

THOMAS BY-PRODUCT COKE WORKS
Birmingham Industrial District
1200 Tenth Street West
Thomas
Jefferson County
Alabama

HAER No. AL-14

Handwritten:
11/17/70
6-

PHOTOGRAPHS
WRITTEN HISTORICAL AND DESCRIPTIVE DATA
REDUCED COPIES OF MEASURED DRAWINGS

Historic American Engineering Record
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HISTORIC AMERICAN ENGINEERING RECORD

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HAER NO. AL-14

Location: 1200 Tenth Street, West, Thomas, Jefferson County, Alabama. The plant is bounded by I-59/20 on the south, by Avenue W on the west, by Pratt Highway/2nd Street on the north, and by Bankhead Highway (US Highway 78) on the east.

Present Owner: Wade Sand and Gravel Company

Present Use: "Moth-balled" in the 1970s, the plant has been de-activated although it is in an exceptional state of preservation.

Significance: The Thomas Coke By-product Works is possibly the finest intact early twentieth century by-product coke works available for interpretation. The construction of the Koppers-Becker coke ovens at Thomas in 1925 marked the end in the process to convert from beehive coking ovens to by-product recovery coking in the Birmingham Industrial District. Thus, the site represents the modern method of extracting by-products from the coking process and using them to make industrial chemicals such as coal gas, tar, ammonia, light oil and naphthalene. The coke was used to fuel the Thomas Company's blast furnaces.

Historian: Jack Bergstresser, Summer 1992

Introduction

The Thomas coke works, located at the Republic Steel Corporation's Thomas foundry iron blast furnace plant in Birmingham, Alabama, is a typical example of the by-product coke plants that made the coke that fueled American blast furnaces and foundries from the early to mid-twentieth century. Coke is almost pure carbon produced from coal that is either heated or partially burned to drive off its volatile matter and impurities. Coke burns hot and clean at a very regular and predictable rate. Known as its combustion rate, these qualities of coke allow a blast furnace to produce high volumes of pig iron of uniform grade.¹

Built in 1925, Thomas coke works was the smallest of Republic Steel's coke works. This was a time when the coking industry passed something of a milestone. The Koppers Company of Pittsburgh was the leading designer of American coke ovens and by-product recovery plants. At the behest the United States Steel Corporation, German-born Heinrich Koppers came to the United States in 1908 to build a plant at Joliet, Illinois that would utilize his patented cross-regenerative, by-product coking system.² In so doing, the Koppers Company ushered in the modern era of American by-product coke ovens.

The Semet-Solvay horizontal-flue by-product oven with its reputation for durability dominated the industry since the 1890s. After its introduction, the Koppers cross-regenerative oven with vertical heating flues soon took the lead. By 1959, seventy percent or 11,280 of the 15,993 by-product coke ovens in the United States were either Koppers or Koppers-Becker ovens.³

Koppers set records for productivity that far exceeded earlier U.S. and European standards. When the stimulus of World War I further encouraged coke oven construction and more extensive by-

¹T.L. Joseph, "Behavior of Coke in the Blast Furnace," Year Book of the American Iron and Steel Industry, New York: American Iron and Steel Institute, 1928, 420-425.

²C.S. Finnley and John Mitchell, "Development of Modern By-Product Coke Ovens" in History of the Coking Industry in the United States. New York: The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., 1961, 49-52.

³C.S. Finney and John Mitchell, "The Coke Industry Today," in History of the Coking Industry in the United States (New York: The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., 1961): 53.

product recovery, Koppers built the largest coke plant in the world at Clairton on the Mongahela river just above Pittsburgh. If the Clairton works represented the climax of a massive building boom, the introduction in 1922 of the Koppers-Becker oven represented a climax in the efforts to produce the most efficient coke oven to date.⁴

When the Thomas plant was built three years later in 1925, it embodied most of the latest design features that Koppers had so recently developed, including the Koppers-Becker oven. When Republic modernized the plant in 1952, it installed many of the latest features of this next generation of coke plant. The Thomas plant included most of the important technological features of the Koppers coke oven and by-product recovery process developed between World War I and the early 1950s, a period that might be considered the golden age of American by-product coke practice.

Blast Furnace Coke in the United States

The first coke made in the United States in retort ovens was not called by-product coke, nor was it used as blast furnace fuel. Instead, the coke was the by-product of a process that produced coal gas. Bright and clean burning, this gas was used for illumination in street lights and interior lighting. The coal gas was considered more valuable and the coke was considered a secondary product to be disposed of in any way possible. It was sold for domestic and industrial heating but was not suited for metallurgical purposes.

This kind of retort coke production, which served as adjunct to the city gas industry, began in 1812 when Frederick A. Winsor established the Gas Light and Coke Company of London, England. City gas was introduced into the U.S. at Baltimore in 1816, Boston in 1822 and New York in 1825. Since the anthracite coal-fired blast furnaces of eastern Pennsylvania dominated the pig-iron industry--providing an inexpensive, readily available fuel source--there was very little impetus even to consider the use of

⁴C.J. Ramsburgh and F.W. Speer, Jr., "By-Product Coke and Coking Operations," Coal Age 13 (27 April 1918): 772; Frank F. Marquard, "Coke Made from High-Volatile Coal," Iron Trade Review 60 (29 May 1919): 1433; Joseph Becker, "Modern By-product Coking", Chemical and Metallurgical Engineering 27 (1 November 1922): 875-881.

retort coke for blast furnace fuel.⁵

The situation began to change following the Civil War as demand within the Pittsburgh district--which steadily had been building a rolling mill industry for the preceding three of four decades--began to outgrow the productive capacity of its charcoal blast furnaces (scattered across the region). Numerous attempts had been made to produce coke pig iron prior to the war, but it was not until the advent of large-batch steel production made possible by the Bessemer converter that correspondingly high volume blast furnaces came into demand; blast was not achievable through the Bessemer process with either charcoal or anthracite as fuel. The remarkably high tonnage achieved at the Lucy and Isabella furnaces along the Allegheny River in Pittsburgh in the 1870s would soon show coke to be the fuel of a new generation of American blast furnaces.⁶

The Prejudice Favoring Connellsville Beehive Coke

Although the first few decades following the development of the Bessemer converter resulted in incredible growth in the number and size of coke blast furnaces, it did not result in the immediate introduction of by-product metallurgical coke making. All the metallurgical coke produced before 1895 was made in open mounds, beehive ovens or some other form of non-by-product coke oven.⁷

⁵C.S. Finney and John Mitchell, "Emergence of By-Product Coking." in History of the Coking Industry in the United States (New York: The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., 1961), 44-45.

⁶For general discussions of the role that coke played in the rise of modern blast furnace practice see William T. Hogan, Economic History of the Iron and Steel Industry in the United States, Vol. 1, Part 1 (Lexington, Mass.: D.C. Heath and Company, 1971: 23-25, 204-208), Kenneth Warren, The American Steel Industry (Pittsburgh: University of Pittsburgh Press, 1973), 34-38, 46-49.

⁷John Fulton, "A Report on Methods of Coking,:" in Coke Manufacture, by Franklin Platt, Second Geological Survey of Pennsylvania, 1875, (Harrisburg: Board of Commissioners, 1876), 55-63; Joseph D. Weeks, Report on the Manufacture of Coke, U.S. Department of the Interior, Bureau of the Census (Washington D.C.: GPO, 1884), 5; The definitive work on the manufacture of coke in the United States is John Fulton, Coke: A Treatise on the Manufacture of Coke and the Saving of By-Products. Scranton, Penn.: The Colliery Engineer Co., 1895.

Considering its many advantages, it would seem that by-product coke making should have been adopted immediately. But for one important reason, it was not. Less than fifty miles to the southeast of Pittsburgh lay the Connellsville region and the Pittsburgh coal seam, which contained immense reserves of the best coking coal in the United States, if not the world. Coal from a very well defined subdistrict of the Connellsville region, known to geologists as the Latrobe and Uniontown synclines and to iron makers and miners as the Old Basin, could be coked in beehive ovens just as it came from the mine. When mined, Old Basin coal broke up into small pieces just the right size for charging into beehive ovens. It contained no more than 7.5 to five percent ash, so low that it did not materially effect the porosity and strength of the coke. Able to produce excellent coke in ovens that could be built very cheaply and easily taken off line during economic down turns, Pittsburgh iron makers had very little inducement to explore more elaborate and costly alternatives. Compounding this inclination was the fact that little market existed for the few by-products produced at that time in by-product ovens.⁸

As Connellsville coke met each new demand placed upon it by ever larger and more productive blast furnaces, iron makers came to incorrectly equate its superior quality with the beehive ovens in which it was made. The bright silvery luster and clear metallic ring of Connellsville beehive coke became the standard by which blast furnace fuel was judged in the United States. Many iron makers became convinced that it was not possible to produce high-quality coke in a by-product oven. The few who spoke in horror of the waste of beehive ovens and the merits of recovering coal by-products, such as Doctor Bruno Terne in 1891, went largely unheeded. As the number of coal-patch company towns in the Connellsville district grew, each with its own batteries of coke ovens and housing devoted to coke oven workers, beehive coke making became a way of life, strengthening the conviction that by-product coke would never surpass its quality. To think otherwise, as one observer put it "was disloyalty to the beehive craft."⁹ By 1909 there were over 30,000 coke ovens in operation in the Connellsville district, each spewing several pounds of

⁸John Fulton, Coke, (Scranton, Pa.: The Colliery Engineer, 1895), 105.

⁹John L Gans, "An Innovation in the Coke Industry," Coal Age 14 (August 1918): 256-257.

smoke, gas and by-products into the air each day.¹⁰

Attitudes began to change during the last decade of the 19th century as the reserves of the best Connellsville coal began to dwindle, new markets for coke by-products emerged, and regions with lesser quality coal sought ways to make coke from their coal that would not coke effectively in beehive ovens.

By-product Coke Ovens

Two thermal processes were widely used to produce coke: partial combustion and distillation. Partial combustion was most effectively conducted in dome-shaped beehive coke ovens. The top inch or so of a 18" to 2' layer of coal in the beehive oven was allowed to burn to provide the heat that bakes the remaining coal into coke. As the coal was coked its volatile material burned in the top of the oven, producing vast clouds of flame and smoke that escaped, wastefully and with immense pollution, into the atmosphere. On the other hand, the distillation process was/is conducted in the air-tight coking chambers of a by-product coke oven. Since no air is present, neither the coal nor its volatile matter can burn. Heat is produced externally by burning gas traveling around the coking chamber in flues, until the coal becomes so hot that most of its gas and impurities are driven off.

