HISTORY OF IRON AND STEELMAKING IN THE UNITED STATES

Publication in one book of a series of historical articles that have appeared in JOURNAL OF METALS, 1956-1961

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HISTORY OF IRON AND STEELMAKING IN THE UNITED STATES

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PREFACE

An historical record of the history of iron—and steelmaking in the United States has long seemed a desirable project to many in The Metallurgical Society of AIME. Over a period of five years, experts in their fields have been asked to put down on paper their knowledge. The series of historical articles has been published in JOURNAL OF METALS, beginning with A. B. Wilder's article in 1956, marking the first one hundred years of Bessemer Steelmaking. The Electric Furnace Committee honored the first half-century of the use of the electric arc furnace in America during their 1956 Conference, and S. B. Casey, Jr., wrote an appropriate article for JOURNAL OF METALS. The historical series was well underway.

Articles soon followed on the history of the blast furnace, on the open hearth furnace, and on ferro-alloy manufacture. The final need was an authoritative article on coke ovens. The publication of the five-part article by C. S. Finney and John Mitchell this summer has concluded our series (but not the march of progress). We now present, between two covers, a comprehensive historical review, the work of 13 authors.

We are hopeful that this book will receive a welcome among ironmakers and steelmakers, and that it will be a valuable reference for home or office library. We hope also that students will find the material helpful in their studies of this most important of American industries. Perhaps also, the historian of Americana will learn something new in searching through these pages.

We are indebted to our authors who have spent much time on historical research, and to their companies who have supported their endeavors.

We acknowledge the support of the National Open Hearth Steel Committee and of the Blast Furnace, Coke Oven, and Raw Materials Committee in jointly assuming the financial risks in publishing this book.

Robert W. Shearman
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BLAST FURNACE

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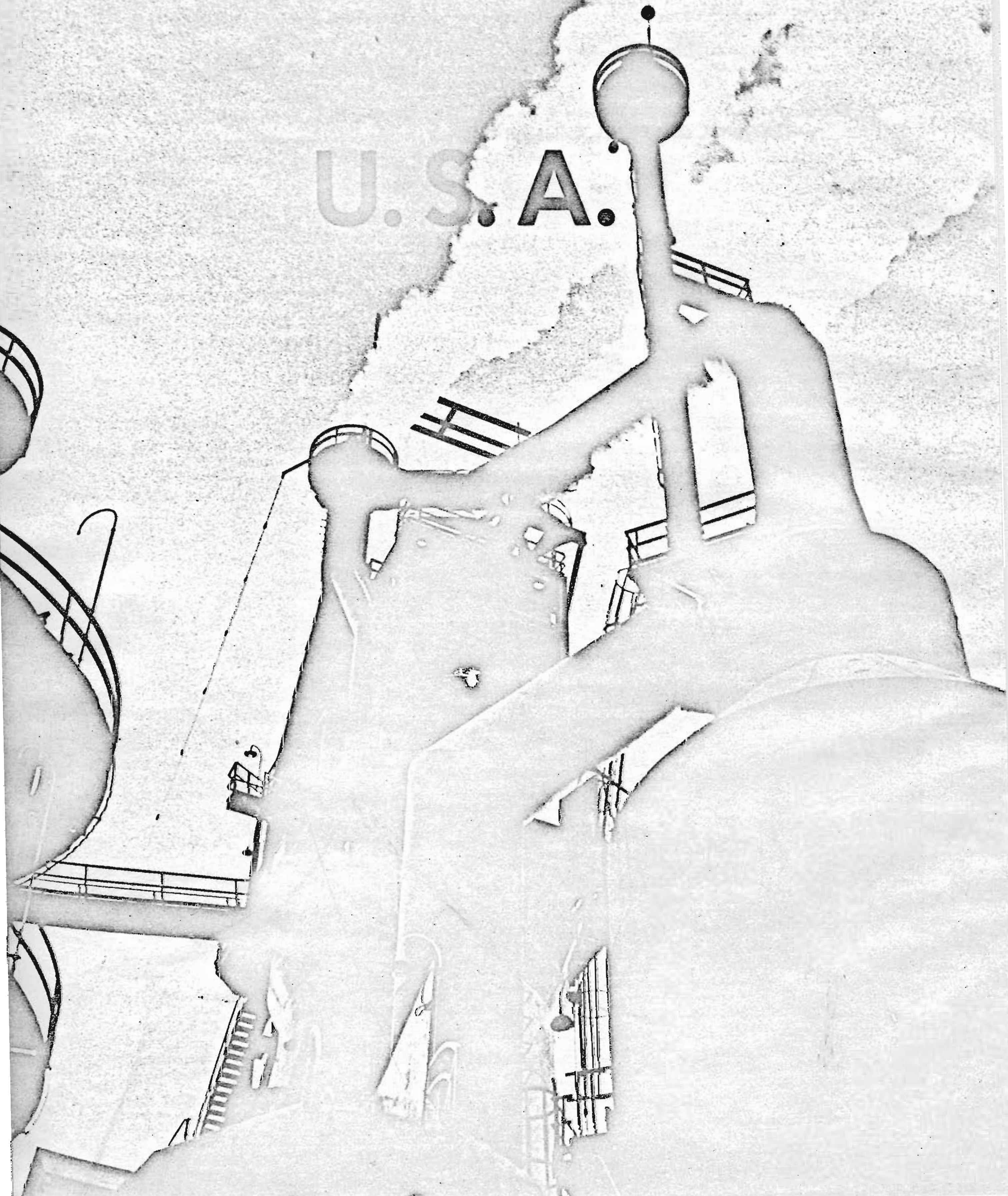

