tons of anthracite fines have been ordered.

In contrast to these rather sanguine opinions and favorable plant-scale test results, there is another side to the picture. It has been mentioned already in an earlier paragraph of this section that the Bethlehem Steel Company was reported to have stopped the use of anthracite fines in the manufacture of blast furnace coke because it was supposed to interfere with the operating cycle.

In 1942, Brown<sup>34</sup> stated that he has had much experience in the coking of thousands of tons of coal containing 5 per cent anthracite, but the product proved to be unsatisfactory for blast furnace operation. This was believed to be due to the cross-fracture which developed with fast coking and, furthermore, did not show up as much in shatter tests as in the blast furnace operation. No details were reported regarding the coals used or the operating methods.

The Rainey-Wood Coke Company is generally recognized as a pioneer in modern times of the use of anthracite fines in by-product coke manufacture, yet in 1942 it was reported<sup>43</sup> that the company was not favorably inclined toward the use of anthracite fines at that time as they did not want to do anything that would reduce the by-product yield. Recently, however, it has been reported<sup>55</sup> that Rainey-Wood has used from 2 to 5 per cent of No. 5 buckwheat anthracite in both the blast-furnace and domestic coke mixture, and at the present time about 2½ per cent anthracite is being used in the blast-furnace coke mixture. No reduction in coking time was attempted; the flue temperatures on blast-furnace coke average 1370°C. (2500°F.).

TABLE 23  
EFFECT OF ANTHRACITE ON SCREEN SIZE AND SHATTER INDEX OF COKE

| Coal, Per Cent |            | Screen Analysis, Per Cent |                   | Shatter Index of  |                     | Note                                    |
|----------------|------------|---------------------------|-------------------|-------------------|---------------------|---|
| Bituminous     | Anthracite | Run-of-Oven Coke          | Foundry-size Coke | Foundry-size Coke | Per Cent Cumulative |   |
| High-Vol.      | Low-Vol.   | on 3-in.                  | on 3½-in.         | on 3-in.          | on 2-inch           |   |
| 75             | 25         | 29.6<br>34<br>26          | 48.5<br>56<br>42  | 28.3<br>35<br>24  | 50.7<br>58<br>42    | Avg. for 27 tests<br>Maximum<br>Minimum |
| 80             | 18         | 31.5<br>41<br>19          | 49.7<br>56<br>42  | 32.6<br>47<br>25  | 56.5<br>69<br>51    | Avg. for 18 tests<br>Maximum<br>Minimum |
| 79             | 18         | 31.9<br>40<br>25          | 49.4<br>62<br>39  | 31.7<br>40<br>27  | 56.2<br>68<br>50    | Avg. for 21 tests<br>Maximum<br>Minimum |
| 78             | 18         | 36.6<br>43<br>29          | 54.0<br>58<br>48  | 39.4<br>48<br>33  | 58.2<br>72<br>53    | Avg. for 9 tests<br>Maximum<br>Minimum  |
| 77             | 18         | 41.8<br>52<br>36          | 59.1<br>70<br>48  | 56.8<br>70<br>38  | 75.1<br>93<br>67    | Avg. for 9 tests<br>Maximum<br>Minimum  |
| 95             | 0          | 29.9<br>45<br>26          | 47.7<br>67<br>42  | 28.9<br>42<br>23  | 55.8<br>68<br>44    | Avg. for 13 tests<br>Maximum<br>Minimum |

At this plant normal breeze production does not appear to materially change due to the use of anthracite, but when coke is crushed for domestic use, the anthracite blend coke does produce more breeze.

Several reports on the use of coke breeze have already been mentioned, but little information seems to be generally available concerning the suitability of the product for either blast-furnace or foundry purposes. In general the problem in the use of coke breeze appears to be one of the economics of drying, grinding and sizing as well as the phenomenon suggested by Roberts that small amounts of fine-sized coke breeze and fine-sized anthracite when blended with coking coals seem not to behave in a similar manner when the blends are converted into coke. However, one very extensive test, conducted in England, on the blast-furnace use of coke produced from a coal with which coke breeze was blended has been reported<sup>14</sup>, but the results were unfavorable. According to Mott and Wheeler<sup>14</sup>, the reason lay not with the use of the coke breeze, but rather to the use of coke breeze with a poor coking coal.

TABLE 24

EFFECT OF ANTHRACITE ON PHYSICAL AND CHEMICAL PROPERTIES OF COKE

| Test No.   | I.    | II.  | III.  |
|--|-------|------|-------|
| <i>Coal, Per Cent:</i> High Volatile               | 75    | 75   | 80    |
| Low Volatile                                       | 25    | 20   | 15    |
| Anthracite   | 0     | 5    | 5     |
| <i>Coal Blend:</i> Moisture, per cent              | 4.1   | 4.6  | 4.6   |
| Volatile Matter, per cent                          | 29.4  | 28.1 | 28.4  |
| Ash, per cent                                      | 7.2   | 7.5  | 7.7   |
| Sulphur, per cent                                  | 0.63  | 0.57 | 0.61  |
| <i>Screen Test:</i> (Run-of-Oven Coke)             |       |      |       |
| On 3½-inch, per cent                               | 28.0  | 55.6 | 45.1  |
| On 3-inch, per cent                                | 49.0  | 72.2 | 60.8  |
| (Foundry-size Coke)                                |       |      |       |
| On 3½-inch, per cent                               | 28.2  | 62.7 | 46.5  |
| On 3-inch, per cent                                | 53.2  | 87.8 | 69.0  |
| <i>Analysis of Coke:</i> Volatile Matter, per cent | 0.3   | 0.4  | 0.3   |
| Ash, per cent                                      | 8.9   | 9.0  | 8.8   |
| Sulphur, per cent                                  | 0.52  | 0.48 | 0.49  |
| <i>Specific Gravity of Coke:</i> Apparent          | 0.936 | 1.01 | 0.977 |
| True   | 1.91  | 1.83 | 1.87  |
| <i>Porosity, Per cent:</i>                         | 51.1  | 45.3 | 47.8  |
| <i>Shatter Index:</i> (Foundry-size Coke)          |       |      |       |
| Cumulative per cent on 2-inch                      | 74.2  | 89.0 | 84.0  |

From the foregoing discussion it is apparent that the amount of factual information on plant-scale use of anthracite fines is increasing. Yet, it is still far from being complete and to some extent, is contradictory in nature. Nevertheless, a number of plants have recently found that the use of small amounts of anthracite fines to be both advantageous and economic for the production of foundry coke, while one reports favorably on both domestic and blast-furnace cokes containing small percentages of anthracite. There remains a need for more factual information regarding the use of anthracite bearing cokes in the blast-furnace before the blast-furnace operators generally will be convinced that anthracite blend cokes will perform satisfactorily.

## CHAPTER IV

### ECONOMIC ASPECTS AND MARKETS

The economics of the use of anthracite fines in conjunction with coking coals for the production of coke involves a number of factors, many of which are directly related to the technical factors discussed in the preceding chapter. Thus, changes in the yields of coke, coke breeze, gas, and other by-products have a material effect upon the economics of anthracite blending. Similarly, the possible increase in throughput, as a result of anthracite blending, influences the conversion cost and hence the overall economic balance. In subsequent sections, the available information is presented and discussed for each of the several major products of carbonization, and an overall equation developed by which the money value of anthracite can be determined for any particular set of conditions under which a given plant may be operating.

#### RETURNS FROM BY-PRODUCTS

In Figure 12 are shown statistical data from the Minerals Yearbook for the gross receipts for the various by-products obtained in coking operations covering the entire United States. Some of these data are directly applicable while others must be modified for use in estimations dealing primarily with conditions in the anthracite marketing area.

Light oil and derivatives, and ammonia and compounds will be of substantially the same value irrespective of the location of the plant and to a large extent the same is true of the tar sold. Moreover, minor changes in the valuation of these by-products do not especially affect the economic balance as a whole. Throughout the subsequent calculation, therefore, average values have been employed.

Returns from the gas, however, will not only vary from state to state but also from plant to plant, so that the average receipts for the United States are of little value. Most of the by-product plants in the anthracite marketing area are very favorably located for disposing of the gas to public utilities or directly to consumers, and as a result, returns from gas sales are substantially higher than the national average. This fact is well illustrated by the data of Table 25, which show the distribution and receipts for gas produced in this area for 1941. Excluding Pennsylvania, where the large furnace plants of the Pittsburgh area lower the average valuation, these data indicate that the average value of all the coke-oven gas produced in the anthracite marketing area is between 21 and 23 cents per MCF. Correspondence with by-product plants concerning prevailing values, suggested that a valuation of 25 cents per MCF might be a fair average under present conditions, and since the value of the anthracite is inversely proportional to the value of the gas, this slightly high-

er valuation for gas has been used in calculating the value of the anthracite.\* On this basis, it is apparent that the value of gas per ton of coke for the area of interest will be in the vicinity of \$3.60 rather than the national average of about \$1.60. As will be seen from subsequent calculations and discussion, this fact materially affects the value of anthracite as a blending agent.

#### GAS

In Chapter II, the effect of anthracite additions upon gas yield has been discussed in detail for a special case (Figure 3) and for the general case (Figure 4). A consideration of these data shows the necessity for correcting the gas yields from anthracite blends to equivalent gas volumes of standard heating value. For computation of the money value of the gas yield from anthracite blends this is even more essential if a true comparison is to be obtained with the money value of gas from bituminous coals alone. Although the money value of the gas fluctuates to some extent with local conditions, as previously mentioned, basic equations are presented by which calculations can be made for any prevailing conditions likely to be encountered.

For the general case where the percentage of each coal used, the actual gas yield, and the heating value of the gas from each component of the blend are known, the money value of the gas per ton of coal may be calculated by the use of Equation 11, or per ton of coke by means of Equation 12.

Equation 11. Money value (\$) of gas per ton of coal =

$$E \left( \frac{\text{byv} + \text{axu}}{100w} \right),$$

Equation 12. Money value (\$) of gas per ton of coke =

$$E \left( \frac{\text{byv} + \text{axu}}{ew} \right),$$

where "E" is the dollar value per MCF of the gas; "e" is the percentage of total coke less breeze, per ton of anthracite-bituminous coal blend; and the remainder of the equation is the same as in Equation 7.

\*Using the higher valuation of the gas gives a more conservative evaluation of the anthracite.

FIGURE 12

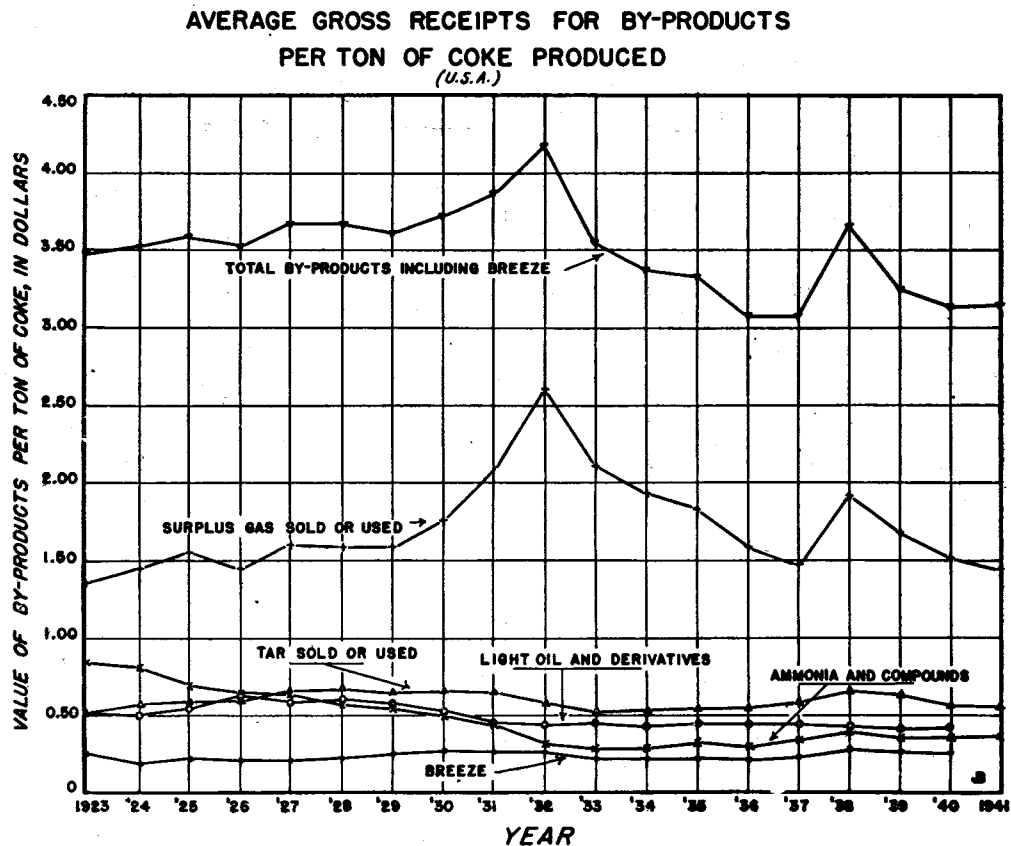


TABLE 25  
DISTRIBUTION AND RECEIPTS FOR COKE OVEN GAS<sup>17</sup>  
(1941)

| Location<br>of<br>Plants | Gas<br>Produced<br>MCF | Gas used in<br>Heating Ovens<br>Value <sup>1</sup> , \$/MCF | %                  | Surplus Gas           |                    |                           |                    |               |                    |                 |                      | Average<br>Value of<br>All Gas<br>\$/MCF |
|--------------------------|------------------------|---|--------------------|-----------------------|--------------------|---------------------------|--------------------|---------------|--------------------|-----------------|----------------------|--|
|                          |                        |   |                    | Used by Producer      |                    |                           |                    | Sold          |                    |                 |                      |  |
|                          |                        |   |                    | Under<br>Boilers<br>% | Boilers<br>\$/MCF  | Affiliated<br>Plants<br>% | Plants<br>\$/MCF   | Domestic<br>% | Domestic<br>\$/MCF | Industrial<br>% | Industrial<br>\$/MCF |  |
| Pa.                      | 253,153,398            | 41  | 0.091              | 1.7                   | 0.091              | 46.4                      | 0.097              | 7.2           | 0.260              | 3.4             | 0.096                | 0.106                                    |
| Mass.                    | 18,158,359             | 24.1  | 0.085 <sup>2</sup> | 0.2                   | 0.085 <sup>2</sup> | <0.1                      | 0.118 <sup>2</sup> | 74.8          | 0.252 <sup>2</sup> | 0.7             | 0.153 <sup>2</sup>   | 0.210                                    |
| N. Y.                    | 77,296,493             | 25.7  | 0.079              | 3.8                   | 0.079              | 16.6                      | 0.115              | 49.6          | 0.371              | 3.5             | 0.149                | 0.232                                    |
| N. J.                    | 16,659,986             | 21.0  | 0.085 <sup>2</sup> | -                     | 0.085 <sup>2</sup> | <0.1                      | 0.118 <sup>2</sup> | 79.0          | 0.252 <sup>2</sup> | -               | 0.153 <sup>2</sup>   | 0.217                                    |

<sup>1</sup>Value of gas used for heating ovens assumed to be the same as value of gas used under boilers by producer.