The Advantages of By-product Coke Ovens

The gas driven from the coal is a valuable fuel. It can be used to heat the coke ovens, to fire boilers or for a variety of other industrial and domestic uses. But the gas is also laden with other by-products, such as tar, ammonia and light oil. To recover these, gas is drawn off the coking chambers through goose-neck pipes into a collecting main by a vacuum created by large gas pumps called exhausters. It is then pumped through a by-product recovery plant where the gas is cleaned and the by-products are

¹⁰Bruno Terne, "The Utilization of the By-Products of the Coke Industry," in Coke, by John Fulton (Scranton, Pa.: The Colliery Engineer, 1895), 186-187; A.O. Backert, The ABC of Iron and Steel, 5th ed., (Cleveland: The Penton Publishing Co., 1925), 62-63; "Coke Manufacturers of the Connellsville District," Coal and Coke Operator 4 (December 1912): 23; Guy E. Mitchell, "Waste in Coking," Colliery Engineer 34 (September 1913): 74-75.

removed.¹¹

Since the coal in a by-product oven can not expand as freely as in a beehive oven, it produces a harder coke that is both stronger and capable of more efficient combustion in a blast furnace or foundry cupola. In most cases, more than 100 pounds less by-product coke is required to produce a ton of pig iron, and the capacity of the blast furnace is materially increased. In addition, since none of the coke is allowed to burn away, a higher percentage of coke is produced per ton of coal. In 1917, for instance, the average yield of pig iron from all the beehive coke produced in the United States was 63.5 percent while the yield was 71.2 percent for by-product coke. Considering that 52,246,612 tons of coal was coked in beehive ovens at the lower percentage of yield, this means that over four million tons of coal was wasted in beehive ovens, not to mention the by-products that also went up in smoke.¹²

Perhaps the most significant factor favoring the expansion of the blast furnace industry, however, was the fact that coals from various sources could be gathered together at a large, centrally located by-product plant and mixed together to produce better coke oven charge. The Chicago district, for instance, could import Pocahontas coal from West Virginia or Connellsville coal and mix it with inferior Illinois coal to produce excellent coke. Used separately, the Illinois coal could not produce an acceptable blast furnace fuel.¹³

All these advantages had to be proven to an industry that was committed to beehive coke, and since Pittsburgh had no incentive to consider by-product coking, the impetus had to come from others who had limited or no over access to Connellsville coal.

¹¹William Hutton Blauvelt, "The Manufacture of Coke." Transactions of the American Institute of Mining and Metallurgical Engineers, (Hereafter referred to as: TAIME), 44 1912, 156-158.

¹²Clarence David King, Seventy Years of Progress in Iron and Steel (New York: The American Institute of Mining and Metallurgical Engineers, 1948), 45.

¹³F.W. Sperr Jr., "Some Characteristics of American Coals in By-product Coking," Coal Age 14 (December 12, 19, 26, 1918.): 1068-1070; For a discussion of the methods developed for producing better grades of coke by those districts possessing inferior coking coals see Jack R. Bergstresser Sr., "Raw Material Constraints and Technological Options in the Mines and Furnaces of the Birmingham District: 1876-1930," unpublished PhD. diss, Auburn University, 1993; 85-112.

Otto Hoffman and Semet-Solvay By-product Ovens

Two separate efforts to introduce by-product coking to the blast furnace industry occurred almost simultaneously in the first half of the 1890s. The first was the work of John Fulton during his tenure as General Mining Engineer with the Cambria Steel Company of Johnstown, Pennsylvania. The second was the work of the Semet-Solvay, company which built the first by-product coke works in the United States at a chemical plant at Syracuse, New York in 1892.

Fulton's work, which would eventually lead to the construction of the first by-product coke plant specifically designed to make blast furnace fuel, began in 1875. The Cambria Iron Company had recently begun to use Lake Superior ore and it was soon learned that the company's coke, made in Belgian ovens from local, or what Fulton called "native coal," would not smelt the new ore effectively. While analyzing the problem Fulton pioneered the use of physical analysis to determine the quality of metallurgical coke. Unfortunately, Fulton found the local coals available to Cambria were not on par with the best Connellsville coal.

Cambria was able to secure some limited reserves of Connellsville coal but its most viable alternative appeared to lay in developing methods of making good coke from lesser quality but more abundant local coals. In 1893, Cambria sent Fulton to Germany to determine if the company's coal could be coked in by-product ovens. Fulton's tests on about eighteen tons of coal produced a significantly higher percentage of coke than could be produced in beehive ovens. Subsequent tests showed that less by-product coke was required to produce a ton of pig iron. This savings in coke was achieved at the same time that the capacity of the blast furnace was materially increased. The company was so impressed that it built two batteries of thirty Otto-Hoffman ovens in 1894. These were the first by-product coke ovens in the United States built specifically to produce blast furnace coke.¹⁴

At about the same time, the Semet-Solvay company shipped coal made in its beehive ovens to Buffalo, New York for use in tests in competition with beehive coke from various sources. The test were conducted by Frank Baird at the Buffalo Union Furnace and showed the superiority of by-product over beehive coke. This was the first by-product coke used in a blast furnace in the United States and its success prompted the operators of the Dunbar Furnaces of the American Manganese Manufacturing Company, located

¹⁴Finney and Mitchell, "Emergence of By-Product Coking," 47-48; King, Progress in Iron and Steel, 30.

along the eastern edge of the Connellsville field, to install two batteries of twenty-five Semet-Solvay ovens each in 1895.¹⁵

Built within a year of each other, the Otto-Hoffman at Cambria and Semet-Solvay at Dunbar were the first by-product coke plants to become part of the integrated operation of blast furnace plants. Along with the United-Otto oven, which was a modification of the Otto-Hoffman design, these ovens dominated the United States by-product coke industry until the introduction of the Koppers oven. Of the sixteen by-product coke plants built at blast furnaces prior to the first Koppers plant built in 1908, nine were Semet-Solvay, four were United-Otto and three were Otto-Hoffman.

The key difference between what came to be the standard Semet-Solvay plant and its two early competitors was the arrangement of their respective heating flues. The Semet-Solvay oven was heated by flues that ran parallel to the coking chambers while the Otto-Hoffman and United-Otto ovens employed vertical heating flues. The Semet-Solvay remained the only major by-product coke oven design in the United States to employ horizontal flues; every subsequent by-product oven in the country employed one version or another of the vertical flue.

It was not their heating flue arrangements, however, that put these earlier by-product ovens at a disadvantage when the Koppers oven was introduced; instead, it was their regenerative chambers that ran longitudinally below the coking chambers along the entire length of the battery. Regeneration chambers heated the air that was used to aid the combustion of the coke-oven gas that heated the coking chambers. Based upon the Siemens principle, regenerative chambers were mazes of brick checker-work heated by the spent coke-oven gas as it exited the heating flues. The

¹⁵John Fulton, Coke: A Treatise on the Manufacture of Coke and the Saving of By-Products (Scranton, Pa.: The Colliery Engineer Co., 1895): 182; William L. Affelder, "The Semet-Solvay Coke Plant at Dunbar, Pa.," Mines and Minerals 20 (February 1900): 298; W.W. Davis W.W. "The Semet-Solvay By-Product Coke Oven," in Proceedings of the Engineer's Society of Western Pennsylvania 26 (Pittsburgh: the Engineer's Society of Western Pennsylvania, 1910) 400; J.M. Hastings, Jr., "By-Product Coke Ovens of Yesterday and Today," Blast Furnace and Steel Plant 9 (January 1921): 12; Phillip S Savage, "Production of Metallurgical Coke," Steel --- (May 2 1949): 102; King, Progress in Iron and Steel, 1948, 30; C.S. Finney and John Mitchell, "Emergence of By-Product Coking." in History of the Coking industry in the United States (New York: The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., 1961): 47-48.

remaining heat in the exiting gas was transferred to the bricks. Once the bricks reached the desired temperature, flow of spent gas was stopped and air was drawn over the bricks in the opposite direction. The heat trapped in the bricks was thus transferred to the air, which was then mixed with the coke-oven gas and ignited. There were several problems with longitudinal regenerators, but the worst was the fact that it was impossible to vary the heat on individual coking chambers.

This problem was never overcome, and ultimately the concept embodied in the Koppers cross-regenerative design proved to be the only solution. In the cross-regenerative design the regenerative chambers ran in the same direction as the coking chambers, across the width of the oven battery rather than along its length. This enabled each coking oven to be serviced by its own regenerative chamber with a subsequent increase in the ability to regulate the heat of each chamber individually.

When Heinrich Koppers built his first coke ovens at Joliet, Illinois in 1908, he was able to maintain his patent on the cross-regenerative concept for ten years. After the patent expired in 1918, however, every major by-product oven builder in the United States adopted Koppers' idea. From that point on, one of the major preoccupations of coke oven designers was in improving the cross-regenerative system and developing techniques for increasing control over the flow of air and gas used to heat the coking chambers.

The Koppers Cross-Regenerative Oven

When US Steel (USS) brought Heinrich Koppers to the United States to build his first plant at the Joliet Works of the Illinois Steel Company in 1908, it was acting upon the recommendations of a specially appointed committee. (The committee--headed by George Gorgon Crawford, later of Tennessee Coal and Iron (TCI) division of USS--produced "one of the finest and most complete reports ever presented on an engineering and general technical subject.") But the cross-regenerative concept was not the only feature that influenced the United States Steel Corporation to invite Koppers to the United States to build their first by-product coke works. Other factors included the decision by USS in 1906 to finally address the question of its future coke supply in light of the dwindling supplies of prime Old Basin coke and the inevitable decline of beehive coke production, and the decision of use

silica, rather than clay, brick in the ovens.¹⁶

The success of Kopper's patented process at the Joliet Works was immediate, achieving both economy in coke production and increased blast furnace capacity and efficiency, making beehive coke production obsolete. USS immediately began to install Koppers plants in regions where their operations relied on lesser coals. In 1911, at the same time that the corporation built the largest coke plant in the world, consisting of 560 Koppers ovens at Gary, Indiana, it also built 280 ovens at TCI's Fairfield Works. As manager of TCI, Crawford not only presided over the construction of the Koppers plant but also articulated its advantages to other local iron makers such as the Woodward Iron company, which immediately installed a smaller Koppers Plant. Thus two of the first four U.S. Koppers plants were built in the Birmingham district. One was at TCI where the second or third Semet-Solvay plant installed at a blast furnace in the United States was placed on line in the fall of 1898. Clearly, the Birmingham district was playing a prominent role in the shift to by-product coke, laying the groundwork for the Koppers-Becker ovens that would be built at Thomas fourteen years later.¹⁷

The decision to use silica brick in place of the clay brick used in European by-product ovens also contributed to the success of the by-product coke works. Cambria had used silica brick as early as 1890s, but the less effective heating system of the Otto-

¹⁶ In an article written in 1918, C.J. Ramsburg and F.W. Sperr of the H Koppers Company reflected upon the phenomenal increase in U.S. coke production precipitated by the War and a series of "high spots" that had occurred within the industry since the introduction of the Koppers patent; these are among them. Ramsburg and Sperr, perhaps without realizing it, alluded to the premunity role that the Birmingham district would play in adopting modern by-product coke making when they pointed out that USS appointed a committee to study the issue, headed by George Gorgon Crawford who moved to Birmingham the next year to serve as manager of the Tennessee Coal and Iron division of USS.