I. Colonial Ironmakers

Blast furnaces are the tools of men, and it is men who have made them great. Here is presented the story of the Ironmakers—the men who first poured hot metal into what would someday be the sinews of a nation.

by M. O. Holowaty and C. M. Squarcy

WHEN the Jacobean merchant adventurers bade farewell to the first ship of colonists sailing for the *new land*, they instructed them to direct all their skill and energy to grow silk worms in Virginia. The adventurers felt sure that they could flood the market with highly priced and much desired goods like silk, sugar, tea, and indigo. They were also convinced that they would fill the needs of the *mother country* for iron.

Early iron production in the colonies

The merchants certainly had a wonderful imagination, for silk and indigo were just as exotic in Virginia as they were in England. The settlers found it more profitable to raise tobacco on the vast stretches of the free, fertile land. Thus the plans of settlers clashed with those of The Virginia Co.; and only point of agreement was the desire to produce iron. But, even there the motives of the settlers and those of The Virginia Co. of London were worlds apart. The settlers wanted to produce the tools badly needed in the colony, while the Company desired to cash in on the rising demand for iron which the home industry could not satisfy.

Both the settlers and the Company lost no time trying to find iron ore. Locations of the early mines are not known. If, however, the reports of the Irishman, Francis Maguel, can be trusted, as early as 1609 a ship sailed for England with a load of 17 tons of crude iron which the East India Co. purchased at £4 per ton. The iron was of excellent quality and considered the best iron made of non-English ore that was ever purchased.

Colonial forges and charcoal blast furnaces

Forges were reported to be quite common during the first years of white man's existence in North America. During the first three years after the founding of Jamestown, machinery had already been erected by settlers who worked the iron mines. It is also known that many small implements were made by the colonists from iron which was produced in local forges or in Catalan forges.

The Massachusetts Bay Colony boasted a number of them during the second half of the 17th century. Bloomery forges of 200 to 400 lb capacity were operated at Mendon, Harvard and Westin. A large bloomery was located at Northborough, famous for a short time for its cast iron pottery and stoves.

An integrated iron works at Westminster supplied slit bars and rods for making tools and implements for the farmers, while the rod and nail mill at Wachusett excelled in spikes, nails, and axes.

The forges stood their ground in the age of the charcoal blast furnace, and began only a gradual retreat in the era of anthracite. Almost all forge plants were established on the basis of home industries and were operated to satisfy local needs. Iron as such was not exported in any quantities to either England or to other countries.

Falling Creek starts as religious venture

In 1619, an anonymous contribution of £500 was made to the Virginia Co. for the distinct purpose of promoting conversion of Indian children living in the colony to the Christian faith. The colonists decided to establish an industry whose profits would be used for the conversion work instead of spending the money directly. Their plan was to multiply the original sum through the growth of the iron industry. They added £3500 to the original contribution and contracted for iron works to be built in Virginia as soon as possible. The profits were to be used in instructing 30 Indian children in the doctrines of the Christian church. Thus, the Southhampton Adventurers intended to accomplish two purposes: promotion of the economic welfare of the colonies and the conversion of the Indian tribes to Christianity.

Subsequently, the steering committee of the Adventurers addressed a letter to Yardley, who was governor of Virginia and captain of the Southhampton Hundred. In this letter Yardley was urged to show utmost care in setting up the project "as upon these works were fixed the eyes of God, angels and men." The London office acted quickly upon Yardley's request, and dispatched Capt. H. Blewit with a group of 80 skilled iron workers to Virginia in the spring of 1621.

Captain Blewit died shortly after reaching Jamestown, but he was quickly replaced with John Berkeley of Gloucestershire. Work on the iron plant started in the fall of 1621 at the location known as

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Falling Creek, about seven miles below the falls of James River. The site had been suggested by Sir Edwin Sandys who also made the original cost estimate of £4000. In making this suggestion he had in mind the proximity of all required raw materials, timber, ore, limestone, water, and also sandstone for the construction of the blast furnace itself.

In February of 1622, Berkeley reported to the Society in London that the blast furnace was just about completed and he expected to make iron very cheaply. The trustees of the company, already in high spirits over the success of the venture, voted to meet their manager's expenses whatever they might be. They did not even dream that on the very day of their voting, Mar. 22, 1622, their men were being murdered and their enterprises destroyed by savage Indians. Only two people escaped the Indian massacre at Falling Creek, a boy and a girl who hid in the bushes. Berkeley, his family, and his workers were murdered ruthlessly without apparent motive or provocation. The tools and the furnace machinery were broken up and tossed into the river.