<sup>2</sup>From undistributed figures.

In the foregoing analysis, consideration has been given only to the change in gas yield and money value of the gas on the weight yield basis. Actually, however, the factor of time should also be considered, since daily capacity is frequently an important factor in overall costs.

The effect of anthracite additions upon coking time has been discussed in a previous chapter and the conservative conclusion reached that a reduction in coking time of about 10 per cent should be possible with additions not exceeding 20 per cent anthracite. Beyond 20 per cent anthracite there is some evidence to indicate that the coking time may be increased. Thus, although the money value of the gas per ton of coal or of coke may be reduced by anthracite additions, the money value of the gas per day may be increased. Similarly, the increased throughput will decrease the conversion costs per ton of coke and this decrease will, in part, be reflected in the value of the gas.

Referring to Table 26, it is apparent that for 5 per cent additions of anthracite the value of the gas per ton of coke is decreased 4.2 per cent. With an increase of 10 per cent in throughput, however, the value of gas per day would be (110) (95.8/100) or 105.4 per cent of that for bituminous coal blend alone, a net increase of roughly 5 per cent. As the amount of anthracite

TABLE 26

EFFECT OF ANTHRACITE ADDITIONS ON MONEY VALUE OF GAS FROM THE 80 PER CENT POWELLTON-20 PER CENT POCAHONTAS NO. 4 COAL BLEND

(Anthracite Replacing the Blend)

| Per Cent Anthracite<br>(83% FC + Ash)                                 | MCF of Gas <sup>1</sup> Per Ton of Coal<br>(as carbonized) |                     | Money Value of Gas <sup>2</sup> , Dollars |                              |
|---|--|---------------------|---|------------------------------|
|   | Actual   | 530 Btu. Equivalent | Per Ton of Coal                           | Per Ton of Coke <sup>3</sup> |
| 0   | 10.400   | 11.500              | 2.87                                      | 4.32                         |
| 5   | 10.145   | 11.094              | 2.77                                      | 4.14                         |
| 10  | 9.888  | 10.689              | 2.67                                      | 3.96                         |
| 15  | 9.633  | 10.284              | 2.57                                      | 3.78                         |
| 20  | 9.380  | 9.879               | 2.47                                      | 3.61                         |
| Per Cent Decrease Upon the Addition of<br>0 to 20 Per Cent Anthracite |  |                     |   |                              |
| 0   | 0  | 0                   | 0   | 0                            |
| 5   | 2.45   | 3.5                 | 3.5                                       | 4.2                          |
| 10  | 4.9  | 7                   | 7   | 8.4                          |
| 15  | 7.35   | 10.5                | 10.5                                      | 12.6                         |
| 20  | 9.8  | 14                  | 14  | 16.7                         |

<sup>1</sup>Saturated with water vapor at 60°F. and 30 in. Hg.

<sup>2</sup>530 Btu. equivalent gas.

<sup>3</sup>Total coke yield less breeze (breeze taken as 6% on per ton of coal basis for this report).

is increased, however, this advantage diminishes, because beyond 5 per cent anthracite there is no evidence to suggest a further reduction in coking time, while the value of the gas per ton of coke decreases progressively. For the particular example used, additions of anthracite greater than 11 per cent would result in a decrease in the daily as well as the per ton returns from gas.

It is impossible to make broad generalizations regarding the percentage of anthracite necessary to produce optimum daily gas returns because the yield, heating value, and money value of the gas will vary from plant to plant depending upon the bituminous coals used and upon the markets available for the gas. Each plant, however, is in a position to determine from the data given the probable effect of anthracite upon the returns from gas for the particular local conditions.

#### TAR, LIGHT OIL, AND AMMONIA

The yield and value of each of the by-products—tar, light oil, and ammonia—is directly proportional to the percentage of bituminous coal in the blend. For calculations based upon the per ton of coal basis the value of tar may be computed from Equation 13 and for calculations on the per ton of coke basis from Equation 14.

Equation 13. Value of tar (\$) per ton of coal =  $bzr$

Equation 14. Value of tar (\$) per ton of coke =  $\frac{bzt}{e}$

Where "b" is the percentage of bituminous coal in the blend, "e" is percentage of coke from the anthracite-bituminous coal blend, "z" is the yield of tar per ton of bituminous coal carbonized alone, and "r" is the unit value in dollars per gallon of the tar.

Similar equations may be used for light oil and ammonium sulphate.

Equation 15. Value of light oil (\$) per ton of coke =  $\frac{bz_1r_1}{e}$

Equation 16. Value of ammonium sulphate (\$) per ton of coke =

$$\frac{bz_2r_2}{e}$$

where "z<sub>1</sub>" and "z<sub>2</sub>" represent the yield per ton of bituminous coal carbonized alone of light oil and ammonium sulphate, respectively, "r<sub>1</sub>" is the value of light oil in dollars per gallon and "r<sub>2</sub>" is the value of ammonium sulphate in dollars per pound.

For convenience in use, Equations 14, 15, and 16 may be combined into a general equation:



Equation 17. Value of tar, light oil, and ammonium sulphate

$$(\$) \text{ per ton coke} = \frac{bC}{e},$$

where  $C = z_r + z_1r_1 + z_2r_2$ , the total value of tar, light oil, and ammonium sulphate per ton of bituminous coal as carbonized.

As in the case of gas, the values of the tar, light oil, and ammonium sulphate have been calculated for additions up to 20 per cent anthracite for the specific bituminous coal blend previously used as an example. The unit value of each of these products was taken as of 1941 from the Minerals Yearbook averages because, as may be seen from Figure 12, the 1941 values appear to be very close to the average for the past 10 years. The calculated values are shown in Table 27.

The foregoing calculations are based solely upon a weight basis and the total value of each of the by-products decreases with increasing additions of anthracite. However, the value of the products on the daily basis may be favorably affected by increased throughput. Thus, for 5 per cent additions of anthracite and assuming a 10 per cent increase in throughput, the net overall daily increase in value of tar, light oil, and ammonia would amount to almost 4 per cent. Anthracite additions of more than 8 per cent result in smaller returns, on both the daily and per ton of coke bases, than are obtained from the original bituminous coal blend.

#### RETURNS FROM COKE

The returns from coke are influenced by such factors as, (1) the value of different sizes of coke and of coke used for different purposes, (2) the yield of marketable coke per ton of coal, (3) the size distribution and quality of the run-of-oven coke, (4) the yield of breeze per ton of coal and the disposal of breeze, and (5) the nature of the markets.

The average receipts for the various sizes and kinds of coke used for different purposes in Pennsylvania as contrasted with the Furnace and Merchant plants of the United States during the years 1931 to 1941 are shown graphically in Figures 13 and 14. The trends of the market have been upward since about 1933, with Pennsylvania prices being generally appreciably higher than the national averages. The yearly fluctuations in the delivered price of foundry coke in three market areas are shown in Figure 15. The close similarity in price of foundry coke at Newark and at Philadelphia is evident. This similarity of two neighboring market areas suggests that any deductions concerning the use of anthracite in Eastern Pennsylvania will no doubt be applicable for the Newark-New York marketing area.

FIGURE 13

#### AVERAGE RECEIPTS FOR BY-PRODUCT COKE SOLD, FOR STATE OF PENNA.

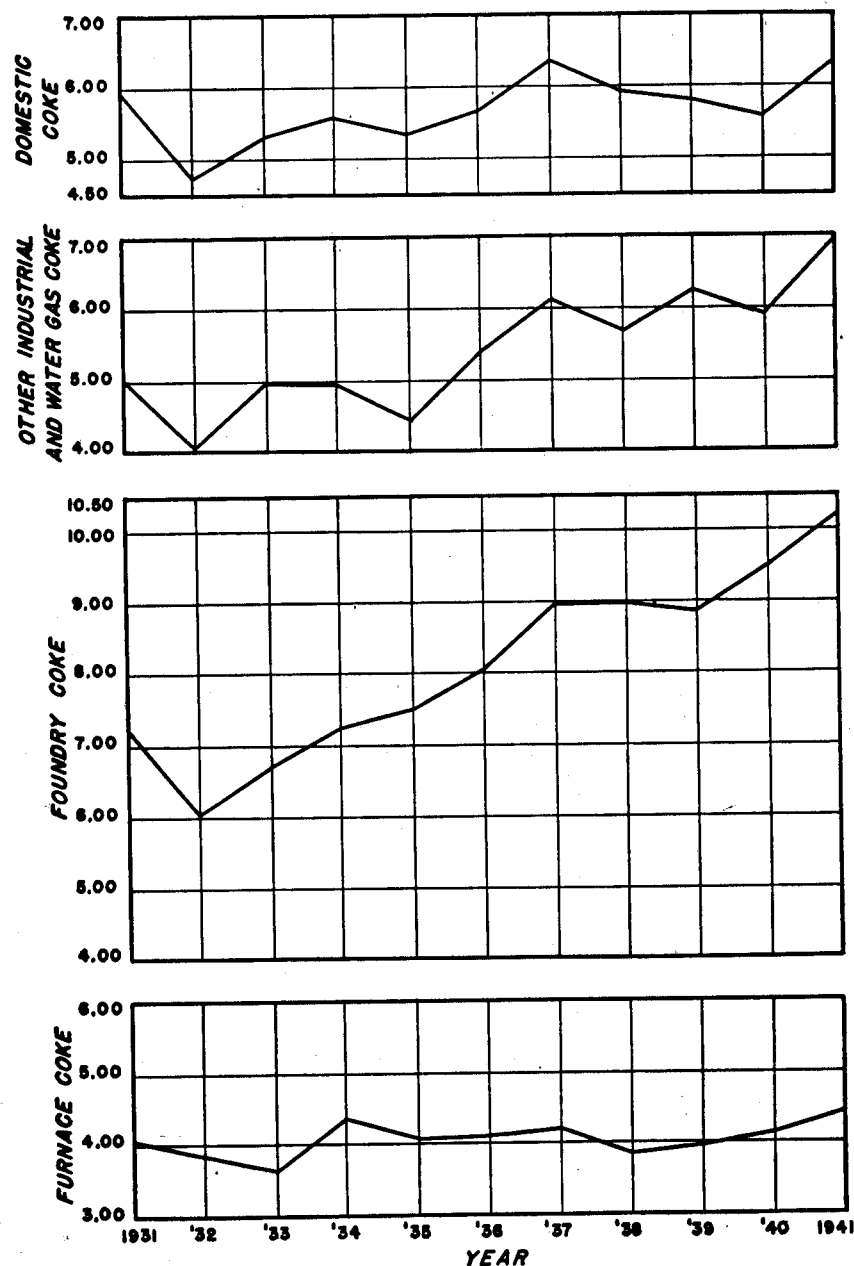


FIGURE 14

AVERAGE RECEIPTS PER NET TON  
FOR BY-PRODUCT COKE SOLD  
AT MERCHANT AND FURNACE PLANTS  
(U.S.A.)