¹⁷C.J. Ramsburg, C.J. and F.W. Speer, Jr., "By-Product Coke and Coking Operations," Coal Age 13 (April, 27; May 4, 11 1918): 773; H.S. Geismer and David Hancock, "Beehive and Byproduct Coke in Alabama," Coal Age 3 (June 7 1913): 879-880; F.W. Miller, "Alabama has Made Great Progress in Coking Coal," Coal Age 26 (October 9 1924): 506; William Hutton Blauvelt, "A Description of the Semet-Solvay By-Product Coke-Oven Plant at Ensley, Alabama," TAIME 28 1889, 578-591; Marjorie Longenecker White, The Birmingham District (Birmingham, Alabama: the Birmingham Historical Society, 1981): 93-94.

Hoffman ovens had prevented development to the full advantage. In tandem with the more uniform heating system of the cross-regenerative vertical-flued Koppers oven, the better insulating silica brick brought about dramatic improvements in coke production. These two innovations made it possible for coke makers to maintain much higher heat and consequently much greater coking velocities. Not only was the yield of individual ovens greatly increased but the coking time per oven was cut almost in half.

In 1922, Joseph Becker wrote about the role silica brick played in enabling United States Coke makers to development what was, in effect, the by-product coke making equivalent of hard-driving blast furnace practice. Becker, who worked for Koppers and had recently introduced the Koppers-Becker oven, had traveled abroad to observe European coke practice. Becker was amazed to see that, after inventing the technology that the U.S. had borrowed, Europeans had lagged in further development. He noted that European ovens were smaller than United States ovens and required from thirty to thirty-three hours coking time compared to fifteen to seventeen hours in the U.S. Moreover, the U.S. had developed a core of trained professionals who used systematic methods to establish such practices as oven pushing schedules, the Europeans were still using rule-of-thumb methods employed by less trained workers. The U.S. had clearly taken the lead in modern by-product coking with the Koppers-Becker oven, which was patented only four years before it was installed in a battery of ovens at Republic's Thomas Furnaces.

The Koppers-Becker versus the Early Koppers Oven

The importance of the Koppers-Becker oven is indicated by a rather curious assertion made by C.J. Ramsburg and F.W. Sperr of the H. Koppers Company. They claimed that there was an optimum limit to the cubical capacity of by-product coking chambers. They attributed this limit to the fact that mechanical and structural factors imposed constraints on the height and length of the coking chamber while heating characteristics placed a limit on its maximum width. What they did not say, or perhaps realize at the time, was that the ovens of greater height would be possible with the Koppers-Becker design. This design improved the structural strength of the coke ovens making it possible to build a higher coking chamber while simultaneously providing for more uniform heating over the larger surface.

The principle limitation of the Koppers oven was its horizontal flue located at the mid-point of the vertical flues on either side of the coking chambers. This horizontal flue was an essential design feature of the single-divided Koppers oven, and

is best understood when the movement of the air and gas through the flues is described. The key difference between the major by-product coke oven designs was their heating systems. The heat to support the coking process was provided by burning gas and preheated air that was channeled through flues surrounding the coke chambers. Each major design routed the burning gas and air differently.

Heinrich Kopper's design employed a set of thirty vertical flues on each side of the coking chamber. A single dividing wall near the mid section, separated the vertical flues into two groups of sixteen and fourteen flues. The burning gas and air passed up through one group of vertical flues, over the dividing wall via a horizontal flue, and down through the other group of flues. The direction of flow was reversed every twenty or thirty minutes.

To achieve a temperature of 2,600 to 2,700 degrees at the base of the flues, it was necessary to preheat the air before it was mixed with the gas by pulling it through a maze of brick checkerwork located below the coke chambers. Separate sets of checkerwork (called regenerative chambers) were located under each group of fourteen and sixteen vertical flues. Spent gas moving down and out the vertical flues passed over the bricks, imparted its residual heat and was carried away via an underground flue to a large exhaust stack. When the flow was reversed, outside air was pulled in over the hot bricks and up to the base of the flues where it was mixed with gas and ignited by the residual heat of the flues.

The Koppers-Becker oven dispensed with the dividing wall. In order to heat one entire wall of the coking chamber at the same time, air and gas were injected into the bottom of every vertical flue on one side of the coking chamber. Combustion occurred on this side of the chamber. The spent gas was routed over the top of the chamber, via crossover flues, into a corresponding vertical flue on the other side of the coking chamber where it traveled down and out through exhaust flues.

This new design initiated a trend toward higher, longer ovens. The dimensions of the Koppers-Becker ovens installed at the Clairton Works in 1924 alongside an original battery of Koppers ovens built in 1918 gives an impression of the initial increase in capacity in the new design. The volume of the Koppers oven was 500 cubic feet. Each oven inside had a length of 37' from door to door at center, a height of 9'-10" from floor to roof and a width that tapered from 17" at the pusher end to 19-1/2" at the discharge end. The Koppers-Becker ovens were more narrow: 16" wide on the pusher end and 18" wide on the discharge end. To accommodate a larger coking volume of 612 cubic feet the coking chamber was 11'-8-1/2" high x 42'-9" long.

Almost immediately however, it was realized that the new design would accommodate much greater height and a corresponding increase in volume. It was at this point that the coke ovens at Thomas were built. After the first step toward a major increase in height, the Columbia Steel Company of Provo, Utah built a battery of 13' high ovens in 1924, Republic installed 13'-6" ovens at Thomas. This trend toward higher ovens climaxed when USS built four batteries of ovens at Clairton in 1928 that were 14' high.

Coke Oven By-products

The by-product recovery plant installed at Thomas was typical of the pattern among U.S. plants following World War I. The feature that distinguished it from other plants of this period was newly developed benzol recovery systems that had not been common before the war. Military demands for light oil derivatives consisting of benzene, toluene, and zylene led to the installation of systems that could remove the light oil from the coke-oven gas and distill it into these homologues. The most crucial of these for war time needs were toluol (toluene) and benzol (benzene) that was used to make trinitrotoluene or TNT. At the end of the war demand for toluene dropped but the value of benzene, which was also called benzol, rose dramatically when it was proven to be a better motor fuel than gasoline. The importance of benzol for this purpose became so great that the system of washers, stills, rectifiers and other equipment used in its recovery came to be called the "benzol plant" at most coke works, despite the fact that several other by-products were also recovered there.¹⁸

The addition of benzol plants marked the last major component added to the standard American coke by-product recovery operation. Some plants located where market conditions were favorable would later install systems that could recover pyradine, phenol, and some other minor products. Some larger plants would install facilities that could further process tar into secondary by-products. But by the time the Thomas Coke works went on line the standard list of by-products produced at U.S. by-product plants was set. They consisted of the coke-oven gas itself (the most valuable), tar, ammonia (made into ammonium sulphate on site), light oil (distilled into benzene), toluene,

¹⁸F.W.Sperr, Jr., "Some Characteristics of American Coals in By-product Coking," Coal Age 14 (December 12, 19, 26 1918): 1068-1070; William Hutten Blauvelt, "By-Products Recovered in the Manufacture of Coke," Yearbook of the American Iron and Steel Institute, 1916, by the American Iron and Steel Institute (New York: American Iron and Steel Institute, 1919): 65-72.

zylene and naphthalene.

The Value and Uses of By-products

If the entire era of by-product coke making is considered, the relative value of by-products as well as their uses have varied greatly. Obviously the most valuable product of a coke plant is the coke itself. The most valuable by-product today is the coke-oven gas. Gas rose to this position shortly after World War I. Originally, ammonium sulphate had been more valuable because the dramatic rise in demand for explosives during the war allowed light oil to assume the lead temporarily. Immediately following the war, gas assumed the leadership which it never lost. Light oil fell no lower than second, however, because once its value for explosives production declined it became nearly as important as a source of benzol for motor fuel. Tar came in third while ammonium sulphate continued as an important by-product even though it never regained its former dominance.

Tar

Tar, the organic matter produced in coking, is condensed out of the coke-oven gas. In the 1950s, usually one net ton of coking coal yielded from eight to twelve gallons of tar. Tar was first used to produce creosote oil, roofing tar, tar paper and other roofing products. This market was inherited by the first by-product plants from the city gas ovens that first produced such products as early as the mid-1850s. Demand expanded on similar lines to include tar used in road building.

Not long after the introduction of by-product ovens, however, tar was recognized as a valuable fuel for steel mill open hearth and heating furnaces or to fire steam boilers. Initially, the percentage of tar used as fuel rose significantly, but it soon declined as the list of chemical products that could be distilled from tar increased. At the beginning of World War II, forty percent of the tar produced at by-product plants was used as fuel. By the end of the war, this percentage had dropped to twenty-five.¹⁹

Coal-tar dyes were the first important chemicals to be recovered. Germany dominated production until the beginning of World War I, retarding the expansion of domestic coal-tar dye production. When

¹⁹William Hutton Blauvelt, "The Byproduct Coke Oven and its Products," TAIME 55, 1919, 448; Wilson and Wells, "Coal Chemical Industry," 110;

the war closed off German imports, U.S. production soared as new by-product plants were built in unprecedented numbers. The tremendous increase in tar production encouraged the growth of the tar distilling industry. Several by-product plants built their own tar distilling operations at the same time that numerous independent tar distilleries were built. Distillers gradually increased the variety of chemical products until most of the tar produced was devoted to chemical production. Perhaps of greatest influence to this trend, was the increase in the production of plastic which could be made in part from coal tar.²⁰

Ammonium Sulphate

Ammonium sulphate is not a direct product of the coking process; instead, ammonia is first used in solution with water as a condensing liquid (known as ammonia liquor) then as a raw material for making ammonium sulphate. Anywhere from twenty to twenty-eight pounds of ammonium sulphate can be recovered from a ton of coal. The chemical symbol for ammonium sulphate, NH_3 , reveals its importance. The nitrogen which it contains is used for fertilizer: with the exception of limited instances, where it was sold to chemical producers who used it as a source of nitrogen, ammonium sulphate was sold almost exclusively as fertilizer. In the late nineteenth and early-twentieth centuries it served as a substitute for the more expensive fertilizers obtained from natural sources such as bat guano and manure. Later, however, its importance declined as petroleum-derived fertilizers became more plentiful. Even though the selling price declined relative to other by-products ammonium sulphate remained a reliable revenue producer for most coke plants.