The real tragedy of Falling Creek was in the annihilation of the iron makers. Judging from the speed with which the plant was built, they were undoubtedly masters of the profession. The colonies recovered quickly from the material loss, but the shortage of skilled men delayed establishment of a successful domestic iron industry for many years to come.

The news of the massacre at Falling Creek shocked the colony, the London offices of the Virginia Co., and even the Royal Court, but it did not diminish the interest in establishing the iron industry in the colonies. More ironmakers were contracted to go to Virginia in early 1623, to repair the damages and put the furnace in operation.

After the accession of Charles I to the English Throne in 1625, the king revoked the charter. Several attempts were made to interest the young monarch in establishing the industry in Virginia, but Charles saw a quicker road to fill his treasure by imposing enormous and unheard-of domestic taxes. King Charles intended to establish a number of royal industries in the colonies. He sent William Capes to Virginia in 1627 or 1628 with a commission to establish a number of industries, including the manufacture of iron. In spite of the great support of the governor and the Burgesses, Capes quickly antagonized colonists and was forced to leave the country before any of his plans could materialize.

Sir Isaac Zouch and his son almost succeeded in reestablishing the Virginia iron industry in 1635. Proceeding on their own they rebuilt part of the machinery of the Falling Creek plant, but were forced to give up because of lack of funds. This was apparently the last attempt to produce iron in early Virginia. In the closing years of the 17th century, Falling Creek was just another forgotten place in the wide open spaces of the *New World.*

The Spotswood furnace at Germanna in Virginia, 1716

One morning in the summer of 1710, a new ship landed at Jamestown, Va. Aboard the ship, was the new lieutenant governor of the colony, Colonel Alexander Spotswood. Spotswood was born of Scotch parents in 1676 at Tangier, at that time a British possession. Raised outside England, he developed an organizational talent to work with people of other nationalities, a foresight and understanding which were rare in his day. As governor of Virginia, he proved to be a brilliant and far-seeking statesman.

Shortly after his arrival, Spotswood was approached by Baron Christopher de Grafenreid, a prominent Swiss landowner who had led a group of his countrymen and Germans to North Carolina. There was talk in 1712 about silver ore in the Massanutten Mountain, and Spotswood and Grafenreid discussed it many times. It was decided that the latter would go to Europe and search for miners.

In the spring of 1714, 40 German miners from the Sieg Valley arrived in Virginia. Spotswood, who paid for their passage settled them permanently along the northwestern frontier. The location was named Germanna, and the place was fortified with a blockhouse and two cannons. Spotswood petitioned London for permission to mine silver, but until the royal sanction was obtained the German settlers had to remain idle. Soon they found outcrops of iron ore and attempted to interest their protector in an iron venture.

In September 1716, the governor decided that iron mining was better than doing nothing, and took out a land patent for 3229 acres in the name of William Robertson, recorded as being in Essex County, in the parish of St. George, approximately 20 miles above the falls of the Rappahannock River. The land patent incuded Germanna and the surrounding country, rich with ore beds and vast timber reserves. The Spotswood blast furnace was built in 1716 or 1717. The exact date is not known but can be deduced from complaints made to the crown about Spotswood's activities during that time.

Spotswood also had his defenders, but the perseverance of his enemies bore fruit, and, after serving 12 years as governor, Spotswood was removed in 1723. He was well provided financially; he owned about 65,000 acres of land, two blast furnaces, an iron bloomery, hemp fields, and plantations. Rather than return to England, Spotswood decided to throw in his lot with the new country and spent the remaining 18 years of his life developing frontiers and, according to his critics "squeezing out his partners from land tracts and enterprises."

The dimensions of the principal blast furnace at Germanna are not known, but judging from the annual average production of 800 tons, it can be assumed that it measured 6 to 7 ft across the bosh. Thus, Spotswood was the first to inaugurate the iron industry in Virginia and to operate a blast furnace exclusively producing pig iron on the American continent.

After several of his original German workers left him, Spotswood decided to run the enterprise with slave labor. To the visiting nobleman, Colonel William Byrd, he explained that except for raising ore and running the blast furnace, he employed solely slave labor. Byrd found that from 100 to 120 slaves were required to run the furnace, including women to cook and farm hands to raise corn and cut hay for feeding the oxen, needed for hauling charcoal and iron ore.

In 1724 a group of English iron masters formed the Principio Co. of Maryland, and blew in a blast furnace in 1725. Soon, however, this young enterprising company extended its interests to Virginia and built a blast furnace at Accokeek on the property belonging to Augustine Washington in Stafford County. Two years later, the stock of the Accokeek plant was valued at £3000, including raw materials, plant facilities, and slaves. Colonel Byrd visited all iron plants of Virginia in 1732; the same year Augustine Washington became the father of a son named George.