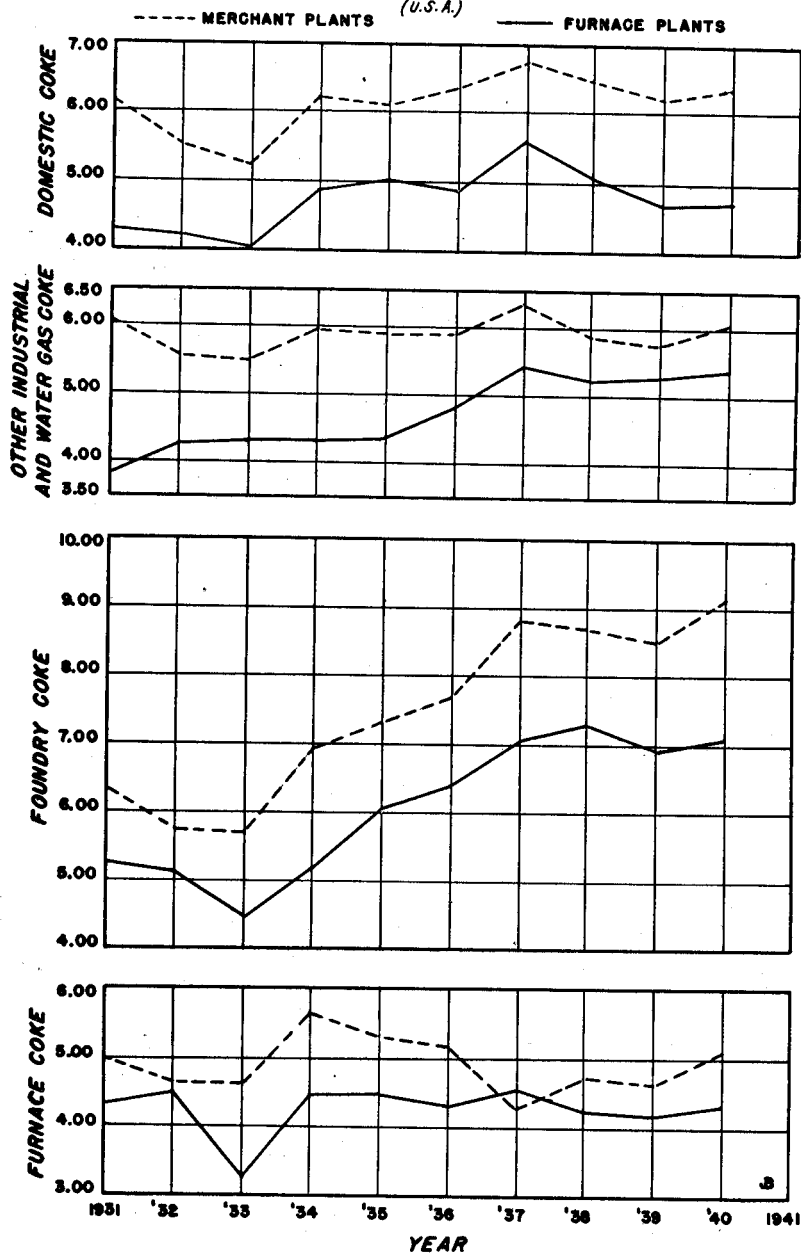


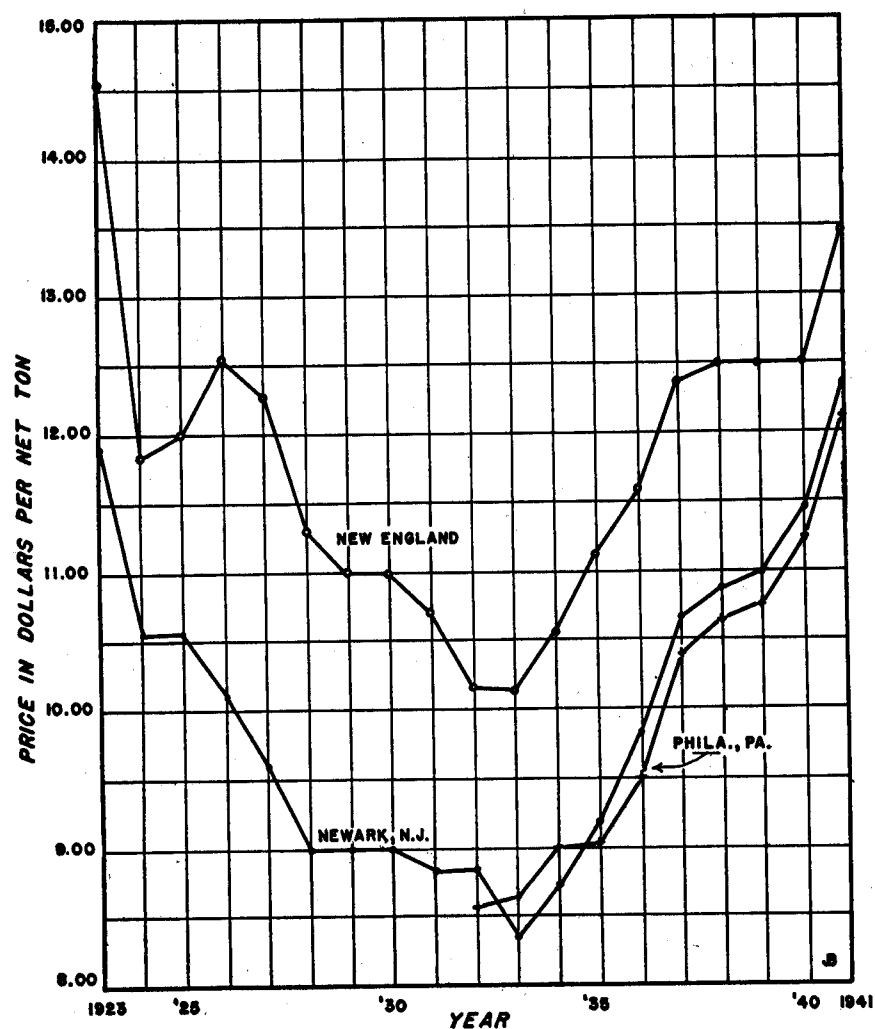
TABLE 27  
EFFECT OF ANTHRACITE ADDITIONS ON MONEY VALUE OF TAR, LIGHT OIL, AND  
AMMONIUM SULPHATE FROM THE 80 PER CENT POWELLTON-  
20 PER CENT POCAHONTAS NO. 4 COAL BLEND  
(Anthracite replacing blend)

| Per Cent<br>Anthracite | Tar                      |                |                |                                   | Light Oil                |                |                |                                   | Ammonium Sulphate         |                |                |                                   |
|------------------------|--------------------------|----------------|----------------|-----------------------------------|--------------------------|----------------|----------------|-----------------------------------|---------------------------|----------------|----------------|-----------------------------------|
|                        | Yield<br>gal/ton<br>Coal | Value          |                | Per Cent<br>Decrease <sup>1</sup> | Yield<br>gal/ton<br>Coal | Value          |                | Per Cent<br>Decrease <sup>1</sup> | Yield<br>lbs./ton<br>Coal | Value          |                | Per Cent<br>Decrease <sup>1</sup> |
|                        |                          | \$/ton<br>Coal | \$/ton<br>Coke |                                   |                          | \$/ton<br>Coal | \$/ton<br>Coke |                                   |                           | \$/ton<br>Coal | \$/ton<br>Coke |                                   |
| 0                      | 12.0                     | 0.564          | 0.849          | 0                                 | 2.72                     | 0.329          | 0.495          | 0                                 | 23.5                      | 0.306          | 0.460          | 0                                 |
| 5                      | 11.4                     | 0.536          | 0.801          | 5.7                               | 2.58                     | 0.312          | 0.467          | 5.6                               | 22.3                      | 0.290          | 0.433          | 5.7                               |
| 10                     | 10.8                     | 0.508          | 0.752          | 11.4                              | 2.45                     | 0.296          | 0.439          | 11.2                              | 21.2                      | 0.276          | 0.408          | 11.4                              |
| 15                     | 10.2                     | 0.479          | 0.705          | 17.1                              | 2.31                     | 0.280          | 0.411          | 16.8                              | 20.0                      | 0.260          | 0.382          | 17.1                              |
| 20                     | 9.6                      | 0.451          | 0.659          | 22.8                              | 2.18                     | 0.264          | 0.385          | 22.4                              | 18.8                      | 0.244          | 0.357          | 22.8                              |

<sup>1</sup>\$/ton coke basis.

FIGURE 15

**AVERAGE YEARLY PRICE PER NET TON OF BY-PRODUCT COKE  
DELIVERED AT CONSUMER'S WORKS FOUNDRY**



In Figure 16, it will be seen that from 1938 to 1941, the average price of coke in the Eastern Pennsylvania area has increased 9 per cent, while the coke production has increased some 72 per cent as contrasted with an increase of coal consumption of about 69 per cent. The discrepancy between the latter two is due to the 2 to 3 per cent increase in the per cent coke yield. The use of some anthracite would show a still greater improvement in the yield per ton of coal.

Figures 16 and 17 show the marked effect of fluctuations in the production of blast-furnace coke on the coal consumption at by-product plants in Eastern Pennsylvania as well as in all of Pennsylvania as contrasted with a more stable consumption area like New York. Since anthracite blend coke has not as yet been fully accepted for blast-furnace use, the application of anthracite will be limited largely to the production of coke for non-furnace use which, although smaller than the furnace coke market, is much more stable.

Another factor which affects the market is the stock of coke on hand. It can be seen from Figure 18 that for Pennsylvania the tendency since 1935 has been toward a steadily decreasing inventory of marketable coke on hand as contrasted with increases in production and price. Although specific consideration of coke inventory will not be made in the subsequent analysis, the fact that inventories are generally decreasing helps make the circumstances more favorable for the use of anthracite because it suggests that current (1943) coke production is hardly meeting the demand. The use of a small amount of anthracite would permit an increase in the production of certain grades of coke, such as foundry coke, by virtue of the increased throughput and greater yield of satisfactory foundry-size coke. No doubt the demand for sizes other than blast-furnace coke could be met with an anthracite blend coke.

With regard to the size distribution and hence quality according to use, the available information is somewhat bewildering. According to Brown's Directory<sup>48</sup>, furnace plants report from about 40 to 100 per cent of blast-furnace size being made, with 0 to 50 per cent of domestic size and as high as about 40 per cent of foundry-size. Merchant plants, on the other hand, report about 40 to 100 per cent of domestic size, up to about 45 per cent blast-furnace size and as much as 60 to 65 per cent of foundry-size as being made. It goes without saying, that the size produced is largely dictated by the market demand. Several of the plants which reported the manufacture of large percentages of foundry-size coke are probably too close to the bituminous producing area for an anthracite blend coke to be economical, because the use of anthracite is not economically feasible when the cost of bituminous coal at the ovens is low. This latter factor will be discussed in more detail later.

Finally, and what is commonly considered the bane of anthracite blend or other inert blend cokes, the question of breeze production must not be overlooked. As may be seen from an examination of Figure 19, the yield of breeze