Light Oil and its Derivatives

Anywhere from two-and-one-half to four gallons of light oil is produced from every ton of coal. Light oil can be distilled to produce a series of homologues including benzol, toluol and zylene. In the early days of by-product coke making in the U.S., no attempt was made to recover light oil. Benzol and toluol

²⁰William Hamilin Childs, "By-products Recovered in the Manufacture of Coke," Yearbook of the American Iron and Steel Institute, 1916, the American Iron and Steel Institute. New York: American Iron and Steel Institute, 1917, 23-64; G.P. Wilson, and J.R. Wells, "Coal Chemical Industry," Chemical Engineering, (December 1946), 110-114.

slowly came into demand around the turn-of-the century for making paints and varnishes, paint and varnish removers and similar products, and Semet-Solvay erected the first light oil recovery system at a by-product plant in 1900.

By far the greatest impetus for light oil production was created by the military demands of World War I. Not only could toluol, benzol and zylene be used in explosives manufacturing but benzol could be used as a substitute for gasoline. The same fuel value could be obtained from 100 gallons of benzol as could be obtained from 115 gallons of gasoline. Many U.S. military trucks were equipped to burn benzol rather than gasoline, providing a tremendous cumulative savings in volume for the allied transportation network that was strained to capacity.²¹

At wars end, demand for explosives dropped dramatically but the advantages of benzene both as a motor fuel and as an "anti-knock" combined to keep it in high demand for the next two decades. In 1939 for example, 46.6 percent of the light oil produced at coke plants was converted into motor benzol. World War II demands for benzol reduced the proportion as motor fuel to about seven percent. Motor benzol never recovered because several more lucrative uses for chemical benzol were developed: demand for chemical benzol for making nylon, synthetic rubber, styrene and other products increased more than four times between 1939 and 1948 from forty to 160 million gallons. Motor benzol soon disappeared from the market, only a few years before chemical benzol was replaced, like toluol, by petroleum derived substitutes.²²

²¹"Light Oil Recovery," Gas Age 40 (15 November 1918): 443-444; E.B. Rosa, "The Relation of the Gas Industry to Military Needs," Gas Age 40 (15 November 1918): 447-448; Sperr, "Coal in By-product Coking," 1070; A.C. Fieldner, and G.W. Jones, "Benzol as a Motor Fuel," Chemical and Metallurgical Engineering 29 (September 1923): 543.

²²Wilson and Wells, "Coal Chemical Industry," 112; United States, Department of Interior, Co-products of Coke in the United States, 1919-1947, by J.A. DeCarlo and J.A. Corgan, Bureau of Mines, Information Circular 7504 (Washington, D.C.: GPO, 1949): 13; United States, Department of Interior, The Possible Effects of the Expanding Use of Natural Gas on the Production of Coke and Coal Chemicals in the United States, by J.A. DeCarlo and J.A. Corgan, Bureau of Mines, Information Circular 7579 (Washington, D.C.: GPO, 1950): 17-18; Savage, "Production of Metallurgical Coke," 103 .

Coke-oven Gas

From 9,500 to 11,500 cubic feet of coke-oven gas is produced from a ton of coal. Coke-oven gas is not only produced in greater volume than any other by-product, but it is also the most valuable.

The uses for coke-oven gas changed over time. In the earliest by-product ovens it was only used to heat the coking chambers, but the by-product recovery process was so inefficient that the gas had to be supplemented by solid fuel to produce enough heat. As the recovery process became more efficient the surplus gas was used to fire steam boilers. There was so little demand for gas for other uses that excessive amounts were wasted. Coke-oven gas was next used extensively for heating purposes in steel mills. The first application was to fire heating furnaces, but by 1919 it had also been adapted to open-hearth steel furnaces. The United States Steel Corporation's Clairton coke works for instance, piped coke-oven gas several miles to the Duquesne, Edgar Thompson and Homestead steel mills.

Coke-oven gas also had been used from its earliest days in the United States as city gas. This increased significantly after 1918 and the release in the United States of the Koppers patent for cross regenerative heating systems. Cross regenerative heating systems were much more efficient, producing a greater surplus of gas which could be sold on the lucrative city gas market. By 1919, forty major cities received all or a major portion of their city gas from by-product coke plants. The returns were so good that several steel plants began using the less valuable blast furnace gas to heat their coke ovens so that most of the coke-oven gas could be sold on the open market. The removal of light oil from coke-oven gas removed some of its heat value, so small amounts of tar were reintroduced into the clean gas to increase its luminosity and heating power. By the 1940s, the introduction of long distance natural gas pipelines of over 1000 miles greatly diminished demand for by-product gas. From a high of around forty-seven percent in 1934, the amount of coke-oven gas sold as city gas dropped to less than twenty-eight percent by 1947.

By-product Coke Making in the Birmingham District

Unlike Pittsburgh, iron makers of the Birmingham district were very much predisposed to accept the new technology of by-product coke ovens when the opportunity presented itself. The reason was not an inherent infatuation with innovative technology but the fact that by-product ovens offered several advantages that could partially offset, if not completely overcome, specific limitations of local coal reserves. The first of these

limitations was the narrow, heavily faulted nature of the Pratt seam, the Warrior coal field's most important metallurgical coal seam. The Pratt seam was narrow, riddled with faults, and banded with layers of impurities, making coal mining less productive. The mines of the Pratt seam were smaller than optimum size and they produced fewer tons per miner than the national average.²³

Mining engineers had worked diligently to overcome lower mining productivity and the subsequently higher cost of fuel at the blast furnace, but the by-product coke oven possessed several advantages that greatly reduced the amount of coal that had to be mined to produce a ton of pig iron. First, by-product ovens were much more productive. Their yield of coke per ton of coal was five to ten percent higher, a significant increase in a high volume operation like a coke plant. In Alabama in 1925 for instance, beehive ovens yielded 64.4 percent coal as coke while by-product ovens yielded 70.3 percent. Secondly, less by-product coke was required in the blast furnace to produce a ton of pig iron. And finally the by-product coke increased the capacity of a blast furnace.²⁴

A second limitation of local coal that could be overcome with by-product coking was its softness or "tenderness." While most of the district's coal produced a suitable metallurgical coke once it had been washed, much of it did not. Soft coal had a greater tendency to crumble and break down into very fine pieces, called breeze, during handling and loading into a furnace. By-product ovens produced stronger, less friable, coke.

The central location of by-product ovens made it possible to bring together and mix different sources of coal and before coking to produce a better product. This was a bonus for Birmingham iron makers, and they expanded their mining operations to bring in coal that would not coke as effectively unless it was mixed with other coal.

These advantages, along with the ability to capture and process valuable by-products, provided economic incentive to install a

²³This discussion of the ways that the inherent limitations of local coal encouraged the adoption of by-product coking in the is based upon Jack R. Bergstresser, "Raw Material Constraints and Technological Options in the Blast Furnaces and Mines of the Birmingham District, 1876-1928" (Ph.D. diss., [in progress], Auburn University);

²⁴Alabama, Statistics of the Mineral Production of Alabama for 1925. Walter B. Jones, Alabama Geological Survey, (Birmingham, Ala.: Birmingham Printing Co., 1928), 114.

by-product plant. While the cost of installing a by-product plant was much greater than beehive ovens, the expense was worth it because of the significant reduction in fuel costs for a blast furnace company. The Birmingham district was willing to accept the equation and began the conversion to by-product coking in 1898 when TCI built 120 Semet-Solvay ovens and a well-equipped by-product recovery plant.

The conversion was completed in 1925 with the construction of Republic's Koppers-Becker ovens at Thomas. The Thomas works was the eighth by-product plant built in the district. These eight plants consisted of 796 Koppers and Koppers-Becker ovens, 420 Semet-Solvay ovens and sixty Wilputte ovens, for a total of 1,276 ovens. Their combined production was 4,583,153 tons of coke, a little over eleven percent of the national total of 39,912,159 tons. Alabama became the fourth largest producer of by-product coke in the U.S., a position which it retained until the present. It enjoyed a rate of growth that was generally equal to the national average.²⁵

Not only was the conversion to by-product coking more complete than in most districts, but it also led to better coke yields than most districts could obtain. In 1925 for instance, after Republic brought the Thomas ovens on line and closed its 910 beehive ovens, the percentage of coke made in beehive ovens in the district dropped to only 1.9 percent while the national average remained at about 22 percent. At the same time, the yield of coke rose slightly above the average for the first time, amounting to 70.3 percent compared to the national average of 69.9 percent. Prior to the firing of the Thomas ovens, Alabama had always lagged behind the national average, perhaps because of its disproportionately large share of Semet-Solvay ovens that usually gave a smaller yield than Koppers ovens. From that time on, Alabama never failed to exceed the national average yield.²⁶ With the exception of a limited amount made at Lewisburg and perhaps a few other ovens during World War II, no more beehive

²⁵Alabama, Statistics of the Mineral Production of Alabama for 1925, Walter B. Jones, Alabama Geological Survey, (Birmingham, Ala.: Birmingham Printing Co., 1928): 110-113; Mable D. Mills, The Coke Industry in Alabama, (University, Ala.: Bureau of Business Research, 1947): 14-20.

²⁶For a comprehensive statistical discussion of coke manufacturing in the Birmingham District, including its relative role in national production see Mable D. Mills, Coke Industry in Alabama (University Alabama: Bureau of Business Research, 1947), *passim*.

coke was made in the district after that year.²⁷

Semet-Solvay in the Birmingham District

In the fall of 1898 TCI began the operation of 120 Semet-Solvay ovens arranged in two parallel blocks of sixty ovens each and capable of producing from 420 to 460 tons of coke per day. Built at the same time as a battery of sixty Semet-Solvay ovens at the National Tube Company of Wheeling, West Virginia, the two plants were simultaneously the second batteries of Semet-Solvay ovens installed at blast furnaces in the United States. The Ensley plant was the largest by-product coke plant in the country, and the Semet-Solvay quickly lived up to the anticipated advantages over the beehives of the district. These 120 ovens could produce the same amount of coke as between 300 and 340 beehive ovens, with fifteen percent less labor. At the same time, the by-product ovens produced from one-sixth to one-fifth more coke per ton of Pratt coke.