Byrd's observent eye caught the features of the Spotswood furnaces, while his keen mind quickly evaluated the problems of ironmaking in the new country. He wrote:

> "We proceeded to the furnace, which is built of rough stone, having been the first of that kind erected in the country. Here the wheel that carried the bellows was no more than twenty feet diameter; but was an overshot wheel that went with little water. This was necessary here, because water is something scarce, notwithstanding it is supplied by two streams, one of which is conveyed one thousand and nine hundred feet through wooden pipes, and the other sixty . . . The name of the founder employed at present is one Godfrey—whose wage is three shillings and six-pence per ton for all the iron he runs, and his provisions . . . He complained that the colonel starves his works out of whimsicalness and frugality, endeavoring to do everything with his own people, and at the same time taking them off upon every vagary that comes into his head . . .
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> "Another newer furnace of Spotswood's is elegantly built of brick, though the hearth be of firestone . . . (The) operator looked a little melancholy, because he had nothing to do, the furnace having been cold ever since May, for want of corn to supply the cattle . . . But having received a small supply they intended to blow very soon. With that view they began to heat the furnace, which is six weeks before it comes to that intense heat required to run the metal in perfection. Nevertheless, they commonly begin to blow when the fire has been kindled a week or ten days. Close by the furnace stood a very spacious house full of charcoal, holding at least four hundred loads, which will be burnt out in four months. The fire in the furnace is blown by two mighty pairs of bellows, that cost one hundred pounds each, and these bellows are moved by a great wheel of twenty-six feet diameter. The wheel again is carried round by a small stream of water conveyed about three hundred and fifty yards over land in a trough, from a pond made by a wooden dam. But there is great want of water in a dry season, which makes the furnace often blow out, to the great prejudice of the works.
>
> ". . . We took a walk to the principal mine, about a mile from the furnace, where they had sunk in some places about fifteen or twenty feet deep. The operator, Mr. Gordon, raised the ore, for which he was to have by contract one and sixpence per cartload of twenty six hundred weight . . . The rate of twenty five shillings a month, and for all that was able to clear forty pounds a year for himself. We saw here several large heaps of ore of two sorts, one rich and the other spongy and poor, which melted together to make the metal more tough. The way of raising the ore was by blowing it up, which operation I saw from beginning to end. They first drilled a hole in the mine, either upright or sloping, as the grain of it required. This hole they cleansed with a rag fastened to the end of an iron with a worm at the end of it. Then they put in a cartridge of powder containing about three ounces, and at the same time a reed full of fuse that reached to the powder. Then they rammed dry clay, or soft stone very hard into the hole, and lastly they fired the fuse with a paper that had been dipped in a solution of saltpetre and dried, which burning slow and sure, gave leisure to the engineer to retire to a proper distance before the explosion. This in the miner's language is called making a blast, which will loosen several hundred-weight of ore at once; and afterwards the laborers easily separate it with pickaxes and carry it away in baskets up to the heap. At our return we saw near the furnace large heaps of mine with charcoal mixed with it, a stratum of each alternately, beginning first with a layer of charcoal at the bottom. To this they put fire, which in time spreads through the whole heap, and calcines the ore, which afterwards easily crumbles into small pieces fit for the furnace. There was likewise a might quantity of limestone brought from Bristol, by way of ballast, at two and sixpence a ton, which they are at the trouble to cart hither from Rappahannock River, but contrive to do it when the carts return from carrying of iron. They put this into the furnace with the iron ore, in the proportion of one ton of stone to ten of ore, with design to absorb the sulphur out of the iron, which would otherwise make it brittle. And if that be the use of it, oyster shells would certainly do as well as limestone, being altogether as strong an alkali, if not stronger. I observed the richer sort of mine, being of a dark color mixed with ruts, was laid in a heap by itself, and so was the poor, which was of liver or brick color. The sow iron is in the figure of a half-round, about two feet and half-long, weighing sixty or seventy pounds, whereof three hundred weight make a cartload . . . When the furnace blows it runs about twenty tons of iron a week. The founders find it very hot work to tend the furnace, especially in summer, and are obliged to spend no small part of their earnings in strong drink to recruit their spirits. Besides the founder, the collier, and miner, who are paid in proportion to their work, the company has several other officers upon wages, a stock-taker, who weighs and measures everything; a clerk, who keeps an account of all receipts and disbursements; a smith to shoe their cattle and keep all their iron work in repair; a wheelwright; cartright; carpenter; and several carters. The wages of all these persons amount to one hundred pounds a year; so that including Mr. Chiswell's salary, they disburse two hundred pounds per annum in standing wages . . .
>
> "Col. Spotswood told me he had iron in several parts of his great tract of land, consisting of forty-five thousand acres. But that the mine he was at work upon was thirteen miles below Germanna . . .
>
> "The Colonel has a great deal of land in his mine tract exceedingly barren, and the growth

> of trees upon it is hardly big enough for coaling . . . All the land hereabouts seems paved with iron ore; so that there seems to be enough to feed a furnace for many ages."