FIGURE 16

## BY-PRODUCT COKE PRODUCTION IN EASTERN PENNA.

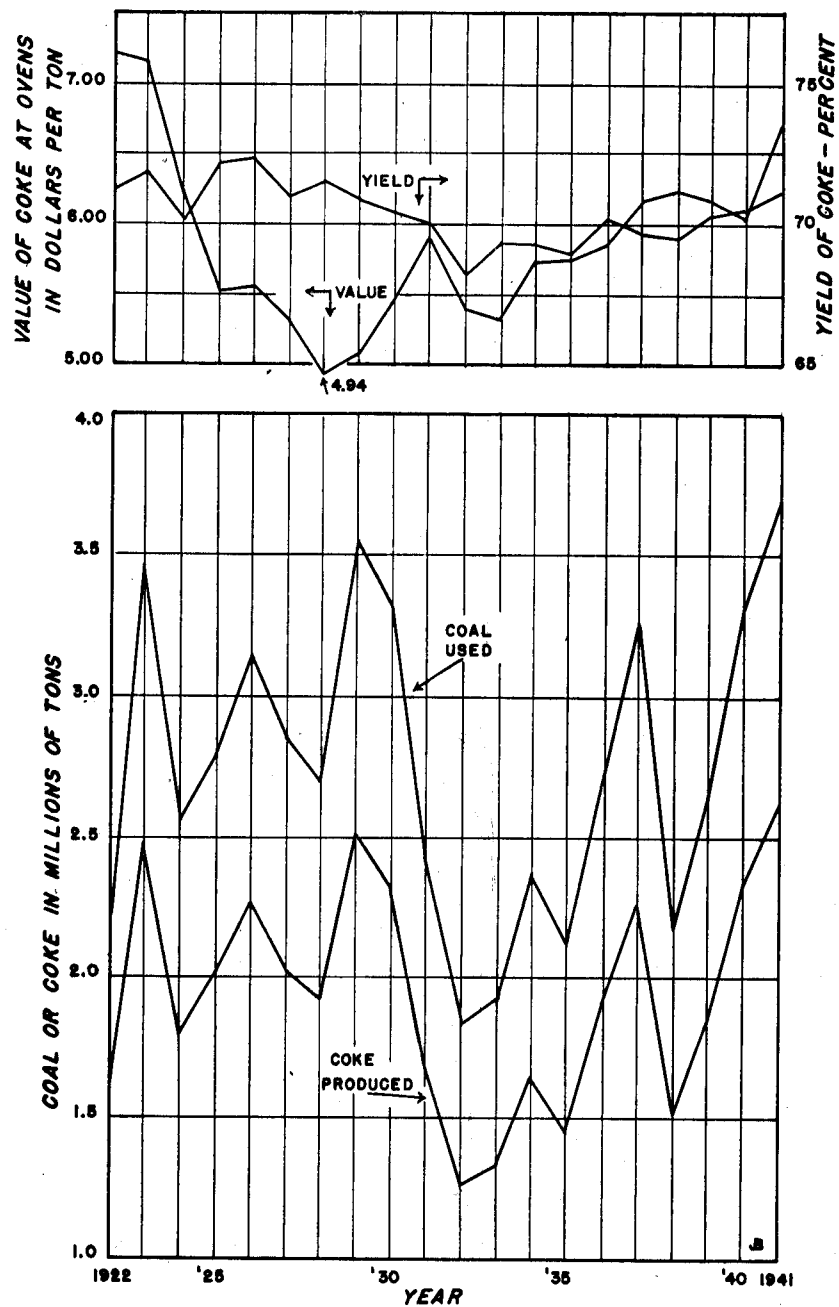
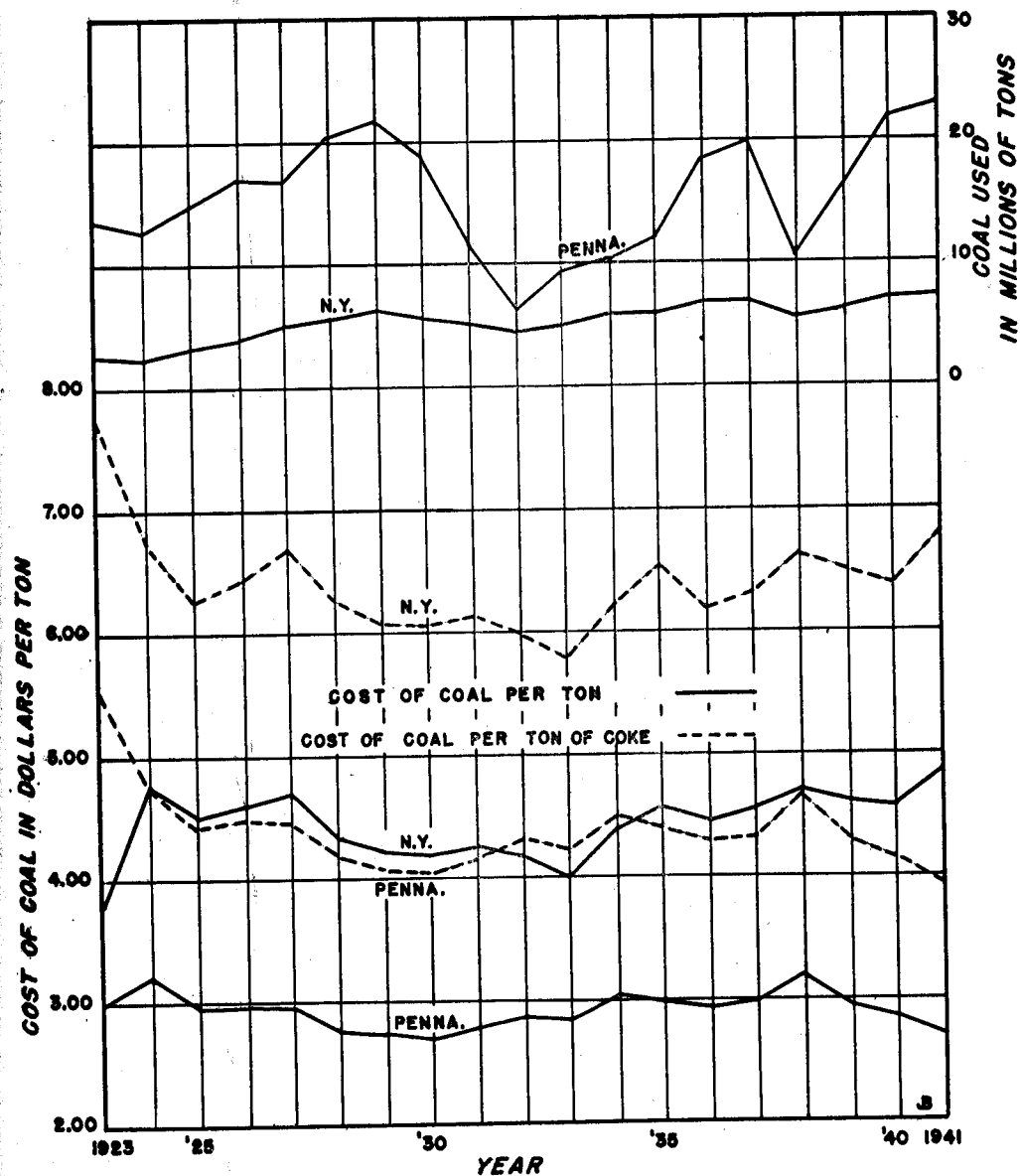


FIGURE 17

## TOTAL QUANTITY AND VALUE OF COAL USED AT BY-PRODUCT OVEN IN MFR. OF COKE FOR NEW YORK AND PENNA.



in Pennsylvania has been relatively stable at about 6 per cent for the past several years. Increasing production of coke has therefore resulted in increasing production of breeze, but as may be seen from the data of Table 28 the percentage of the breeze used by the producer in Pennsylvania for steam raising has likewise increased. As a result of the increased use, the stocks of breeze have not shown any serious increase.

From the discussion presented in previous sections, it appears probable that the use of small percentages of anthracite in the coking blend will have only a minor influence upon the percentage of breeze in run-of-oven coke produced. However, the increased throughput possible with the addition of anthracite will increase the daily yield of breeze by an amount at least equal to this increase. The relatively low stocks of breeze and the trend toward increased use of breeze by producers suggests that the increased breeze production will not introduce a serious problem at most plants.

Throughout subsequent economic analyses, the yield of breeze from anthracite blend coking operations has been assumed to be 6 per cent on the basis of coal charged. It is probable that this figure is a little low for some plants and high for others; much will depend upon the adequacy of mixing and blending and upon the choice of coals used.

As previously stated, the addition of anthracite increases the proportion of the larger sizes of coke, especially those suitable for foundry purposes. Similarly, the available information would indicate that the anthracite coke should be suitable for the domestic and industrial markets. These are the premium price markets upon which the merchant plant relies for the major portion of the coke profits. At the present time, however, the demand for

TABLE 28  
PER CENT OF TOTAL BREEZE USED BY PRODUCER FOR  
STEAM RAISING IN PENNSYLVANIA  
(Minerals Yearbook)

| Year | Per Cent |
|------|----------|
| 1941 | 88.3     |
| 1940 | 91.6     |
| 1939 | 85.5     |
| 1938 | 83.6     |
| 1937 | 88.5     |
| 1936 | 85.5     |
| 1935 | 85.0     |
| 1934 | 80.0     |
| 1933 | 75.0     |
| 1932 | 60.0     |

FIGURE 18

### STOCKS OF COKE AND COKE BREEZE AT BY-PRODUCTS PLANTS ON JAN. 1 FOR PENNA.

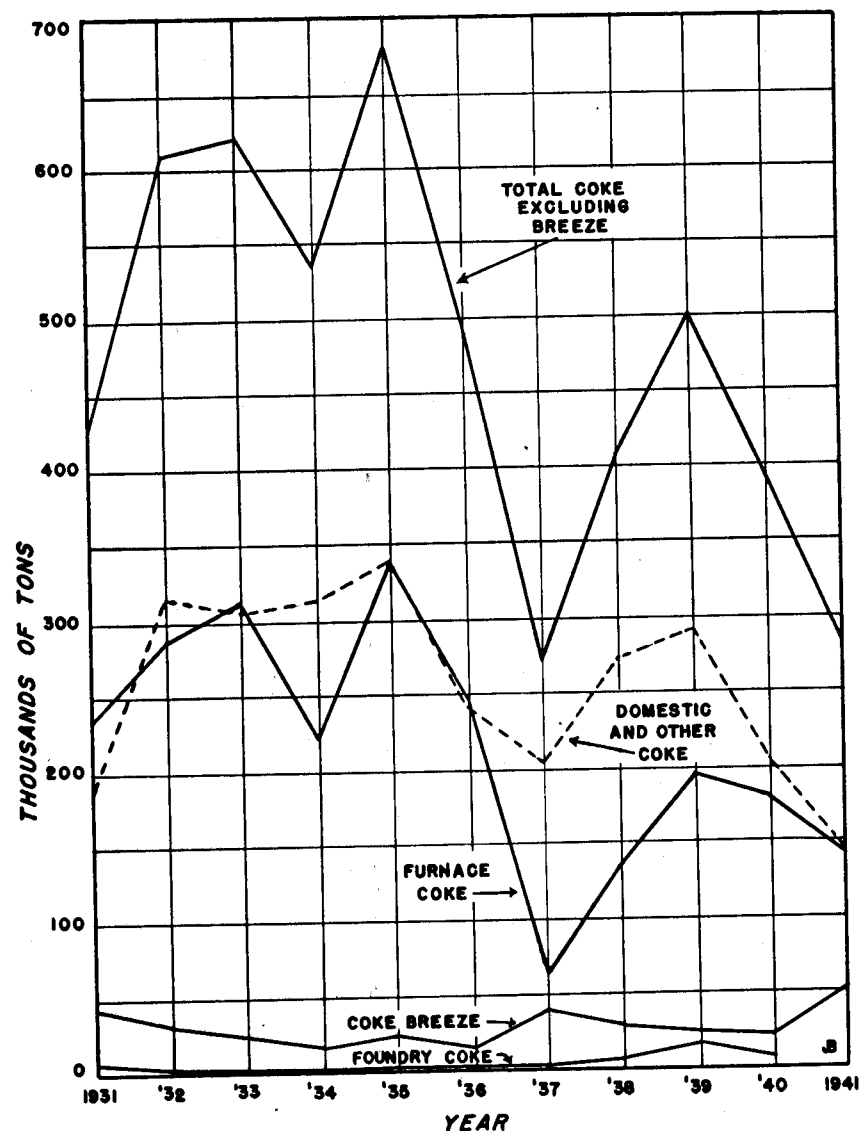
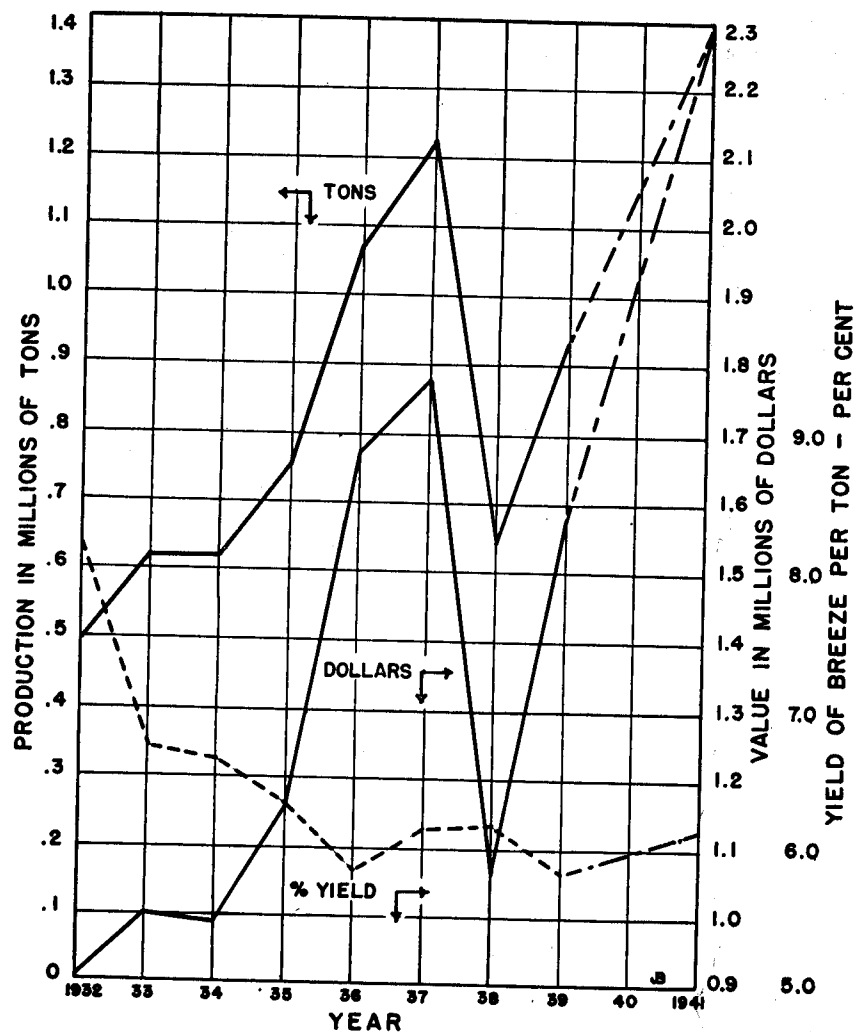


FIGURE 19

## PRODUCTION OF PENNA. COKE BREEZE



metallurgical coke is such that it is difficult for many plants to supply all these markets with the available facilities. A means by which increased yields of the larger sizes and increased throughput can be attained should, therefore, be of interest to a number of plants.

For the specific bituminous coal blend previously used as an example, the effect of anthracite additions upon the gross returns from coke has been calculated and is shown in Table 29. In these calculations the average valuation of \$8.25 has been used for the marketable coke. This figure was furnished by one of the large Eastern by-product plants supplying coke primarily for the domestic and nonfurnace markets. An analysis of the Minerals Yearbook statistics for 1941 shows a weighted average valuation of \$7.50 per ton for nonfurnace coke for all of Pennsylvania. Detailed information for the Eastern market is not listed but since it is well known that the coke value is higher in Eastern than in Western Pennsylvania, the use of the \$8.25 valuation appears justified. Similarly, the value of breeze has been assumed to be \$2.41 per ton. This figure is the average valuation of breeze for 1941 and is probably as representative as any other that could be chosen, because valuations from \$1.65 to \$3.00 per ton are reported by plants in the anthracite marketing area.