Another advantage of the Ensley coke plant was the by-products that it produced. A tar distilling plant adjacent to the coke ovens made roofing pitch, tar paper and creosoting oils from the tar produced in the coking process. Recovered ammonia was converted into ammonium sulphate, a valuable substitute for natural fertilizer. All these products found a ready market in the district, particularly the fertilizer that was in great demand in the predominantly agricultural state.

The success of the by-product coke plant so impressed TCI that the company added four additional batteries in 1902. The operating record of the Ensley plant and ovens, built at Holt in 1906, did a great deal to enhance the reputation of Semet-Solvay process. An article written in 1921 by W.L. Graul, manager of the Holt plant, clearly established the remarkable durability of the design, attributable primarily to the heavy wall that separated the horizontal flues and coking chambers of the individual ovens.²⁸

²⁷American Iron and Steel Institute, Directory of the Iron and Steel Works of the United States and Canada, 1945, (New York: American Iron and Steel Institute, 1945), 365.

²⁸It is interesting to note that while W.L. Graul was praising the fact that the Semet-Solvay by-product ovens had established a commendable longevity in 1921 after fifteen years of operation he probably had no notion that the ovens would eventually establish a United States if not the world record for time in service by continuing to produce coke to this present day. W.L. Graul, "By-Product Yield From Fifteen-Year-Old Coke Plant," Blast Furnace and

Their admirable operating record so impressed the Sloss Furnace Company that, when shifting to by-product ovens in 1920, it chose to build Semet-Solvay ovens. The coking chambers in the twin batteries of sixty ovens each measured 11' high x 36' long, making them the largest ovens in the state at that time. The Sloss by-product plant was a new departure in the district because it supplied surplus coke-oven gas to the city of Birmingham. This new source of gas, expected to reach 7,000,000 cubic feet per day, would reduce the cost of gas to consumers in the city by eight cents per thousand feet. This savings reduced the net rate cost of gas in the city to 80 cents per thousand, among the lowest rates in the country.²⁹

Sloss was able to supply such a large amount of surplus gas from its by-product ovens because their new cross-regenerative heating system greatly reduced the amount of gas required to heat the coking chambers. The new heating system, developed by Semet-Solvay after the expiration of the U.S. patent on the cross-regenerative process and introduced into the United States in 1908 by Heinrich Koppers, expired in 1918.

Koppers Ovens in the Birmingham District

Like Semet-Solvay oven when it was first introduced, the Birmingham district was quick to adopt the Koppers oven after its introduction into the United States at Joliet in 1908. Three years after the Joliet plant was built, the Woodward Iron Company and TCI both installed Koppers ovens, (the same time as the Gary Works of US).³⁰

The Birmingham district gained a reputation for being very receptive to the latest by-product coking technology, a reputation continued when Republic installed the Koppers-Beckers ovens at Thomas. Since its introduction three years earlier, the Koppers-Becker oven had proven itself capable of supporting taller coking chambers than previously had been possible. Beginning with a battery of 13' tall coking chambers built at Provo, Utah, Koppers experimented to determine how high coking chambers could go before reaching an optimum height. The Provo

Steel Plant 9 (May 1921): 313-314.

²⁹J.M., Hastings Jr. "By-Product Coke Ovens of Yesterday and Today, "Blast Furnace and Steel Plant 9 (January 1921): 10-13; J.M. Hastings Jr. "Modern Coke Plant at Birmingham," Gas Age 44 (December 1920): 461-464.

³⁰King, "Progress in Iron and Steel," 32.

ovens were 13' high compared with pervious ovens that averaged around 11'; the Thomas ovens were 13-1/2' tall. The highest ovens, built at Clairton the following year, were 14' tall. After that, Koppers withdrew slightly back to about 12' which still allowed a substantial increase in capacity over previous designs.³¹

Republic Steel's Thomas Blast Furnaces and Coke Works

The Republic Steel Corporation's Thomas By-product Coke Works was located at the rear of the company's blast furnace plant at Thomas, a company-built town later incorporated into the city of Birmingham, Alabama. The company town and original blast furnace plant were built in 1888 by Samuel Thomas, son of David Thomas, who first introduced anthracite blast furnaces into the United States. Based on the plan for Hokendauqua, Pennsylvania, the community at Thomas featured brick houses, schools, churches and other facilities. Most of the community is still in existence.

The Thomas family, which owned one of the most successful foundry pig iron companies in Pennsylvania, built the Pioneer furnaces between the years 1888 and 1890. Each furnace was 75' high and 17' wide at the bosh. Hot blast was provided by eight Siemens-Cowper-Cochrane fire-brick stoves. Operating as the Pioneer Mining and Manufacturing Company, the company specialized in foundry pig iron sold under the brand name "Pioneer."³²

The Pioneer furnaces were purchased by the Republic Iron and Steel Company in October, 1899 and eventually came to be called the Thomas furnaces. Republic modernized the plant in 1902 by adding a third furnace that was 90' x 18-1/2' and enlarging the old furnaces to the same dimensions. The combined annual capacity of the plant was 270,000 tons of foundry and mill pig iron.

Republic updated the plant on a regular basis. To provide basic pig iron to its steel mill at Gadsden, the company installed one of the District's first Uehling pig casting machines sometime before 1906. They also installed the District's first Dwight-Lloyd sintering plant on a site adjacent to the blast furnace

³¹Geismer and Hancock, "Beehive and Byproduct Coke," 879; Miller, "Alabama Progress in Coking," 507; King, "Progress in Iron and Steel," 37.

³²Woodward Iron Company, Alabama Blast Furnaces, (Woodward, Ala.: Woodward Iron Company, 194.): 155-158.

stock bins, in 1936.³³

Like other major blast furnace companies in the Birmingham District, the Pioneer Mining and Manufacturing Company took advantage of the close proximity of raw materials in the Birmingham District. The furnaces were built atop extensive seams of limestone and dolomite. These materials, which were used as fluxing agents, could be quarried and loaded directly into the furnaces at minimum cost. The deposits are so extensive that they are still being mined by The Wade Sand and Gravel Company which operates one of the largest and deepest quarries in the eastern United States.

Ore was procured either from open-pit brown ore mines located about fifteen miles southwest or from underground red ore mines on and near Red Mountain, about eight miles to the south. Red ore came from Shannon mine, a steep slope mine in Shades Valley, and the Spaulding and Raimund mines located along the northeastern slopes of Red Mountain.

The majority of the coal coked at the Thomas ovens came from Republic's Sayerton mine, only two miles from the coke plant. Additional local coal was supplied by the Risco and Warner, Virginia and Republic mines, none of which were over 20 miles from the coke plant.³⁴

Until 1925 the coke that fueled the Thomas Blast furnaces was made exclusively in beehive ovens. Most of this coke came either from a battery of 100 beehive ovens at the Republic mine or 910 ovens located behind the blast furnace plant.

The By-product Coke Works

The coke works were built in 1925 and modernized in 1952. The original plant featured a battery of fifty-seven Koppers-Becker by-product ovens that were replaced in 1952 by a battery of sixty-five Koppers ovens. The plant layout and equipment were based on designs developed by German-born Heinrich Koppers. In addition to many pieces of equipment that were designed and built by the Koppers company, the plant also contained several standard features designed and built by outside suppliers. The original

³³M.F. Morgan, "Sintering Plant Improves Blast Furnace Practice," Steel, 100 (8 February 1937): 60-61; F.R. Crockard "Five Years of Progress in Southern Blast Furnace Practice," TAIME, 1936 Vol. 124, 36-45.

³⁴Woodward Iron Company, Alabama Blast Furnaces, 157.

ovens had a capacity of 623 cubic-feet each. Each coking chamber was 42'-2-1/2" long x 13'-1/2" tall and tapered from 13" on the pusher side to 15" on the coke side. The 1952 battery consisted of gun-flue type Koppers ovens. The coking chambers were 40'-9-1/2" long x 12'-8" high and the average width when hot was 16-5/8". The capacity of each chamber was 657.88 cubic-feet.

When the plant was modernized in 1952, the original battery was torn down, but the loading hopper and other coal handling facilities were left in place. One end of the replacement battery was under the coal loading bins and extended to the west of the original battery. The foundation of the old battery and building which housed the air and gas reversing engine was left standing. The old quenching tower was also preserved. Once in operation the new battery was serviced by the original coal handling system and quenching tower.³⁵

The original by-product recovery plant was also selectively modernized. All of the important original buildings were retained, but their interiors were significantly altered by the removal of old equipment and the addition of new equipment. The two original Connersville exhausters, which pulled gas of the coke ovens and pumped it through the by-product recovery systems, were retained along with their horizontal steam engines, but were augmented by the addition of a steam turbine-driven exhauster. At some point prior to the 1952 modernization, an additional Ingersol-Rand gas pump (booster) and horizontal steam engine were added at the western end of the building to supply coke-oven gas to an adjacent city gas main and subsequent interstate natural gas line. Other changes were made in the eastern end of the building. Originally that part of the building had contained some of the preliminary processing equipment for the light oil recovery system alongside the ammonia stills and ammonium sulphate processing and storage facilities. During modernization,

³⁵Most of the information contained in the following discussion of the plant alterations and materials flow is based upon the extensive set of engineering drawings which are still stored at the in the old headquarters building. Other information was obtained through a series of informal conversation with Tim Tankersley, Vice President of the Wade Sand and Gravel Company which owns the site. When information was obtained from other sources, they are cited. Records of plant operation are limited to a short run of interoffice correspondence from the mid 1930s and a collection of mixed records from the last few years of the plant's operation. In sum, these plant records which are located at The Archives of the Birmingham Public Library, at the W.S. Hoole Special Collections of the University of Alabama Library and at the Thomas site provide very little information on day to day operation.

the light oil recovery equipment was all removed to the benzol plant at the west end of the by-product building. Equipment in the brick building at the benzol plant was also altered but to a lesser extent. The main alteration consisted of removing the pure still tank from directly under the rectifying column and replacing it with a larger tank located outside the building.