Byrd seems to have been very much interested in the "art of iron making," for he spent some time with Mr. Chiswell, Manager of the Germanna furnace, inquiring about the details of operation. Chiswell assured him

> "that the first step I was to take was to acquaint myself fully with the quantity and quality of my ore. For that reason I ought to keep a good pick-axe man at work a whole year to search if there be a sufficient quantity, without which it would be a very rash undertaking. That I should also have a skillful person to try the richness of the ore. Nor is it great advantage to have it exceedingly rich, because then it will yield brittle iron, which is not valuable. But the way to have it tough is to mix poor ore and rich together, which makes the poorer sort extremely necessary for the production of the best iron. Then he showed me an example of the richest ore they have in England . . .
>
> "He told me, after I was certain my ore was good and plentiful enough, my next inquiry ought to be, how far it lies from a stream proper to build a furnace upon, and again what distance that furnace will be from water carriage; because the charge of carting a great way is very heavy, and eats out a great part of the profit. I was in the next place to consider whether I had woodland enough near the furnace to supply it with charcoal, whereof it would require a prodigious quantity. That the poorest wood for that purpose was that of oily kind, such as pine, walnut, hickory, oak, and in short all that yields cones, nuts, or acorns. That two miles square of wood supply a moderate furnace; so that what you fell first may have time to grow up again to a proper bigness (which must be four inches or over by that time the rest is cut down.
>
> "He told me further, that one hundred and twenty slaves, including women, were necessary to carry on all the business of an iron work, and the more Virginians amongst them the better; though in that number he comprehended carters, colliers, and those that planted the corn. That if all these circumstances should happily concur, and you could procure honest colliers and firemen, which would be difficult to do, you may easily run eight hundred tons of sow iron a year."

Only a few miles away from Germanna, Byrd inspected an air furnace or a bloomery which was also owned and operated by Spotswood. The blast furnaces were idle at the time of the visit. The Germanna furnace was down for repairs, and the Fredericksville furnace, which during the preceding year produced 1200 tons of iron, was down temporarily for lack of feed for the oxen. This eventually proved to be the main reason for abandoning the Fredericksville furnace in 1735 or 1736.

Alexander Spotswood died in 1740 without leaving an heir. He was followed closely by Augustine Washington. For a while their works lived after them, Augustine Washington's place on the board of the Principio Co. fell not to the 11-year-old George, but to his half brother, Lawrence, from Augustine's first marriage with Jane Butler.

In 1750 Virginia and Maryland together exported to England about 2460 tons of pig iron. One sixth of this supposedly came from the Accokeek furnace. However, after the death of Lawrence Washington in 1753, the Principio Co. moved all its stock and men to Maryland. The Germanna furnace was still active in 1750 when 410 tons of Germanna pig iron were sent to England. Since no further information could be found in the literature, it can be assumed that it ceased to operate shortly after 1750.

There are no ruins left of any of the Spotswood furnaces. Mr. H. W. Johnson, who visited the site in 1936, found only a steel signboard which read:

"Spotswood's Furnace

Four miles north on this side road is the site of an ancient iron furnace, established about 1716 by Governor Alexander Spotswood, the first fully equipped furnace in the colonies. Iron was hauled along this road to the Rappahannock River for shipment. William Byrd visited the furnace in 1732 and described it."

Johnson adds, "If you turn down the side road, you find the ground more uneven than along the highways, a scrub growth borders the road, interrupted only here and there by a wagon road or a shack. The road has recently been improved and covered with a layer of gravel, which on examination looks very much like broken blast furnace slag . . ."

The Principio Co., established in 1714 to produce iron in Maryland

The British custom officers did not believe their eyes—the ship that just arrived brought a load of iron bars from American consigned to Joshua Gee of Shrewsbury and William Chetwynd, Esq., of London. The year was 1718 and the shipment was small—only 3½ tons, but nevertheless, it was there and was probably just the beginning of what eventually would pour from the colonies. The custom officers were right—for the flow of the iron from the colonies increased considerably during the next decade, especially so from one iron works, the Principio plant of Maryland.

The Principio Co. had its beginning in England. In 1714, a group of businessmen headed by the brothers Joshua, Samuel, and Ozgood Gee; William Chetwynd; and Sir Nicholas Carew, decided to venture into production of iron in the colonies to supplement the diminishing production and the increasing need for iron in the mother country. The undertaking seemed promising enough—if Capt. John Smith, who in 1606 reported iron ore in the Chesapeake Bay area, could be trusted. In any case, it appeared worthwhile to dispatch Mr. Joseph Farmer to the new country, with the instructions to decide if and where to build the iron works.