From these data it would appear that the total coke returns per ton of coal charged will increase approximately one cent for each per cent of anthracite added. Although this example is specific in the choice of coals and values used, it shows the general trend that will be found using other data.

As well as producing a small increase in the yield of coke per ton of coal, the use of anthracite additions permits an increased throughput which is of significant proportions. Available information indicates this increase to be at least 10 per cent, which if attained would produce a 10 per cent increase in the daily realization from coke.

TABLE 29

EFFECT OF ANTHRACITE ON VALUE OF THE COKE PER TON OF COAL  
(Anthracite Replacing the 80% Powellton-20% Pocahontas No. 4 Blend)

| Per Cent Anthracite | Total Coke Yield (%) | Breeze (%) | Marketable Coke (%) | Value \$/ton of Coal |        |       |
|---------------------|----------------------|------------|---------------------|----------------------|--------|-------|
| (83% FC+Ash)        |                      |            |                     | Marketable Coke      | Breeze | Total |
| 0                   | 72.4                 | 6.0        | 66.4                | 5.48                 | 0.14   | 5.62  |
| 5                   | 72.9                 | 6.0        | 66.9                | 5.52                 | 0.14   | 5.66  |
| 10                  | 73.5                 | 6.0        | 67.5                | 5.57                 | 0.14   | 5.71  |
| 15                  | 74.0                 | 6.0        | 68.0                | 5.61                 | 0.14   | 5.75  |
| 20                  | 74.5                 | 6.0        | 68.5                | 5.65                 | 0.14   | 5.79  |

## COSTS OF HANDLING, GRINDING AND BLENDING

The blending of anthracite, even in small amounts, will entail some increase in handling costs, because of the necessity for separate storage and movement prior to blending. Where the percentage of anthracite used in the blend is less than 20 per cent, it appears unlikely that any drying of the anthracite at the coke plant will be necessary. Should drying be necessary, however, the handling cost will unquestionably increase, and allowance must be made for this increase in considering the value of the anthracite.

All available data indicate that No. 5 buckwheat anthracite is suitable for use directly without any further grinding so that no additional expense is entailed for size reduction of the anthracite. However, the size of bituminous coal may have to be reduced in order to produce optimum results when blending with anthracite and this may increase the overall grinding costs at some plants. In general, however, it is unlikely that the grinding cost for bituminous coal will be affected, since most by-product plants at which blending of bituminous coals is practiced already crush the bituminous coals to the fineness required for satisfactory blending with anthracite.

In the use of anthracite the cost of blending will be increased, because unless blending is carefully conducted so as to obtain thorough and complete dispersal of the anthracite throughout the mixture, localized weaknesses in the resultant coke will occur. The tendency in past trials with anthracite has been to neglect this important factor and arbitrarily blame poor results on the use of anthracite when the real fault lay with inadequate mixing.

It is obviously impossible to cite specific figures for increases in the cost of handling, grinding or blending, because these costs will depend entirely upon existing equipment, plant layout and plant practice, and no two plants operate under the same conditions. Moreover, each plant is in a position to know from past experience the probable amount of such charges and due allowance can be made in the final calculation of the dollar value of the anthracite for any increase in conversion cost resulting therefrom. As a general average, the conversion costs are usually assumed to be roughly \$2.00 per ton of coal carbonized, but considerable variations from the average figure will be found for specific plants. A substantial portion of this conversion cost is generally overhead or fixed charges which remain constant or nearly constant irrespective of the throughput. Increasing the throughput, therefore, will decrease the overall conversion cost per ton.

In subsequent analysis of the value of anthracite as a blending agent, it is assumed that the increased cost of handling, grinding, and blending due to anthracite additions will be offset by the decrease in overhead per ton of coke resulting from increased throughput. Depending on the particular plant, of course, it may be more or less, and if the discrepancy is large enough to be of significance, the correction can be made directly to the calculated value of anthracite as determined in the subsequent section. These calcula-

tions are based upon the assumption that the differential between cost of materials and value of products remains constant for the range of anthracite blends under consideration.

## MARKET VALUE OF ANTHRACITE AS A BLENDING AGENT

In considering the market value of anthracite as a blending agent in by-product coke production, there are two bases upon which the value can be established, that of the coke plant operator, and that of the anthracite producer. The coke plant operator is interested primarily in the delivered cost of the anthracite, its ash and moisture content, and its suitability as a blending agent. The producer is interested primarily in the value of the coal at the point of origin and is concerned with ash, moisture, and suitability only in so far as they influence production costs. In the following discussion, the value of anthracite delivered at the by-product oven is established first, and consideration then given to value of the anthracite at the colliery.

## VALUE OF ANTHRACITE AT THE BY-PRODUCT PLANT

In establishing the value of anthracite at the by-product plant, there are so many variables involved that specific data can only be presented where definite assumptions such as location, plant, cost of raw materials, and value of products are first established. Such conditions are known or can be established for a specific case with reasonable accuracy, and this procedure has been followed in two examples in order to demonstrate the procedure that must be followed.

Two examples are developed; in the first, conditions regarding cost and values are assumed as of April, 1943, and in the second, costs and values for what may be considered normal times are used. In this latter analysis, the data used are those of the year 1939 because this year appeared to represent most nearly the conditions which may be expected to prevail during so-called normal times. In both examples, a location in the metropolitan area of Southeastern Pennsylvania has been chosen; however, it is believed that the data are also applicable to conditions which prevail in the metropolitan area in the vicinity of New York City, since both areas are similarly located with respect to the anthracite producing areas and the product markets are much the same—the coke going largely into nonfurnace uses and the gas going largely into domestic and industrial channels.

As in previous specific examples used throughout this report, the bituminous coal blend of 80 per cent Powellton-20 per cent Pocahontas No. 4 coals has been used in two examples for determining the value of anthracite. Detailed calculations of yield of products and justification of values chosen for products have been discussed in previous sections and are shown in Tables 30 and 31; these data are used without further explanation. The delivered prices of the bituminous coals were obtained from current quota-



tions for present conditions, and from the Federal Register<sup>49</sup> for the year 1939. All the data used are tabulated in Tables IV-A and IV-B of Appendix I.

Parts A, B, and C of Tables 30 and 31 are self-explanatory but some of the data of Part D require elaboration. For the calculation of Part D, it is necessary to establish a base value for the coal cost and value of carbonization products per ton of coke for the bituminous coal blend carbonized alone. With the 80-20 Powellton-Pocahontas No. 4 blend, the tons of the coking blend necessary to yield 1 ton of coke (see Part A) is  $100 \times 1/66.4$  or 1.506 tons; the cost of this coal delivered, using the costs previously referred to, is \$10.482. The total value of all carbonization products per ton coke (from Part C) is \$14.602. Thus, the difference or differential (for our purpose considered to be conversion cost plus profit) is simply \$14.602 minus \$10.482 or \$4.120 per ton coke, equivalent to \$2.736 per ton coal. This differential per ton of coke is the basis for estimating a value for anthracite. Taking the blend containing 20 per cent of anthracite as an example, let us see the manner in which the anthracite value is deduced. From Part D it is clear that in order to make one ton of (marketable) coke from the coal blend containing 20 per cent of anthracite, 1.168 tons of the 80-20 blend of bituminous coal and 0.292 tons of anthracite are necessary. These two quantities must be determined individually, since it was shown in the coke yield section in Chapter II that the coke yields of the component coals of a blend containing anthracite usually differ. The cost of the 1.168 tons of bituminous coal in the coal blend containing 20 per cent anthracite is \$8.129. The total value of all products from the 1.46 tons of coal ( $1.168 + 0.292$ ) is \$13.467 per ton of coke. Here the differential is \$13.467 minus \$8.129 or \$5.338 per ton of coke, \$1.218 greater than the differential obtained when using 100 per cent bituminous coal. But it will be observed that for the blend containing 20 per cent anthracite, the cost of the anthracite coal was not included in the initial computation. Hence, it appears, taking the \$4.120 differential as a "standard conversion cost plus profit," that the \$1.218 represents the maximum value of the 0.292 tons of anthracite which was used in producing the one ton of anthracite blend coke; computation of the value of the anthracite per ton is obvious. In Table 31, as already mentioned, the method of calculation is identical.

The data of Part D, Table 31, are shown graphically in Figures 20 and 21. The cost of coal and the value of the products per ton of (marketable) coke produced, using 0 to 20 per cent of anthracite in the coal blend, are shown in Figure 20, while Figure 21 shows the proportionate cost of anthracite and bituminous coals per ton (marketable) coke, using 0 to 20 per cent anthracite in the blend. For purposes of comparison, Figure 22, based on Minerals Yearbook statistics and showing the cost of coal and value of all products per ton of (marketable) coke for all by-product plants (furnace and merchant) in the United States, has been included.

TABLE 30  
MARKET VALUE OF ANTHRACITE AS A BLENDING AGENT FOR 1943 IN THE  
METROPOLITAN AREA OF SOUTHEAST PENNSYLVANIA AND OF NEW YORK CITY

| Yield Per Ton of Coal as Carbonized                           |                                   |                       |                         |   |                               |  |                                   |                                  |  |
|---|-----------------------------------|-----------------------|-------------------------|---|-------------------------------|--|-----------------------------------|----------------------------------|--|
| % Anthracite<br>(83% FC+Ash)                                  | Gas, cu.ft. of<br>530 Btu. Stand. | Tar,<br>Gals.         | Light Oil<br>Gallons    | (N <sub>2</sub> ) SO <sub>2</sub><br>Lbs. | Total Coke                    |  | Marketable <sup>1</sup><br>Coke % | Breeze<br>Per Cent               | Total value of products<br>per ton of coke |
|   |                                   |                       |                         |   | Per Cent                      |  |                                   |                                  |  |
| 0   | 11,499                            | 12.0                  | 2.72                    | 23.5                                      | 72.4                          |  | 66.4                              | 6.0                              |  |
| 5   | 11,094                            | 11.4                  | 2.58                    | 22.3                                      | 72.9                          |  | 66.9                              | 6.0                              |  |
| 10  | 10,689                            | 10.8                  | 2.45                    | 21.2                                      | 73.5                          |  | 67.5                              | 6.0                              |  |
| 15  | 10,284                            | 10.2                  | 2.31                    | 20.0                                      | 74.0                          |  | 68.0                              | 6.0                              |  |
| 20  | 9,879                             | 9.6                   | 2.18                    | 18.8                                      | 74.5                          |  | 68.5                              | 6.0                              |  |
| B. Values (Per Ton Coal as Carbonized) <sup>2</sup> , Dollars |                                   |                       |                         |   |                               |  |                                   |                                  |  |
| 0   | \$2.875                           | \$0.564               | \$0.329                 | \$0.306                                   |                               |  | \$5.478                           | \$0.145                          |  |
| 5   | 2,774                             | 0.536                 | 0.312                   | 0.290                                     |                               |  | 5,519                             | 0.145                            |  |
| 10  | 2,672                             | 0.508                 | 0.297                   | 0.276                                     |                               |  | 5,569                             | 0.145                            |  |
| 15  | 2,571                             | 0.479                 | 0.280                   | 0.260                                     |                               |  | 5,610                             | 0.145                            |  |
| 20  | 2,470                             | 0.451                 | 0.264                   | 0.244                                     |                               |  | 5,651                             | 0.145                            |  |
| C. Values (Per Ton Coke) <sup>2</sup> , Dollars               |                                   |                       |                         |   |                               |  |                                   |                                  |  |
| 0   | \$4.330                           | \$0.849               | \$0.495                 | \$0.461                                   |                               |  | \$8.250                           | \$0.218                          | \$14.602                                   |
| 5   | 4,146                             | 0.801                 | 0.465                   | 0.433                                     |                               |  | 8,250                             | 0.217                            | 14,313                                     |
| 10  | 3,959                             | 0.753                 | 0.440                   | 0.409                                     |                               |  | 8,250                             | 0.215                            | 14,026                                     |
| 15  | 3,781                             | 0.704                 | 0.412                   | 0.382                                     |                               |  | 8,250                             | 0.213                            | 13,742                                     |
| 20  | 3,606                             | 0.658                 | 0.385                   | 0.356                                     |                               |  | 8,250                             | 0.212                            | 13,467                                     |
| D. Value of Anthracite at the Coke Plant                      |                                   |                       |                         |   |                               |  |                                   |                                  |  |
| % Anthracite<br>(83% FC+Ash)                                  | Per Ton of Coke Basis             |                       |                         |   | Total<br>Value of<br>Products | Differential<br>Conversion Cost<br>Plus Profit | Maximum<br>Cost of<br>Anthracite  | Per Ton Basis                    |  |
|   | Tons<br>Coal                      | Tons<br>Blend<br>Coal | Tons<br>Anthra-<br>cite | Cost of<br>80-20<br>Blend                 |                               |  |                                   | Maximum<br>Cost of<br>Anthracite | Cost of<br>Anthracite                      |
| 0   | 1.506                             | 1.506                 | 0                       | \$10.482                                  | \$4.120                       |  |                                   |                                  |  |
| 5   | 1.495                             | 1.420                 | 0.0748                  | 9.883                                     | 4.430                         | \$0.310  | \$4.14                            |                                  |  |
| 10  | 1.481                             | 1.333                 | 0.148                   | 9.278                                     | 4.748                         | 0.628  | 4.24                              |                                  |  |
| 15  | 1.471                             | 1.250                 | 0.221                   | 8.700                                     | 5.042                         | 0.922  | 4.17                              |                                  |  |
| 20  | 1.460                             | 1.168                 | 0.292                   | 8.129                                     | 5.338                         | 1.218  | 4.17                              |                                  |  |

<sup>1</sup>Hereafter designated simply as coke.