Three major pieces of equipment were removed and replaced by more modern equivalents. The old flushing liquor tank was replaced along with most of its ancillary equipment; the original Pelouze and Audouin tar extractor was replaced with an electrostatic precipitator; and the old acid saturators were replaced by a newly designed spray-type ammonia absorber. To accommodate both major and minor alterations, considerable changes were made in the piping that carried ammonia liquor, tar, water, steam and coke-oven gas. While substantial, these alterations did not significantly alter the general appearance of the plant. The major buildings remained unchanged and the general material flow was unaltered. The line of by-products remained the same, consisting of tar, ammonium sulphate, light oil (which was further refined into benzol, toluol and xylene), and naphthalene (which was recovered at both the final cooler and in the benzol plant).

Koppers-Becker versus Kopper Ovens

The key difference between the original Koppers-Becker ovens and the later Koppers ovens were the heating systems. The heat to support the coking process was provided by burning gas and preheated air that was channeled through flues surrounding the coke chambers. Each major design routed the burning gas and air differently. The Kopper oven employed a set of thirty vertical flues on each side of the coking chamber. A dividing wall near the middle separated the vertical flues into two groups of sixteen and fourteen flues. The burning gas and air passed up through one group of vertical flues, over the dividing wall via a horizontal flue and down through the other group of flues. The direction of flow was reversed every twenty or thirty minutes.³⁶

To achieve a temperature of 2,600 to 2,700 degrees at the base of the flues it was necessary to preheat the air before it was mixed with the gas by pulling it through a maze of brick checker-work located below the coke chambers. Separate sets of checker-work

³⁶The following description of the Koppers and Koppers-Beckers ovens is based primarily on Joseph Becker, "Modern By-product Coking," 875-881, and J.M. Camp, The Making, Shaping and Treating of Steel. 4th ed. Pittsburgh: Carnegie Steel Company, 1925.

(called regenerative chambers) were located under each group of fourteen and sixteen vertical flues. Spent gas moving down and out the vertical flues passed over the bricks, imparted its residual heat and was carried away via an underground flue to a large exhaust stack. When the flow was reversed, outside air was pulled in over the hot bricks and up to the base of the flues where it was mixed with gas and ignited by the residual heat of the flues.

In 1921 while working for the Koppers Company, Joseph Becker increased the capacity of the Koppers oven by adding a new heating system featuring crossover flues. In Beckers design, gas was burned on one entire side of the coking chamber rather than on one-half as in the Koppers oven. The spent gas then flowed over the top of the coking chamber and down along the entire opposite wall. The entire process was reversed at thirty minute intervals.

Reversing the flow of air and gas was accomplished in both the Koppers and Koppers-Becker ovens by a reversing engine located in a room at one end of the battery below the coal hopper. The reversing engine was monitored by the heater man who watched a series of gauges that recorded air flow and temperatures in the ovens. The reversing engine was controlled by a mechanical timer that automatically reversed the flow of air and gas at predetermined twenty or thirty minute intervals. Arms mounted to the engine pulled a set of pulley mounted wire ropes and rods connected to individual air and gas levers on each side of every oven.

Plant Operation

The best way to discuss the structures and equipment at the Thomas coke works is by describing the flow of material on the site. The Thomas Coke Works was actually two plants: a coke plant and a by-product plant. Since the principal function of the coke works was to provide coke for fuel in the adjacent blast furnaces, the coke plant was the most important part of the site.

The coke plant was made up of a coal handling system, the coke ovens themselves, and a gas collecting main. The coal handling system transferred coal from incoming railroad cars into large storage bins directly atop one end of the coke ovens where the coal could be loaded into the ovens as needed. The coke handling system took coke from the ovens and either moved it by conveyors to the blast furnace stock bins or loaded it onto railroad cars for shipment to other Republic Steel Corporation blast furnaces and to outside customers. The gas collecting main pulled gas from the individual coke ovens, via goose-neck pipes, and sent it to

the by-product plant.

The purpose of the by-product plant was two-fold. Primarily it was intended to clean the coke-oven gas, the most valuable by-product produced. Secondly, it was intended to remove as many other marketable by-products from the coke-oven gas as economically feasible, routing the gas via a gas pipe line, past a series of sub-systems, each of which each processed the gas in a specific way.

In the absence of adequate documentation, it is difficult to establish the exact number of workers required to operate the 1952 coke works. A brief report written in 1937 listing the crew required for the old plant provides some clue, however, because the labor force for both operations would have been roughly equivalent. The 1937 report set forth a list of workers needed if the plant were to operate on a 108-oven or a sixty-six-oven schedule. These numbers referred to the number of times that the fifty-seven ovens would be pushed in a twenty-four hour period.³⁷

Such pushing schedules were a legacy of the systematic control of coking operations that became a hallmark of American coking practice after the introduction of the Koppers oven into the United States by US Steel. These schedules were based upon precise calculations and stood in stark contrast to the old European rule-of-thumb method. They were based upon the fact that every feature of the coke ovens and by-product recovery plant was affected by the pushing of an individual oven. The 108-oven schedule required a crew of seventy-six workers while the sixty-six-oven schedule required a crew of fifty.

The Flow of Coal and Coke

Coal from a variety of sources, but principally from Republic's Sayreton mine, was received at the coke plant in bottom-dump rail cars. It was dumped onto a conveyor that could either send the coal directly to the coke ovens or send it through a Bradford breaker that served the dual function of reducing the size of the coal while partially cleaning it. Out of the Bradford breaker the coal was transferred by conveyor belts to the top of a large coal hopper where it was loaded into bins to await charging into the coke ovens.

Coal ready to be charged into the ovens was discharged via chutes into a track-mounted larry car that traveled across the top of the coke battery. The larry car had four round bins that

³⁷"Operation of the Thomas Ovens on a sixty-six-oven schedule," Report in the Possession of Wade Sand and Gravel Company, Birmingham, Alabama.

corresponded to four openings in the top of each coking chamber. To load coal into an oven the larry car stopped directly atop the four charging holes and lower guides onto each opening. In addition to maneuvering the coal into the charging holes, the guides also prevented the escape of excess gas from the ovens. They were equipped with return pipes that routed the escaping gas back into the ovens.

Pushing the coke from a coking chamber was accomplished by the combined effort of a coke pusher on one side of the battery and a coke guide and track-mounted quenching car on the other. The coking chamber had a door on both sides of the battery and it was essential that the correct doors on either side be opened. On the Thomas ovens this was assured by a small radioactive charge mounted in the coke guide that was monitored by a device located in the pusher. If the pusher-mounted device did not register a signal from the radioactive charge it was an indication that the wrong door had been opened.

Once the doors were removed the coke pusher pushed a large ram through the coking chamber forcing the coke out the other side through the coke guide and into the quenching car. Once the coke was removed the doors were closed and coal was charged into the oven. A leveling bar was then pushed through the coking chamber from the pusher to level the coal.

The red hot coke in the quenching car was then carried to the quenching tower where it was sprayed with water to arrest combustion and partially cool the coke. Once cooled the coke was returned to the coke wharf and side dumped into the brick-lined receptacle to be fed onto a conveyor system. A worker in the coke wharf operated a series of chutes that fed the coke onto a conveyor that transported the coke to a loading station.

At the loading station the coke was sized by a series of screens. It could then be sent directly to the blast furnace raw material storage bins or top loaded into waiting railroad cars positioned on tracks below the loading station.

Gas Flow Through the By-product Plant

The coke ovens produced gas that was not only valuable in its own right as a clean burning fuel, but also was laden with other valuable by-products. The original purpose of the by-product plant was to clean the gas for use in heating the coke ovens, but over time that process had been expanded to include recovery and processing of the other by-products removed from the gas during cleaning. The best way to show how the plant worked is to trace the movement of the gas through the plant and describe how various by-products were recovered and processed at specific points along its journey. The Thomas plant is typical of most plants in that it recovered what might be called the standard

range of by-products. These included, in addition to the gas, tar, ammonia, light oil and naphthalene. The ammonia, which was handled in the form of ammonia liquor, a mixture of ammonia and water, was further processed into ammonium sulphate, while the light oil was refined into benzol, toluol, zylene and solvent naphthalene. In later years, however, as petroleum derived substitutes were developed, the Thomas plant discontinued the recovery of benzol and its homologues, simplifying the operation to produce only crude and secondary light oil.³⁸

The first step in cleaning the oven gas and recovering the by-products was to draw the gas from the coking chambers. A light vacuum created by the exhauster pumps pulled the gas off the ovens through goose-neck pipes and into a collecting main. In the process the gas was sprayed with flushing liquor, a weak solution of ammonia liquor that condensed much of the tar and ammonia out of the gas. The tar and now-strengthened ammonia liquor flowed along the bottom of a large pipe called the suction main along with the gas to a downcomer.

At the downcomer the ammonia liquor, tar, and gas flowed under baffles that created a quick up-and-down movement, allowing the condensed tar and ammonia liquor to drop out. The gas then traveled to the primary coolers while the tar and ammonia was diverted to the tar and liquor recovery system.³⁹

The first stop for the tar and ammonia was the flushing liquor decanter tank where the two products were allowed to separate by gravity. The tar floated to the top of the tank and was removed to storage tanks while the ammonia liquor settled at the bottom and was pumped off to its respective storage tanks. The tar was held for shipment to outside customers. The ammonia liquor either

³⁸A good discussion of the by-products recovered in the coking process can be found in William Hamlin Childs, "By-products Recovered in the Manufacture of Coke." Also see J.M. Camp, The Making, Shaping and Treating of Steel, 1925, and subsequent editions of the same work, and J.E. Christopher, Modern Coking Practice, (New York: D. Van Nostrand Co., 1921).

³⁹The best description of the recovery of by-products as it was conducted by the Republic Steel Corporation at its plants in the late 1950s is found in R.E. Conn and C.R. Liphart. "Coal Chemical Recovery and Processing Operations at the Youngstown Plant of Republic Steel Corporation," In Proceedings of the Blast Furnace, Coke Oven, and Raw Materials Committee, vol. 19, by the American Association of Mining, Metallurgical and Petroleum Engineers. York Pa.: The Maple Press Co., 483-504. While Conn and Liphart's article refers specifically to Republic's Youngstown plant, their discussion of the flow of materials through a by-product plant of the 1950s era is contained in Savage, "Production of Metallurgical Coke."

was sent back to the collecting main to be used as a flushing liquor, used as a processing liquid in other parts of the plant, or sent to the ammonia stills for conversion into ammonia vapor to make ammonium sulphate.

The next stop for the coke-oven gas was the primary coolers where the gas passed up and down seven times while coming into contact with cooling water coils. This cooled the gas for further processing and condensed out additional tar and ammonia liquor that was pumped to the back to the tar and ammonia liquor storage tanks.