Joseph Farmer arrived in New Castle in the spring of 1715, and began immediate inquiries about the iron industry of the new colonies. He was informed about the earliest furnace at Falling Creek, which could be reconditioned and put in operation. He also heard the stories about John Winthrop's iron ventures at Saugus and Braintree, and their rather indifferent success. The Winthrop furnaces were down completely and the Philadelphia Quakers strongly advised Farmer against New England, which had only bog ore, and even that was low in iron and quantity.

There were rumors about bloomeries and forges in Maryland, and Farmer decided to follow these up because of Maryland's proximity to the open waters of the Atlantic Ocean and thus to England. Exploring for a blast furnace location, the English ironmaster rode along the Back Creek, which for some reason fascinated him. Farmer could perceive the sound of falling water, and forcing his way through a virtual jungle, he faced a waterfall. Excited by this find, he rode down the river looking for iron ore which was reported by Captain Smith. The deepening water forced him to take to the red river bank and here to his happiness he found what he was searching—lumps, chunks, and granules of grayish iron ore.

The only thing that troubled him was whether the Back Creek connected to Chesapeake Bay. Pushing further down the river, Farmer suddenly realized that just ahead of him was the smooth and calm surface of the mighty Bay. The way for the construction of the blast furnace was clear, and Farmer hurried back to his tavern headquarters to report the findings to his friends.

Farmer obtained a lease on the Back Creek land from the Lord Proprietary of Baltimore, who was extremely anxious to obtain settlers for his crown land.

The shortage of labor was very serious. African Negroes were hard to get, and the Indians did not stay on the job. Hoping to get assistance, Farmer set out to Philadelphia. Labor problems here were just as bad as near the Back Creek, but a Quaker friend advised Farmer to get a regular blast furnace crew from England. He wrote a letter to his British partners, requesting them to send to the colonies a group of 20 to 30 indentured workmen from the English prisons. About six months later, Stephen Onion and the brothers William and Thomas Russell, brought a group of some 20 workmen whom they placed at the disposal of the Principio's master.

Construction started almost immediately, but the work progressed slowly. The workers were not happy with their lot and spent most of their meager wages on rum, which was plentiful and cheap in the colonies.

The construction of the stack was started in the fall of 1720, but the shortage of suitable sandstone for the structure of the furnace made the work exceedingly slow. By 1722, the letters of Farmer to his masters in England grew more and more flowery, but there were no shipments or iron outside the 3½ tons of forged bars produced in 1718. Farmer arrived in London late in 1722, and gave an enthusiastic account of his accomplishments. This made the financiers of the Principio project even more suspicious and they decided to have an impartial expert, John England, investigate the entire matter.

Although John England was received with cordiality by Stephen Onion and William and Thomas Russel, they departed shortly for England, without accounting for the company's expenditures and the stock of the Principio plant. Both were in a sad state. In his report to London, John England complained bitterly about almost everything he found in Maryland, particularly the financial situation and the crew which was just about ripe for rebellion.

Inspection of the company-owned lands showed some to be entirely worthless. Investigation of the company finances disclosed that the treasurer, Stephen Onion, had used the money for his private deals, and mismanagement in the charcoal-making operation had almost doubled the price of this material. During the summer of 1723, England tried to bring the company business in order and periodically reported what little progress there was to London. The workmen were somewhat calmer now but occasionally England had to prove his superiority by sheer physical strength. His homelife was shattered when his wife died of homesickness in the early fall of that year. The outlook was indeed black—and yet, John England stuck to his young plant.

Gradually the situation improved. John England was declared the sole master over the company's entire operations in America. Starting just above the level of the two tuyeres, where Farmer left off, England's masons were now speedily finishing the construction of the Principio furnace.

Shaping of the interior was his personal concern. The furnace bosh, very carefully lined, widened rapidly a short distance about the hearth, to form a huge belly to hold charcoal, ore, and fluxes.

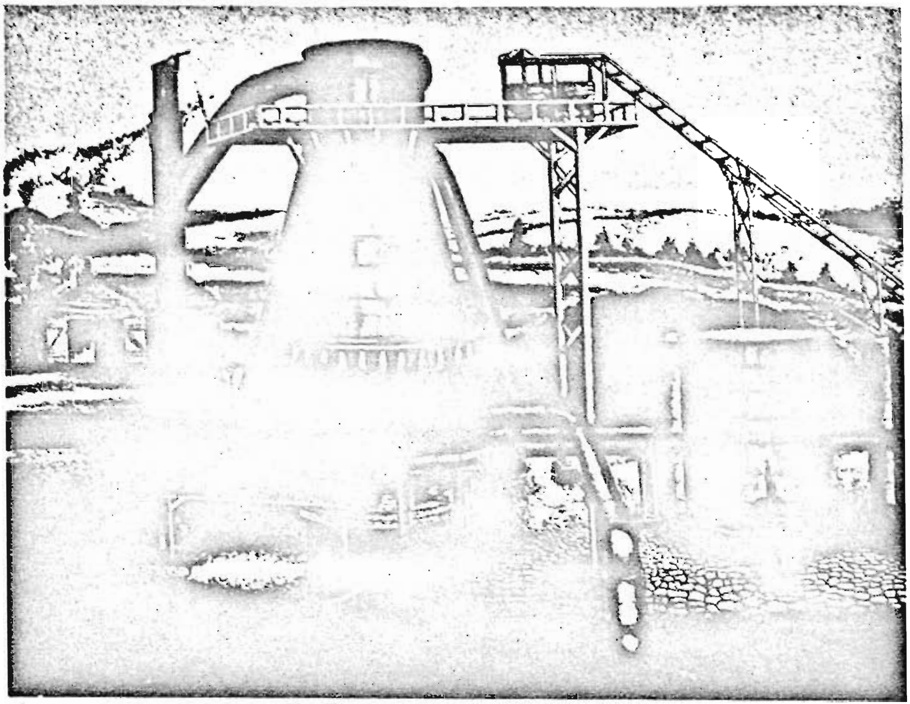
In the fall of 1724 the furnace was blown in. Right from the beginning, Principio iron flowed to Liverpool and Birmingham where it was sold at a most favorable price. However, the Principio Company was by now not only an iron plant but also boasted a complete plantation raising its own wheat, cattle, and vegetables, maintaining its own stores. The fame of the Principio Works and its manager spread quickly throughout the colonies and even Europe, with the result that many an ironmaster came to work for John England of Maryland.