<sup>2</sup>All cost and value data are tabulated in Table IV-A, Appendix I.

TABLE 31

MARKET VALUE OF ANTHRACITE AS A BLENDING AGENT IN "NORMAL" TIMES FOR  
EASTERN PENNSYLVANIA AND OTHER NORTHEASTERN AREAS

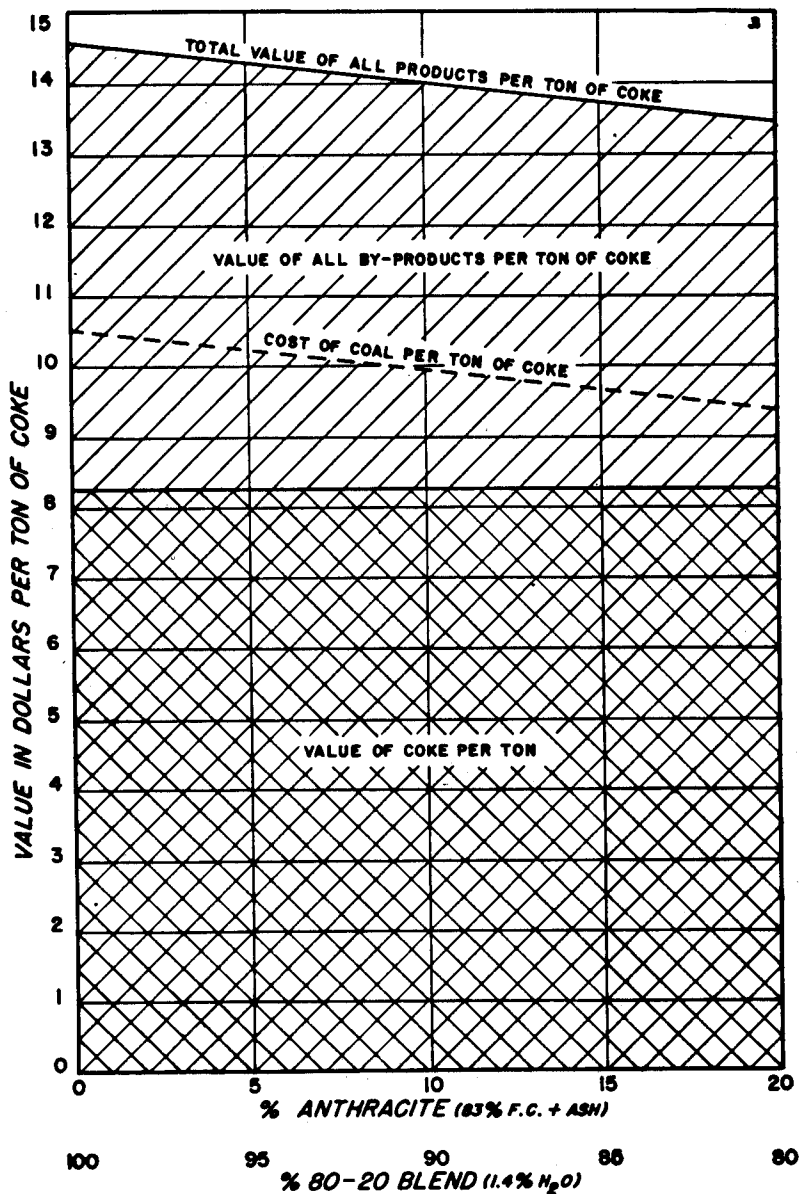
| A. Yield Per Ton of Coal as Carbonized                        |                                   |                                  |                         |   |                               |  |                                  |  |
|---|-----------------------------------|----------------------------------|-------------------------|---|-------------------------------|--|----------------------------------|--|
| % Anthracite<br>(83% FC+Ash)                                  | Gas, cu.ft. of<br>530 Bru. Stand. | Tar,<br>Gals.                    | Light Oil,<br>Gallons   | (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub><br>Lbs. | Total Coke<br>Per Cent        | Marketable <sup>1</sup><br>Coke %              | Breeze<br>Per Cent               | Total value of products<br>per ton of coke     |
| 0   | 11,499                            | 12.0                             | 2.72                    | 23.5  | 72.4                          | 66.4   | 6.0                              |  |
| 5   | 11,094                            | 11.4                             | 2.58                    | 22.3  | 72.9                          | 66.9   | 6.0                              |  |
| 10  | 10,689                            | 10.8                             | 2.45                    | 21.2  | 73.5                          | 67.5   | 6.0                              |  |
| 15  | 10,284                            | 10.2                             | 2.31                    | 20.0  | 74.0                          | 68.0   | 6.0                              |  |
| 20  | 9,879                             | 9.6                              | 2.18                    | 18.8  | 74.5                          | 68.5   | 6.0                              |  |
| B. Values (Per Ton Coal as Carbonized) <sup>2</sup> , Dollars |                                   |                                  |                         |   |                               |  |                                  |  |
| 0   | \$2.875                           | \$0.576                          | \$0.324                 | \$0.259   |                               | \$4.281  | \$0.148                          |  |
| 5   | 2.774                             | 0.547                            | 0.307                   | 0.245   |                               | 4.314  | 0.148                            |  |
| 10  | 2.672                             | 0.518                            | 0.292                   | 0.233   |                               | 4.352  | 0.148                            |  |
| 15  | 2.571                             | 0.490                            | 0.275                   | 0.220   |                               | 4.385  | 0.148                            |  |
| 20  | 2.470                             | 0.461                            | 0.259                   | 0.207   |                               | 4.417  | 0.148                            |  |
| C. Values (Per Ton Coke) <sup>2</sup> , Dollars               |                                   |                                  |                         |   |                               |  |                                  |  |
| 0   | \$4.330                           | \$0.867                          | \$0.488                 | \$0.390   |                               | \$6.448  | \$0.223                          | \$12.746                                       |
| 5   | 4.146                             | 0.818                            | 0.459                   | 0.366   |                               | 6.448  | 0.221                            | 12.458   |
| 10  | 3.959                             | 0.767                            | 0.433                   | 0.345   |                               | 6.448  | 0.219                            | 12.171   |
| 15  | 3.781                             | 0.721                            | 0.404                   | 0.324   |                               | 6.448  | 0.218                            | 11.896   |
| 20  | 3.606                             | 0.673                            | 0.378                   | 0.302   |                               | 6.448  | 0.216                            | 11.623   |
| D. Value of Anthracite at the Coke Plant                      |                                   |                                  |                         |   |                               |  |                                  |  |
| Per Ton of Coke Basis   |                                   |                                  |                         |   |                               |  |                                  |  |
| % Anthracite<br>(83% FC+Ash)                                  | Tons<br>Coal                      | Tons 80-20<br>Blend Bit.<br>Coal | Tons<br>Anthra-<br>cite | Cost of<br>80-20<br>Blend                               | Total<br>Value of<br>Products | Differential<br>Conversion Cost<br>Plus Profit | Maximum<br>Cost of<br>Anthracite | Per Ton Basis<br>Maximum Cost of<br>Anthracite |
| 0   | 1.506                             | 1.506                            | 0                       | \$8.569   | \$12.746                      | \$4.177  | --                               | --   |
| 5   | 1.495                             | 1.420                            | 0.0748                  | 8.080   | 12.458                        | 4.378  | \$0.201                          | \$2.69   |
| 10  | 1.481                             | 1.333                            | 0.148                   | 7.585   | 12.171                        | 4.586  | 0.409                            | 2.76   |
| 15  | 1.471                             | 1.250                            | 0.221                   | 7.113   | 11.896                        | 4.783  | 0.606                            | 2.74   |
| 20  | 1.460                             | 1.168                            | 0.292                   | 6.646   | 11.623                        | 4.977  | 0.800                            | 2.74   |

<sup>1</sup>Hereafter designated as coke.

<sup>2</sup>All cost and value data are tabulated in Table IV-B, Appendix I.

FIGURE 20

THE COST OF COAL AND VALUE OF PRODUCTS  
PER NET TON OF COKE PRODUCED  
USING 0 TO 20% ANTHRACITE



ALL COALS ON THE AS CARBONIZED BASIS

FIGURE 21

PROPORTIONATE COST OF ANTHRACITE  
AND BITUMINOUS COALS IN 0 TO 20%  
ANTHRACITE BLENDS

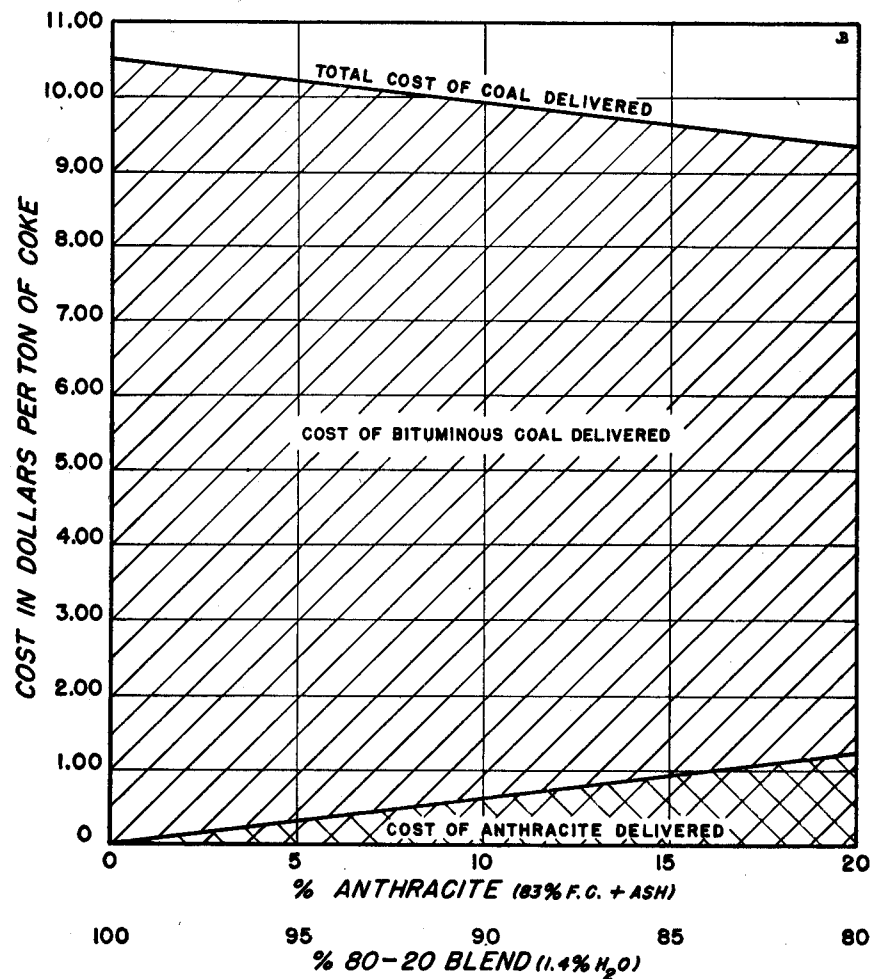
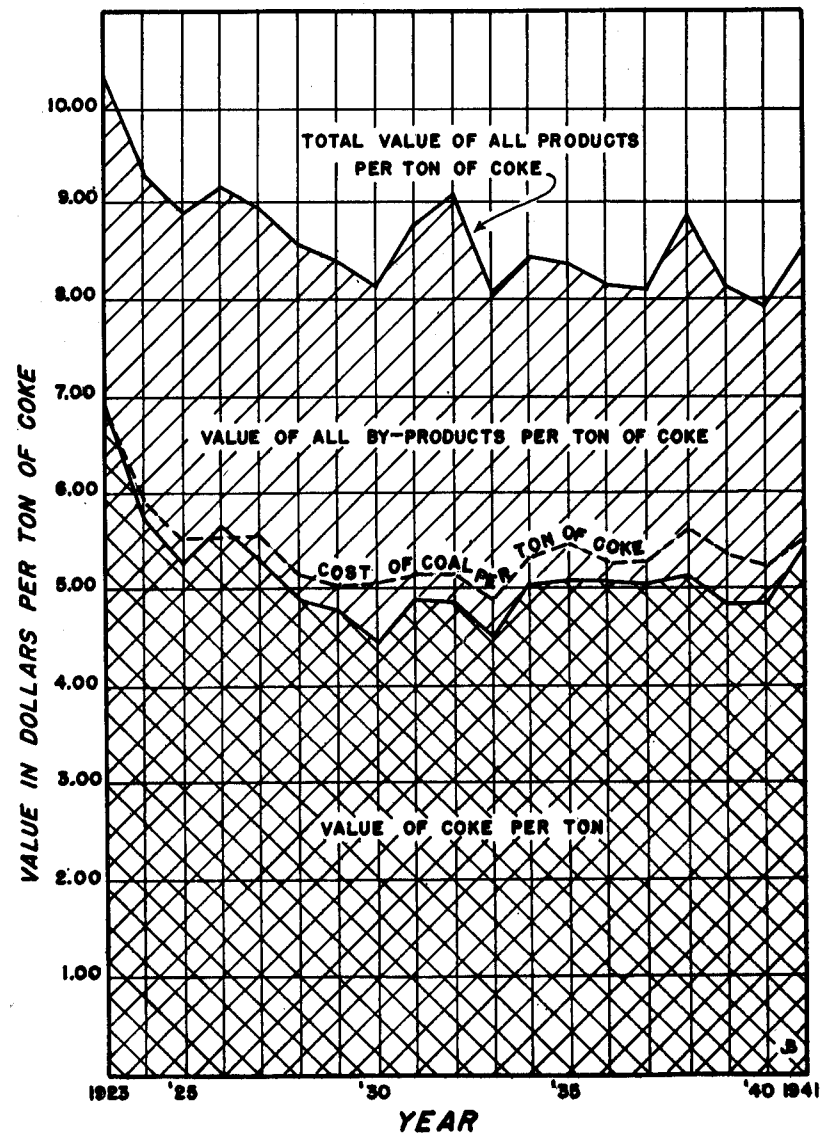


FIGURE 22

COST OF COAL AND VALUE OF ALL  
PRODUCTS PER NET TON OF COKE PRODUCED  
FOR BY-PRODUCT COKE  
(U.S.A.)