The first major difference in the path of the gas between the original plant and the 1952 plant occurred at this point. In the older plant the gas would have passed out of the primary cooler and into a Pelouze and Audouin (P&A) tar extractor. In the newer system the P&A tar extractor was removed so that the gas passed directly to the exhausters, which then pumped it through the remainder of the by-product plant. The first step after the exhausters in the 1952 plant was an electrostatic precipitator or detarrer which replaced the old P&A tar extractor.⁴⁰

Both the tar extractor and the detarrer performed the same function, removal of the last fine mist of tar entrained in the coke-oven gas. If not removed, this small amount of tar would discolor the ammonium sulphate that would be produced in the next stage of the by-product recovery process. The P&A tar extractor used a mechanical impingement process whereby the force of the gas as it impacted on a perforated metal plate caused the tar to stick while the gas passed on by. The tar was then removed and sent to the tar storage tank. In the electrostatic precipitator the tar mist was imparted with an electrostatic charge, causing it to be drawn to hanging rods that contained an opposite charge. After passing through the detarrer the gas then passed on to the ammonium sulphate recovery system, but not before it was injected with ammonia vapor that had been produced in the ammonia stills.

In the old plant the coke-oven gas and the newly injected ammonia vapor would have passed through a saturator. The saturator contained a tank of dilute sulfuric acid. Gas was injected into the bottom of the acid tank; as it bubbled upward the ammonia in the gas combined chemically with sulphur in the acid to form ammonium sulphate crystals. Once the concentration of ammonium sulphate crystals reached sufficient concentration a portion was drawn off, dried in a centrifugal dryer and stored for sale as fertilizer. The depleted acid solution was replenished from a tank called a mother liquor storage tank; the acid solution was called mother liquor.

⁴⁰Information regarding the replacement and addition of equipment in the by-product plant is taken from engineering drawings in the possession of the Wade Sand and Gravel Company.

The ammonia absorber that was installed in 1952 to replace the saturator worked on the same principle of chemical separation, but the gas was brought into contact with an acid spray rather than being bubbled through an acid bath. The concentrated ammonium sulphate crystals were then dried in a more modern centrifugal dryer.

After passing through the ammonium sulphate processing system the gas was pumped through a final cooler and two benzol washers. In the final cooler the gas flowed upward against a downward flow of cooling water, reducing the temperature of the gas (which had risen due to the combined effects of the pressure created by the exhausters and the processing in the ammonia absorber). The cooling water picked up naphthalene which was recovered from a pump near the final cooler.

The benzol washers extracted light oil from the coke-oven gas. The gas was pumped upward through the washers against a downward flow of petroleum wash oil. The petroleum wash oil, also called straw oil, absorbed the light oil to form a solution of about five percent light oil that was called benzolized wash oil. The benzolized wash oil was piped to the benzol plant to be converted into benzol and its homologues.

The second step in the production of benzol consisted of recovering the light oil from the wash oil in the wash oil still. Prior to introduction into the wash oil still, however, the wash oil had to be preheated. This was done in two phases. In the first phase the oil traveled through a vapor to oil heat exchanger, passing through tubes countercurrent to crude light oil vapor that had just been drawn from the wash oil still. The wash oil absorbed some of the heat from the crude light oil vapor and passed on to a preheater where it was further heated by passing countercurrent to steam in tubes.

In the wash oil still the wash oil was heated until the light oil vaporized and passed out the top of the still. This is where the high boiling point of the wash oil was important because it remained in liquid while the light oil with its lower boiling point was quickly vaporized by exposure to steam. The wash oil, relieved of its crude light oil and now called debenzolized oil was returned to the benzol washers while the crude light oil vapor passed through the vapor to oil heat exchanger and on to the light oil rectifier.

The light oil rectifier separated crude light oil vapor into intermediate and secondary light oil. Crude light oil vapor was injected into the middle of the light oil rectifier where it traveled upward against a downward flow of intermediate light oil. The intermediate light was continuously circulated from top to bottom of the rectifying column by a reflux pump. As it flowed downward against the crude light oil vapor it condensed out an additional amount of intermediate light oil, producing a more

concentrated intermediate light oil and a noncondensed vapor that was a more concentrated secondary light oil. Excess intermediate light oil was drawn off and sent to storage, while the secondary light oil containing benzol and its homologues was sent to the agitator.

In the agitator the now-condensed secondary light oil was rid of its impurities, which were absorbed by a bath of swirling, dilute sulfuric acid. In addition to the impurities, solvent naphthalene was also produced in this process. The cleansed secondary light oil was then sent to the pure still tank.

The pure still tank revaporized the secondary light oil, which was then sent to the pure still. The pure still was a fractionating column or batch still that sequentially removed benzol and its homologues according to their progressively higher boiling points. This was accomplished by bringing the secondary light oil only up to the temperature where benzol, with its low boiling point, vaporized. The benzol vapor was then drawn off and condensed while the remaining secondary light oil was heated to the boiling point of toluol. The toluol vapor was then drawn off and vaporized while the remaining secondary light oil was heated to the boiling point of zylene which was in turn vaporized. A batch run was completed once the zylene was removed and new secondary light oil was drawn into the fractionating column to start another batch.

Conclusions

The Thomas Coke Works produced coke and by-products for slightly over six decades. There was nothing extraordinary about its operating history. It was the smallest of the Republic Steel Corporation's eight coke plants, producing only 123,419 tons of coke in 1975 compared to the company's largest plant at Cleveland which produced 1,657,221 tons that same year.⁴¹ Nor did it ever conduct any secondary processing or produce any of the more complicated by-products such as phenol. The only exceptional technological feature of the plant was the unusually high coking chambers of the original 1924 Koppers-Beckers ovens that were replaced by a battery of more conventionally proportioned Koppers ovens in 1952.

Instead, the most distinctive feature of the Thomas coke ovens and by-product recovery plant is the fact that it is so standard in design and construction, and because it produced the typical range of by-products made at Koppers coke works. Koppers became the leading design used by American iron and steel makers to

⁴¹"Republic Steel Corporation and Subsidiaries, Coke Plants, 1975" Republic Steel Corporation Papers, W.S. Hoopes Special Collection, University of Alabama Library, Tuscaloosa, Alabama.

produce fuel for their blast furnaces and foundry cupolas.

The Thomas plant contains the well-preserved material remains of every major component of a typical Koppers plant, including patented ovens, material handling machinery and chemical processing equipment developed by German-born Heinrich Koppers and brought to the United States around 1907. It was essentially this assemblage of imported equipment that, in the hands of U.S. engineers and plant operators, was brought to a level of productivity that was unprecedented in Europe, and came to represent the coke making equivalent of American hard driving blast furnace practice.

Many of the components of the Thomas works, such as the coal feed system, primary coolers, and exhaustor engines, are very similar to the original Koppers designs. Since most coke making operations were upgraded every twenty years or so, particularly since the advent of more stringent pollution restrictions during the last two decades, early coke plant equipment is rare in most surviving plants. Thomas is an exception, with many original components preserved, although when the plant was modernized in the 1950s, several new features were installed to replace older equipment, including a new battery of coke ovens that were simply built into the original coal feed system, coke wharf, and coke screening and loading facility. Surviving components of plants from this relatively recent date however, have themselves, become fairly uncommon.

The most significant feature of the site is the overall integrity of its layout. Metallurgical cokemaking and the production of commercially valuable by-products were indispensable elements of twentieth century American iron and steelmaking, and the Thomas Coke Works are so well preserved that every standard step in the very elaborate process can be explained by the equipment and structures that remain on the site.

Bibliography

Affelder, William L. "The Semet-Solvay Coke Plant at Dunbar, Pa." Mines and Minerals 20 (February 1900): 297-298.

Alabama. Iron Making in Alabama, by William Battle Phillips, Monograph No. 3, Alabama Geological Survey, Montgomery, Ala.: Jas. P. Armstrong, 1896.

--- Report of Progress for 1875, by Eugene A. Smith with a section by Truman H. Aldrich, Alabama Geological Survey, Montgomery, Ala., W. W. Screws, 1876.

---. Alabama, Statistics of the Mineral Production of Alabama for 1925, by Walter B. Jones, Alabama Geological Survey, Birmingham, Ala.: Birmingham Printing Co., 1928.

Armes, Ethel. The Story of Iron and Coal in Alabama. facsimile ed. Leeds, Ala.: Beechwood Books, 1987.

Atwater, R.M. "The Effect of Coke Oven Construction on Coke." In Proceedings of the Engineer's Society of Western Pennsylvania 12 Pittsburgh: the Engineering Society of Western Pennsylvania, 1896, 73-86.

Backert, A.O. The ABC of Iron and Steel, 5th ed. Cleveland: The Penton Publishing Co., 1925.

Becker, Joseph. "Modern By-product Coking." Chemical and Metallurgical Engineering 27 (1 November 1922): 875-881.

Blauvelt, William Hutton. "By-Product Coke Ovens." In The Mineral Industry, 4, ed. Richard P. Rothwell, New York: The Scientific Publishing Co., 1896, 214-242.

----. "A Description of the Semet-Solvay By-Product Coke-Oven Plant at Ensley, Alabama." TAIME. vol. 28, 1889, 578-591.

----. "The Manufacture of Coke." TAIME. vol 44, 1912, 154-169.

----. "By-Products Recovered in the Manufacture of Coke." Yearbook of the American Iron and Steel Institute, 1916, by the American Iron and Steel Institute. New York: American Iron and Steel Institute, 1919, 65-72.

----. "The By-product Coke Oven and its Products." TAIME. vol. 55, 1919, 436-455.

Bowron, Charles. "Waste Heat and Gases From Coke Ovens."