A year after blowing in the Principio furnace, John England proposed to his British associates an expansion of the operations into Virginia. There, he wrote to London, were large deposits of good ore and extensive supplies of charcoal timber. He even selected the land which appeared most promising for the construction of a blast furnace—the property of Captain Augustine Washington. John England visited Captain Washington at the latter's Pope Creek home and proposed a partnership according to which Captain Washington would own two twelfths of the new plant while the rest would be divided among the English partners of the Principio Co., including John England. Captain Washington also contracted to haul iron ore to the furnace at the fixed fee of 20 shillings per ton of contained iron.

In the summer of 1726, the blast furnace on Washington's land was blown in and named Accokeek, which was the name of an Indian chief befriended by Washington.

Iron production of the Accokeek furnace exceeded the most enthusiastic expectations of the Principio Co., averaging from 40 to 50 tons per week. Both the Principio furnace and the Accokeek furnace became the center of attraction of the iron men from the colonies and the European countries.

The greatest tribute paid John England was by a man who had never seen the Principio installation; Emanuel Swedenborg, in his celebrated book *De Ferro* called Principio iron the best man ever made. John England was old by now, with hollow cheeks, and a long, patriarchal beard. De Ferro's remarks were almost like an obituary, for John England died only a few weeks later, in the autumn of 1734.



The David Thomas Co. furnace located at Catasauqua, Pa. Illustrations by E. W. Hale.

BLAST FURNACE U. S. A.

II. The Age of Mineral Coal

1750 to 1850: The scene shifts westward across the Alleghenys to the young town of Pittsburgh; charcoal gives way to mineral coal as furnaces grow larger and the blast is heated; above all, Pennsylvania iron is adding strength to the new Nation and building an empire in the West.

by M. O. Holowaty and C. M. Squarcy

TWO names are inseparably associated with the Pittsburgh iron industry—those of George Anschutz and John Hayden.

The iron ore deposits of southeastern Pennsylvania were found and developed early in the 18th century, and several forges and furnaces were built and operated. It was only after the revolution that the iron men crossed the Susquehanna River, built furnaces in the neighborhood of ore deposits of Franklin County, then along the Juniata River and its valley. Juniata Iron found a ready market in the Pittsburgh area. However, difficulty in transporting it across the Allegheny Mountains induced iron masters to seek ore and plant locations in the Pittsburgh district. One of the first to reach this area was George Anschutz, who migrated to America in 1789 at the age of 36, reaching Pittsburgh in the fall of 1790. Anschutz immediately set out to organize an iron company in Pittsburgh, and was able to interest some residents in his project. After being informed of an iron ore deposit located only three miles out of town (on the site of the present 26th St. and the Allegheny River) he decided to build there his blast furnace and foundry plant. Total cost of the installation was $300.

When the furnace was put in operation, Anschutz, now known as Red George, found that the ore deposit was only an insignificant one and would last no more than a few weeks. A new deposit was found on Roaring Run, in the southeastern corner of Armstrong County. Anschutz transported some of this ore to the mouth of Two Mile Run, where it was loaded on horse wagons and transported to the furnace. In this way, he operated off and on for several months, until the furnace was blown out in 1794.

After working for a year as plant manager for John Probst at Langhorntown, he built the Hunting-

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ton blast furnace in the county of the same name for Mr. M. Massey and Judge John Gloninger. This operated successfully, and he finally acquired one quarter interest in the plant. Anschutz retired in 1833, and died four years later in his beloved Pittsburgh.

While it was Anschutz who built the first blast furnace in Pittsburgh, the credit for being first to reduce iron ore goes to the Englishman John Hayden of Fayette County. In the summer of 1790, while searching for limestone, he found a deposit that closely resembled the bluish limestone shale of New Jersey, in the vicinity of the present city of Uniontown.