It will be observed that the differential shown in Figure 20 is high compared to that for Figure 22. Evidently this is, in part, due to the lower average value placed on the coke and the lower average value of the gas (implicit) in Figure 22, because of the much greater weight effect of the furnace plants on average values as compared with merchant plants. Probably the differential in Figure 20 is similar to that for many merchant plants.

In order to simplify the computation of the value, delivered at the plant, of anthracite used for blending purposes, Equation 18 has been developed. This equation, as were the previous equations relating to by-products, was developed as a result of the computations involved in preparing Tables 30 and 31. This equation should be of interest to the coke plant operator because it is believed to be generally applicable to conditions at any plant where the use of anthracite is contemplated. It is also of value to the anthracite operator as a means of determining the value of his coal as a blending agent at a particular coke plant.

$$\text{Equation 18. } Q_p = 1/a \left[ bC + Ds + E \left( \frac{byv + axu}{w} \right) + Fe - Me - bG \right]$$

$Q_p$  = Anthracite value in dollars per ton delivered at the plant.

$a$  = Per cent anthracite in the anthracite-bituminous coal blend (as carbonized basis).

$b$  = Per cent bituminous coal in the anthracite-bituminous coal blend (as carbonized basis).

$e$  = Per cent total coke yield less breeze from one ton of the anthracite-bituminous coal blend (as carbonized basis). At a plant the total yield of coke may be determined by the use of Figure 1, while the breeze yield can be estimated.

$s$  = Per cent of coke breeze from a ton of bituminous coal, or the estimated breeze (per cent yield) from one ton of the anthracite-bituminous coal blend (as carbonized basis).

$u$  = Actual heating value in gross Btu. per cu. ft. of the gas from the anthracite; may be taken as 340 Btu. per cu. ft. for most buckwheat No. 5 anthracite of low- and medium-volatile matter content.

$v$  = Actual heating value in gross Btu. per cu. ft. of the gas from the bituminous coal.

$w$  = Standard heating value in Btu. per cu. ft. used by the plant (530 Btu. per cu. ft. is generally used in Pennsylvania).

$x$  = MCF of gas (saturated with water vapor at 60°F. and 30" Hg.) from one ton of the anthracite coal as carbonized; may be taken as 5.3 MCF for most buckwheat No. 5 anthracite of low- and medium-volatile matter content.

$y$  = MCF of gas (saturated with water vapor at 60°F. and 30" Hg.) from one ton of the bituminous coal as carbonized.

$C$  = Total value in dollars of the tar, light oil, and ammonium sulphate (equivalent of all  $\text{NH}_3$ ) per ton of bituminous coal carbonized alone.

$D$  = Value of breeze in dollars per ton.

$E$  = Value of gas per MCF, in dollars.

$F$  = Value of coke in dollars per ton.

$G$  = Cost of bituminous coal in dollars per ton delivered.

$M$  = "Differential" (conversion costs plus profit, etc.) in dollars *per ton coke*, operating with bituminous coal alone.

The use of this equation is perhaps most clearly explained by means of a numerical example. Using data for the 20 per cent anthracite blend from Table 30 and values from Table IV-A, Appendix I, it is set up as follows:

$$Q_p = 1/20 \left[ (80) (1.20) + (2.41) (6) + (0.25) \left( \frac{(80) (10.4) (586) + (20) (5.3) (340)}{530} \right) + (8.25) (68.5) - (4.120) (68.5) - (80) (6.96) \right]$$

where

$$\begin{array}{llll} a = 20\% & x = 5.3 & u = 340 & F = \$8.25 \\ b = 80\% & y = 10.4 & v = 586 & G = \$6.96 \\ e = 74.5-6.0 & D = \$2.410 & w = 530 & M = \$4.120 \\ s = 6.0\% & E = \$0.250 & C = \$0.564 + \$0.329 + \$0.305 = \$1.20 \end{array}$$

Simplifying and solving the above:

$$Q_p = 1/20 [(96) + (14.46) + (0.25) (987.91) + (565.13) - (282.29) - (556.80)]$$

$$Q_p = 1/20 (83.48) = 4.17 \text{ dollars per ton, delivered value of anthracite.}$$

In using this equation, it is necessary that the utmost care be exercised in substituting the various quantities in the proper place and in avoiding small arithmetic errors. Otherwise, erroneous and misleading values may result.

As a result of the analysis in the preceding pages and other analyses not reported, the following interesting generalizations concerning the value of anthracite as a blending agent have been deduced:

(1) In general, the value of anthracite as a blending agent in by-product coking practice is directly proportional to the cost of the bituminous coal. In other words, when the cost of the bituminous coal at the plant is low, the value of the anthracite is low, and it is often not great enough to pay the freight on the anthracite. This may be seen by comparing the anthracite values per ton coal in Part D, Tables 30 and 31.

(2) There appears to be a relationship, unfortunately not well defined, between the per cent anthracite blended and the value of the anthracite per ton. In both Tables 30 and 31, the value seems to be a maximum at 10 per cent anthracite.

(3) The value of the anthracite per ton appears not to be affected by changes in the average value of the coke.

(4) In general, the value of the anthracite per ton is inversely proportional to the value per MCF of the gas.

(5) Increased throughput as a result of anthracite blending would probably have an influence on (1) and (4) because of the decrease in conversion cost per ton, thus tending to increase the value of the anthracite per ton.

#### VALUE OF ANTHRACITE AT THE COLLIERY

In the foregoing section the value of anthracite at the by-product oven has been evaluated, and this value will be one of the controlling factors in determining whether or not the coke oven operators are willing to use anthracite. The question still remains, however, as to whether the extent and future of this market justifies the anthracite producer in making an intensive bid for this market, and this is largely contingent upon the returns for the anthracite at the colliery.

The value of anthracite at the colliery is the value at the by-product oven minus the freight and, in Table 32, the value at the colliery has been calculated for anthracite from several localities when delivered at Philadelphia, Bethlehem, or Kearney under present conditions. Other examples can be readily calculated by the reader for coal from other regions or delivered at plants in other localities.

It is apparent from these figures that under existing bituminous coal prices and existing freight rates, the anthracite operator may expect a fair return on No. 5 buckwheat size anthracite used for blending purposes. Under conditions which may be expected to prevail during more nearly normal times, however, the picture is less satisfactory as may be seen from a consideration of the data shown in Table 33.

It appears from this analysis that the probable returns for the anthracite would be inadequate except possibly at Bethlehem where the freight rates are more favorable than for the other localities.

As was stated in previous sections of this report, the average value placed upon the gas is an important item in the final valuation placed upon the anthracite at the oven and, therefore, in the valuation at the colliery. If the average value of the gas is less than 25c per MCF, the value of the anthracite increases; if more than 25c, the value of the anthracite decreases. In order to arrive at definite valuation for the anthracite at any particular plant, therefore, it is essential that complete cost and valuation data be available. Knowing specific data for a given plant, the value of the anthracite at the oven can be calculated from Equation 18 and this minus the freight rate is the value at the colliery.

TABLE 32

VALUE OF ANTHRACITE AT COLLIERY, CONDITIONS AS OF APRIL, 1943

| From Anthracite Region | To Vicinity of    | Via Railroad          | Freight rate <sup>1</sup> \$/net ton | Value at colliery \$/net ton |
|------------------------|-------------------|-----------------------|--------------------------------------|------------------------------|
| Lehigh                 | Philadelphia, Pa. | LV for PRR delivery   | 2.10                                 | 2.07                         |
| Schuylkill             | " "               | PRR " " "             | 2.10                                 | 2.07                         |
| Wyoming                | " "               | " " " "               | 2.22                                 | 1.95                         |
| Lehigh                 | Bethlehem, Pa.    | LV for RDG delivery   | 1.32                                 | 2.85                         |
| Schuylkill             | " "               | RDG " " "             | 1.38                                 | 2.79                         |
| Lehigh                 | Kearney, N. J.    | CNJ " CNJ "           | 2.22                                 | 1.95                         |
| Wyoming                | " "               | DL&W for CNJ delivery | 2.34                                 | 1.83                         |
| D. L. & W.             | " "               | Erie " Erie "         | 2.34                                 | 1.83                         |

<sup>1</sup>Includes Federal Tax.

TABLE 33

VALUE OF ANTHRACITE AT COLLIERY, CONDITIONS AS OF NORMAL TIMES

| From Anthracite Region | To Vicinity of    | Via Railroad         | Freight rate <sup>1</sup> \$/net ton | Value at colliery \$/net ton |
|------------------------|-------------------|----------------------|--------------------------------------|------------------------------|
| Wyoming                | Philadelphia, Pa. | PRR for PRR delivery | 2.22                                 | 0.48                         |
| Wyoming                | Bethlehem, Pa.    | LV " RDG "           | 1.43                                 | 1.27                         |
| Lehigh                 | " "               | LV " " "             | 1.32                                 | 1.38                         |
| Lehigh                 | Kearney, N. J.    | CNJ " CNJ "          | 2.22                                 | 0.48                         |

<sup>1</sup>Existing freight rates, including Federal Tax, have been used since no information is available as to future trends.

## VALUE OF ANTHRACITE IN TERMS OF MOISTURE CONTENT

The foregoing calculations have considered only the possibility of shipping the normal run of colliery No. 5 buckwheat anthracite which normally carries a moisture content of 10 to 14 per cent. In some instances, however, the possibility of drying the coal prior to shipment is worthy of consideration.

In general, the moisture content of the anthracite, if used in quantities of less than 10 per cent of the blend, will not be a problem to the by-product operator, but its value as a blending agent will be less due to the lower content of actual coal. Likewise, the cost will be higher at the oven due to added freight charges on the water.

The increased value of the anthracite at the colliery as a result of removing part or all of the water can be calculated from Equation 19, expressed in terms of dollars per ton of wet coal or from Equation 20, expressed in terms of dollars per ton of dried coal.

$$\text{Equation 19. } W_w = \left[ \left( \frac{100-s}{100-t} \right) V - V \right] \left[ \frac{100-t}{100-s} \right],$$

$$\text{Equation 20. } W_d = \left( \frac{100-s}{100-t} \right) V - V,$$

where  $V$  = delivered cost of wet coal at the by-product oven,  $s$  = per cent moisture in dried coal, and  $t$  = per cent moisture in wet coal.  $W_w$  and  $W_d$  = increase in value (\$) of the coal on the wet or dried coal basis, respectively. This can also be considered the amount (\$) available for drying the coal.

Using the specific example calculated in the previous analysis of the value of anthracite and assuming that a 12 per cent moisture content coal is to be dried to 4 per cent moisture content. The increased value of the anthracite is 35 cents per ton of original wet coal (12% moisture) at the colliery or 38 cents per ton of 4 per cent moisture coal. Whether this differential is sufficient to justify drying of the coal at the colliery will depend upon the facilities available, waste heat available, etc. As may be seen from a study of Equations 19 and 20, the differential available for drying increases as the value of the anthracite at the by-product plant increases. For example, it will be 45, 36, and 27 cents for anthracite costing \$5.00, \$4.00 and \$3.00, respectively, per ton delivered at the coke plant. Where both the bituminous coal and anthracite carry high freight rates as delivered at the oven, the value of the anthracite at the oven increases and the differential available for drying the anthracite becomes appreciable.

## POTENTIAL MARKETS

From the discussion presented in the previous chapters it is apparent that the blending of anthracite fines with coking coals has for one reason or another failed to produce a product which as yet is fully acceptable to the blast-furnace trade. For the immediate future, therefore, it appears reasonably certain that the potential market for anthracite fines as a blending material in coke manufacture will be limited to nonfurnace uses.

In Figure 23 is shown the distribution of by-product coke sold by producers in Pennsylvania from 1926 to 1941. These data include some coke sold by furnace plants, but for the most part represent that produced by merchant plants. It is apparent from these data that the major portion of this coke is used in blast-furnaces. The domestic market has ranged between 500,000 and 850,000 tons per year for the past ten years, while the foundry and industrial uses have averaged together about 400,000 tons per year. Thus, for Pennsylvania, the potential market for anthracite would range from about 70,000 to 140,000 tons per year, assuming the use of 5 to 10 per cent anthracite in the blend.