- Colliery Engineer and Metal Miner 18 (1898): 60-61.
- "By-Product Coke Outstrips Beehive." Iron Trade Review -- (2 January 1919): 99-100.
- "By-Product Coke, Pittsburgh Coal and Natural Gas." Coal and Coke Operator 15 (August 1912): 68-70.
- Camp, J.M. and C. B. Francis. The Making, Shaping and Treating of Steel. 4th ed. Pittsburgh: Carnegie Steel Company, 1925.
- Christopher, J.E. Modern Coking Practice. New York: D Van Nostrand Co., 1921. R669.8
- Chapman, Henry Hollis. The Iron and Steel Industries of the South. Tuscaloosa, Ala.: Univ. of Ala. Press, 1953.
- Childers, James Saxon. Erskine Ramsay: His Life and Achievements. New York: Cartwright and Ewing, Publishers, 1942.
- Childs, William Hamlin. "By-products Recovered in the Manufacture of Coke." Yearbook of the American Iron and Steel Institute, 1916, by the American Iron and Steel Institute. New York: American Iron and Steel Institute, 1917, 23-64.
- "Coalburg, Ala. Coal Mines of the Sloss Iron and Steel Company." Colliery Engineer 8 (February 1888): 153.
- "Coke-Making by the Sloss Iron and Steel Company." Colliery Engineer. 9 (July 1889): 271.
- "Coke Manufacturers of the Connellsville District." Coal and Coke Operator 15 (December 1912): 23.
- "Comparison of Beehive and By-Product Coke." Blast Furnace and Steel Plant 9 (November 1921): 638-639.
- "Connellsville Coke The Best." Coal and Coke Operator 18 (February 1909): 129.
- Conn, R.E. and C.R. Liphart. "Coal Chemical Recovery and Processing Operations at the Youngstown Plant of Republic Steel Corporation." In Proceedings of the Blast Furnace, Coke Oven, and Raw Materials Committee, vol. 19, by the American Association of Mining, Metallurgical and Petroleum Engineers. York Pa.: The Maple Press Co., 483-504.
- Davis W.W. "The Semet-Solvay By-Product Coke Oven." In Proceedings of the Engineer's Society of Western

Pennsylvania 26 Pittsburgh: Engineer's Society of
Western Pennsylvania, 1910, 399-423.

"Developments in the By-product Coke-Oven Field." Chemical
and Metallurgical Engineering 30 (18 September 1924): 282.

Enman, John Aubery. "The Relationship of Coal Mining and
Coke Making to the Distribution of Population
Agglomerations in the Connellsville
(Pennsylvania) Beehive Coke Region."
Ph.D. diss., University of Pittsburgh,
1962.

Espenhahn, E.V. "By-products from Coke Oven Gases." Chemical
and Metallurgical Engineering 30 (21 April 1924): 629-
631.

Fieldner, A.C. and G.W. Jones. "Benzol as a Motor Fuel." Chemical and Metallurgical Engineering 29 (September
1923): 543.

Finney C.S. and John Mitchell, "Emergence of By-Product
Coking." In History of the Coking Industry in the
United States. New York: The American Institute of
Mining, Metallurgical, and Petroleum Engineers, Inc.,
1961, 43-48.

---. "Development of Modern By-Product Coke Ovens." In
History of the Coking Industry in the United States. New
York: The American Institute of Mining,
Metallurgical, and Petroleum Engineers, Inc.,
1961, 49-52.

---. "The Coke Industry Today." In History of the Coking
Industry in the United States. New York: The American
Institute of Mining, Metallurgical, and Petroleum
Engineers, Inc., 1961, 53-56.

Fulton, John. Coke: A Treatise on the Manufacture of Coke
and the Saving of By-Products. Scranton, Penn.: The
Colliery Engineer Co., 1895.

Gans, John L. "An Innovation in the Coke Industry." Coal Age
14 (August 1918): 256-257.

Garrett, R.E. "Raw Material Problems in Birmingham." In
Yearbook of the American Iron and Steel Institute,
1948, by the American Iron and Steel Institute. New
York: 1948, 208-216.

Geismer, H.S. and David Hancock, "Beehive and By-product
Coke in Alabama." Coal Age 3 (June 7 1913): 879-882.

- Harris, Garrard. "Wofford Oil Company Made Market for Birmingham-Made Benzol." ----- 1 (May 1925): 1-?
- Hartman William E. "By-Product Coke Ovens." In Proceedings of the Engineer's Society of Western Pennsylvania 28 Pittsburgh: Engineer's Society of Western Pennsylvania, 1912, 311-357.
- Hastings, J.M., Jr. "By-Product Coke Ovens of Yesterday and Today." Blast Furnace and Steel Plant 9 (January 1921): 10-13.
- . "Modern Coke Plant at Birmingham." Gas Age 44 (December 1920): 461-464.
- Hill, J.T. "Thomas Coking Oven." In Proceedings of the Alabama Scientific and Industrial Society, by the Alabama Scientific and Industrial Society, Tuscaloosa: (sic) Book and Job Printing Press of Jno. F. Warren, 1892, 1, no.2: 86-90.
- Jacobson, D.L. International Handbook on the By-Product Coke Industry, New York: The Chemical Catalog Company, Inc., 1932.
- Johnson, J.E. Blast Furnace Construction in America, New York: McGraw-Hill Book Company, Inc., 1917.
- King, Clarence David. Seventy Years of Progress in Iron and Steel. New York: The American Institute of Mining and Metallurgical Engineers, 1948.
- "Light Oil Recovery." Gas Age 40 (15 November): 443-446.
- Lucas, F.E. "The Manufacture of Coke." TAIME, vol. 44, 1912, 170-183.
- Marquard, Frank. "Coke Made from High-Volatile Coal." Iron Trade Review -- (29 May 1919): 1433-1435.
- McGannon, Harold E., ed. The Making, Shaping and Treating of Steel. 9th ed., Pittsburgh: Herbeck and Held, 1971.
- Miller, M. "The Purification of Coal Gas by Electricity." Coal Age 14 (12 December 1918): 1071.
- Miller, F. W. "Alabama has Made Great Progress in Coking Coal." Coal Age 26 (October 1924): 506-508.
- . "By-product Coking in Alabama." TAIME, vol. 71, 1925, 1106-1111.

- Mills, Mable D. The Coke Industry in Alabama. University, Ala.: Bureau of Business Research, 1947.
- Mitchell, Guy E. "Waste in Coking." Colliery Engineer 34 (September 1913): 74-75.
- Mobley, W.M. Coal Cleaning Methods in Alabama. Technical Publications No. 1882, by the AIME, 1946.
- Muns G.E. and C.V. Thompson, "Problems in the Disposal of Phenol Waste in Coke Plants." 41 (July 1953): 761-769.
- Pechin, Edward C. "Iron Making in Birmingham, Alabama." Iron Age (July 1894): 26.
- Pennsylvania. Annual Report of the Secretary of Internal Affairs of the Commonwealth of Pennsylvania for 1874-5. Part III, Industrial Statistics, by John Fulton, Vol. 13, Harrisburg: B.F. Meyers State Printer, 1876.
- Ramsburg, C.J. and F.W. Speer, Jr. "By-Product Coke and Coking Operations." Coal Age 13 (27 April, 4, 11 May, 1918): 772-777, 870-872.
- . "Structure and Standard Grading of By-Product Coke." Gas Age 41 (15 December 1918, 1 January 1919): 549-552, 8-13.
- Ramsey, Erskine and Charles E. Bowron. "Coal Washing in Alabama." Mines and Minerals. 25 (December 1905): 227-231.
- Rosa, E.B. "Relation of the Gas Industry to Military Needs." 40 (15 November 1918): 447-455.
- Savage, Phillip S. "Production of Metallurgical Coke." Steel --- (May 2, 9, 16 1949): 98-103, 121-131, 102-113.
- Schlamp, H. "Recovering the Sludge Acid in Benzol Refining." Chemical and Metallurgical Engineering 30 (4 February 1924): 188.
- Schulte, E.V. "Recent Developments in Producing By-Product Ammonium Sulphate." Blast Furnace and Steel Plant 34 (May 1946): 573-625.
- "Southern Coke in the Furnace." Iron Age 36 (November 1885): 21-22.
- Sperr, F.W. Jr. "Some Characteristics of American Coals in By-product Coking." Coal Age 14 (12, 19, 26 December 1918): 1068-1071, 1114-1117, 1156-1159.

Swank, James M. Introduction to a History of Iron Making and Coal Mining in Pennsylvania. Philadelphia: James M Swank, 1878.

Terne, Bruno. "The Utilization of the By-Products of the Coke Industry." In Coke, by John Fulton, 186-187. Scranton, Pa.: The Colliery Engineer, 1895.

Thau, A. "Ammonia and Benzene Column Stills." Chemical and Metallurgical Engineering 23 (22 December 1920): 1203-1207.

---. "Formation of Coke." Chemical and Metallurgical Engineering 30 (11 February 1924): 222-227.

---. "Coke Surface and Structures." Chemical and Metallurgical Engineering 30 (25 February 1924): 306-310.

---. "Combustibility of Coke." Chemical and Metallurgical Engineering 30 (3 March 1924): 347-350.

U.S. Department of the Interior. Report on the Mining Industries of the United States, by Raphael Pumpelly, Bureau of the Census, Washington D.C.: GPO, 1886.

---. Department of the Interior. Report on the Mineral Industries of the United States, by David T. Day, Bureau of the Census, Washington D.C.: GPO, 1892.

---. Department of the Interior. Mineral Resources of the United States, by Raphael Pumpelly, Bureau of the Census, Washington, D.C.: GPO, 1902.

---. Department of the Interior. The Coke Industry of the United States, as Related to the Foundry. by Richard Moldenke, Bureau of Mines, Bulletin 3, Washington D.C.: GPO, 1910.

---. Department of the Interior. Iron Ores, Fuels and Fluxes of the Birmingham District, Alabama, by Ernest F. Burchard, Charles Butts and Edwin C. Eckel, Geological Survey. Washington D.C.: GPO, 1910.

---. Department of the Interior. Mineral Resources of the United States, 1920, Part I-Metals, Geological Survey, Washington, D.C.: GPO, 1922.

---. Department of Interior. Co-products of Coke in the United States. by J.A. DeCarlo and J.A. Corgan, Bureau of Mines, Information Circular 7504, Washington, D.C.: GPO, 1949.

---. Department of Interior. The Possible Effects of the

Expanding Use of Natural Gas on the Production of Coke and Coal Chemicals in the United States. by J.A. DeCarlo and J.A. Corgan, Bureau of Mines, Information Circular 7579, Washington, D.C.: GPO, 1950.

---. Department of Commerce. Coal Washing Investigations. by H.F. Yancey and Thomas Fraser, Bureau of Mines, Bulletin 300, Washington, D.C.: GPO, 1929.

White, Marjorie Longenecker, The Birmingham District. Birmingham, Alabama: The Birmingham Historical Society, 1981.

Wilson, Phillip J. and Joseph H. Wells. "Coal Chemical Industry Trends and Problems." Chemical Engineering -- (December 1946): 110-114.

---. Coal, Coke and Coal Chemicals. New York: McGraw-Hill Book Company, 1950.

Woodward Iron Company. Alabama Blast Furnaces. Woodward, Ala.: Woodward Iron Company, 1940.