For the anthracite marketing area the data shown in Table 34 indicate: a total nonfurnace potential market of about 300,000 to 600,000 tons per year on the same basis. By way of comparison, the potential market for anthracite fines on the same basis and for the same marketing area would be between 1,650,000 and 3,300,000 tons if the anthracite blending produced a suitable product for blast-furnace use. However, it is extremely doubtful whether anthracite could compete economically in the Pittsburgh area even assuming a satisfactory coke could be produced so that the total potential market including furnace coke would probably not exceed 1 to 2 million tons.

The possibility of developing a suitable coke for blast-furnace use when using anthracite in the blend should not be considered improbable, and with the indicated potential market the matter is worthy of consideration. Considerably more research on both a laboratory and plant-scale will have to be completed, however, before the blast-furnace trade will be convinced that the anthracite cokes are suitable for blast-furnace use.

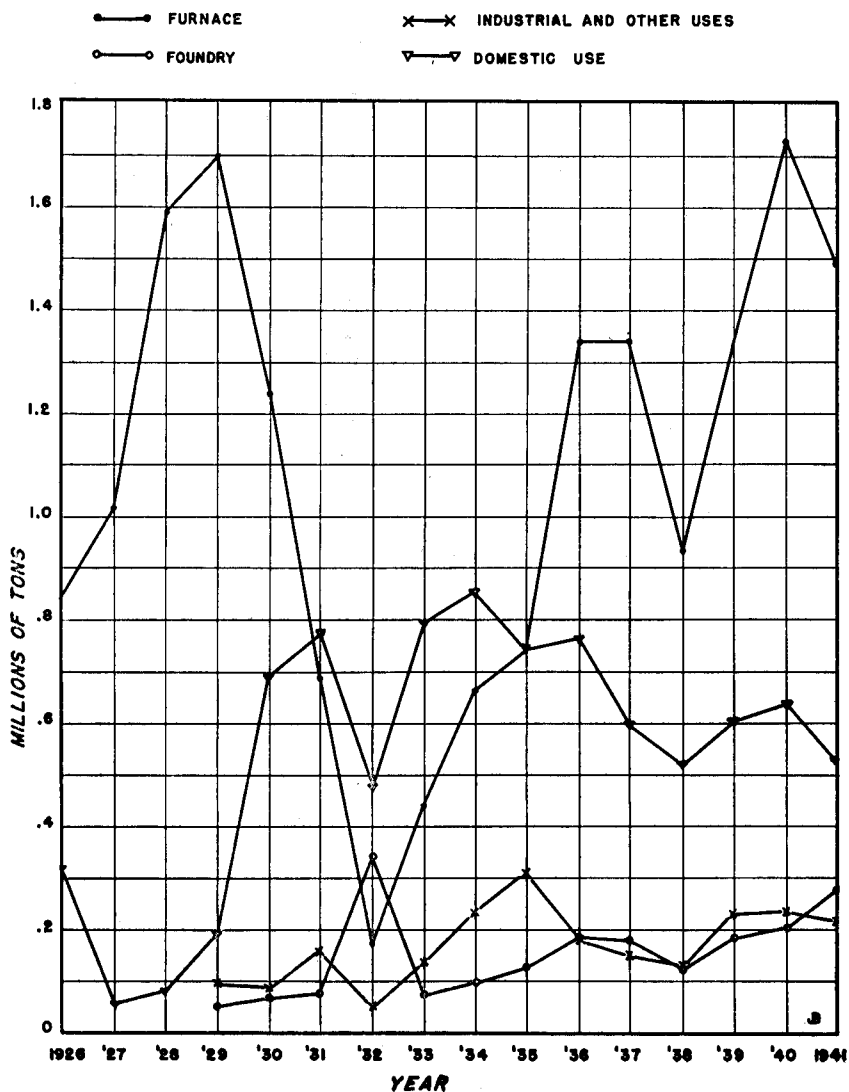
TABLE 34  
 BY-PRODUCT COKE PRODUCED AND SOLD BY PRODUCERS IN 1941  
 (Minerals Yearbook)

| Location of<br>Producing Plant | Total<br>Tons Coke<br>Produced | Tons Coke Sold |         |           |            |           |
|--------------------------------|--------------------------------|----------------|---------|-----------|------------|-----------|
|                                |                                | Furnace        | Foundry | Domestic  | Industrial | Total     |
| Pennsylvania                   | 15,632,354                     | 1,498,875      | 275,194 | 528,335   | 219,496    | 2,521,900 |
| Massachusetts                  | 1,161,732                      | 9,955          | 84,275  | 897,532   | 45,509     | 1,037,271 |
| New York                       | 5,116,308                      | 1,758,964      | -       | 1,236,484 | 221,013    | 3,216,461 |
| New Jersey                     | 1,031,569                      | 23,553         | 57,186  | 460,334   | 256,752    | 797,625   |
| Total for Area                 | 22,941,963                     | 3,291,347      | 416,655 | 3,122,685 | 742,770    | 7,573,257 |
| Total Nonfurnace Coke          |                                |                |         |           |            | 4,282,110 |



FIGURE 23

DISTRIBUTION OF BY-PRODUCT COKE SOLD BY PRODUCER FOR PENNA.



# APPENDIX I

TABLE I

PROXIMATE ANALYSES, ETC. OF COALS USED IN COKE YIELD, ASH CONTENT AND BY-PRODUCT CALCULATIONS

| Coal Designation <sup>1</sup> | Proximate Analysis, Per Cent <sup>2</sup> |                 |              |      | Sulfur Per Cent <sup>2</sup> | Air Drying Loss, % | AST °F. |
|-------------------------------|---|-----------------|--------------|------|------------------------------|--------------------|---------|
|                               | Moisture                                  | Volatile Matter | Fixed Carbon | Ash  |                              |                    |         |
| Coal 28 (Pittsburgh)          | 1.8                                       | 35.1            | 57.7         | 5.4  | 0.9                          |                    | 2740    |
| Coal 57 (Pocahontas No. 4)    | 1.4                                       | 16.0            | 75.6         | 7.0  | 1.1                          | 1.0                | 2750    |
| Coal 62 (Powellton)           | 2.5                                       | 33.7            | 61.1         | 2.7  | 0.6                          | 1.3                | 2890    |
| Coal 62C                      | 1.4                                       | 29.5            | 65.6         | 3.5  | 0.7                          | 0.3                | 2790    |
| Buckwheat No. 5 Anthracite    | 12.7                                      | 4.7             | 70.7         | 11.9 | 0.65                         |                    |         |

<sup>1</sup>Coal 28. Pittsburgh bed, Warden Mine, Allegheny County, Pa. U. S. Bureau of Mines Mono. 5 (1934).

Coal 57. Pocahontas No. 4 bed, No. 4 mine, Raleigh County, W. Va. U. S. Bureau of Mines Tech. Paper 604 (1940).

Coal 62. Powellton bed, Elk Creek No. 1 mine, Logan County, W. Va. U. S. Bureau of Mines Tech. Paper 630 (1941).

Coal 62C. Blend of 80 per cent Coal 62 and 20 per cent Coal 57. Ibid.

Buckwheat No. 5 Anthracite, probably from the Hazleton District of Pennsylvania. Analysis calculated from data of Roberts.

<sup>2</sup>Per Cent on as carbonized basis.

TABLE II

BM-AGA CARBONIZATION ASSAY TEST 900°C YIELDS FOR COAL 62C USED IN THE REPORT (B.M.T.P. 630) (1941)

| Product  | Amount Per Ton of Coal | Per Cent by Weight | Calorific Value   |
|--|------------------------|--------------------|-------------------|
| Gas <sup>1</sup>   | 10,400 cu. ft.         | 13.5               | 586 B.T.U./cu.ft. |
| Tar  | 12.0 gal.              | 5.8                |                   |
| Light Oil  | 2.72 gal.              | 0.97               |                   |
| (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> <sup>2</sup> | 23.5 lb.               |                    |                   |
| Coke   |                        | 72.4 <sup>3</sup>  |                   |

<sup>1</sup>Saturated with water vapor at 60°F. and 30 in. Hg.

<sup>2</sup>The yield of ammonium sulphate at 800°C. is used in calculating (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> yields Fieldner and Davis (B.M. Mono. 5, p. 52) suggest that yields at 800°C. more nearly approach the plant yields at 900°C. No 800°C. (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> yields (in 18 in. retort) are given for Coal 62C in T. P. 630, but the yield of 23.5 lb. at 800°C. was calculated from the respective 800°C. yields for the two components, assuming that the yields are additive, although this is not strictly true. The yield is the ammonium sulphate equivalent of all forms of ammonia produced as a result of the carbonization.

<sup>3</sup>The reported yield of 72.7% was calculated to a volatile matter content of one per cent which is the standard use in this report, thus giving the value 72.4%.

TABLE III

PROXIMATE ANALYSIS OF COKING COALS USED BY MOTT AND WHEELER IN THE TESTS WITH ANTHRACITE FINES WITH A SOUTH YORKSHIRE COKING COAL BLEND: 67% OF PARKGATE COAL, 33% OF SILKSTONE COAL

|           | Moisture (Air dry basis) | Volatile Matter (Dry, ash-free basis) |
|-----------|--------------------------|---------------------------------------|
| Parkgate  | 1.0%                     | 37.0%                                 |
| Silkstone | 0.8                      | 35.3                                  |

From p. 165, Mott and Wheeler: *Coke for Blast Furnaces* (1930).

|           | Proximate Analysis, Per Cent (Air dry basis) |                 |              |     | Volatile Matter (Dry, ash-free basis) |
|-----------|--|-----------------|--------------|-----|---------------------------------------|
|           | Moisture                                     | Volatile Matter | Fixed Carbon | Ash |                                       |
| Parkgate  | 1.3  | 31.5            | 62.1         | 5.1 | 33.6                                  |
| Silkstone | 1.3  | 35.0            | 61.2         | 2.5 | 36.4                                  |

From p. 204, Mott and Wheeler: *The Quality of Coke* (1939).

TABLE IV-A

DATA USED IN THE ECONOMIC ANALYSIS FOR 1943 (Eastern Pa.)

| By-Product Values                                 |                     |  |
|---|---------------------|--|
| Tar Value*  | 4.7 cents per gal.  | 1941 average value in U.S.A.                       |
| Light Oil Value*                                  | 12.1 cents per gal. | 1940 average value in U.S.A.                       |
| (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> * | 1.3 cents per lb.   | 1941 average value in U.S.A.                       |
| Coke Value  | \$8.25 per ton      | April, 1943 value from an Eastern by-product plant |
| Breeze Value*                                     | \$2.41 per ton      | 1941 average value in U.S.A.                       |
| Gas Value   | 25 cents per MCF    | April, 1943 value from an Eastern by-product plant |

## COAL AND FREIGHT COSTS

Powellton\*\* \$3.25 per net ton + \$3.80 freight = \$7.05 per net ton track delivered to Philadelphia.

Pocahontas No. 4\*\* \$2.80 per net ton + \$3.80 freight = \$6.60 per net ton track delivered to Philadelphia.

80% Powellton and 20% Pocahontas No. 4 = \$6.96 per net ton track delivered to Philadelphia.

\*From Minerals Yearbook

\*\*Coal and Freight costs as of April 17, 1943 quoted by an Eastern broker (The gross ton freight rate is \$4.26 for track delivery).

TABLE IV-B

DATA USED IN THE ECONOMIC ANALYSIS FOR NORMAL CONDITIONS  
(Eastern Pa.)

| By-Product Values  |                     |   |
|--|---------------------|---|
| Tar Value <sup>1</sup>                                       | 4.8 cents per gal.  | 1939 average value in U.S.A.                                      |
| Light Oil Value <sup>1</sup>                                 | 11.9 cents per gal. | 1939 average value in U.S.A.                                      |
| (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> <sup>1</sup> | 1.1 cents per lb.   | 1939 average value in U.S.A.                                      |
| Coke Value <sup>1</sup>                                      | \$6.448 per ton     | 1939 weighted average value for<br>nonfurnace coke sold in Penna. |
| Breeze Value <sup>1</sup>                                    | \$2.47 per ton      | 1939 average value in U.S.A.                                      |
| Gas Value  | 25 cents per MCF    | 1939 estimated value for Eastern<br>Pennsylvania                  |

## COAL AND FREIGHT COSTS

Powellton \$1.90<sup>2</sup> per net ton + \$3.80<sup>3</sup> freight = \$5.70 per net ton track  
delivered to Philadelphia.

Pocahontas No. 4 \$1.86<sup>2</sup> per net ton + \$3.80<sup>3</sup> freight = \$5.66 per net  
ton track delivered to Philadelphia.

80% Powellton, 20% Pocahontas No. 4 blend = \$5.69 per net ton track  
delivered.

<sup>1</sup>From the Minerals Yearbook.

<sup>2</sup>Taken from the Federal Register, June 29, 1939.

<sup>3</sup>Freight rate as of April 17, 1943 from an Eastern broker.

TABLE V

## MISCELLANEOUS DATA

Screen analysis of the Buckwheat No. 5 size of Pennsylvania Anthracite used by  
Roberts<sup>16</sup> in full-scale oven tests.

|               |               |
|---------------|---------------|
| on 10-mesh    | 0.5 per cent  |
| 10 x 20-mesh  | 15.9 per cent |
| 20 x 40-mesh  | 68.7 per cent |
| 40 x 100-mesh | 14.1 per cent |
| thru 100-mesh | 0.8 per cent  |

100 Per Cent

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