To convince himself of the find, he built a small kiln. After burning the stone for some time, he noticed that the particles fused together and had metallic luster. An examination convinced him that he had found iron ore and not limestone.

Hayden decided then to produce a sufficient amount of iron for a casting, by reducing the ore on a blacksmith forge. A blacksmith in Connelsville took interest in Hayden's problem and ran the experiment which produced several pounds of good grade iron. Hayden now knew that he had struck an iron ore deposit of major significance and decided to exploit it. Carrying his piece of iron, Hayden set out for Philadelphia with the intention of persuading his uncle, John Nicholson, the comptroller of the Commonwealth of Pennsylvania, to invest money in the venture.

Nicholson did not fail his nephew, and in 1791 Hayden was able to lay foundations for his furnace at Fairfield, about seven miles south of Uniontown. Construction was completed and the furnace blown-in in the summer of 1792. Hayden operated the furnace profitably for several years, and then sold it to Oliphant Brothers.

Although Hayden had a good start over his competitors, obtaining the necessary funds delayed him considerably, and before he was ready to produce, two other furnaces were already in operation. The first furnace west of the mountains was built by William Turnhill and Peter Marmie of Philadelphia, on the south side of the Jacobs Creek. The furnace was blown-in Nov. 1, 1790, and soon established an excellent reputation as part of the Alliance Iron Works.

The second furnace of Western Pennsylvania was built a few months later at Dunbar, by the famous Colonel Isaac Meason. Both furnaces were frequently called upon to work for the Government. Major Isaac Craig, deputy commander of Fort Pitt, ordered from Alliance Iron Works two tons of 6 lb solid shot, one ton of 3 lb shot and one ton grape. These were sent to Fort Washington (Cincinnati, Ohio) and used by General Wayne in the Battle of Fallen Timbers against united Indian tribes on the Maumee River. This encounter can be regarded as the first victory for Western Pennsylvania iron.

About the end of the 18th century, the future of the charcoal blast furnaces appeared bleak, in spite of the thriving market, because of the shortage of fuel. Fuel was available, but it had to be transported over increasing distances, which eventually brought the price of iron to the point where it was cheaper to buy iron imported from Europe than to use the domestic product.

Mineral coal furnaces—Early failures

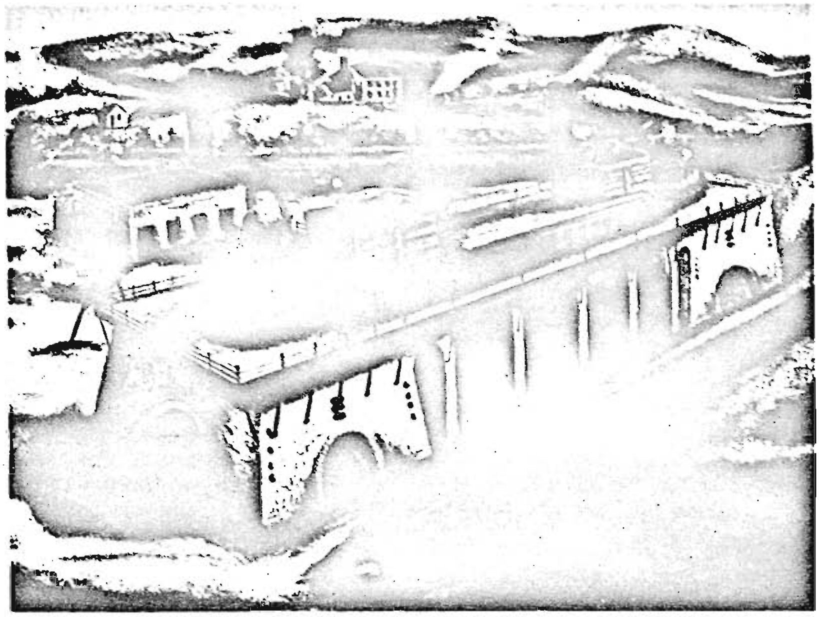
The first step to remedy the fuel situation was to reduce the consumption of charcoal by mixing it with mineral fuels which were readily available. It is almost impossible to determine when the first attempt in this direction was made, but it appears that the old Sterling charcoal furnace was among the first. The furnace was a small one, 5 ft diam at the bosh and 25 ft high. It was built, owned, and operated by the family of Townsends who were related to the Leonards of Saugus fame. The original furnace was located two miles north of the Sterling Iron Works in Warwick Township, Orange County, N. Y. It was apparently around 1770 or 1780 that small amounts of coal were added to the furnace burden. After many experiments, it was decided that coal from Schuylkill County, Pa., was well suited for the one tuyere, cold blast furnace if it did not exceed 1 bushel per 14 bushels of charcoal (approximately 10 pct by weight). This amount, however, was not enough to save the furnace, which was blown out around 1800. Experiences at Sterling profited other ironmakers in similar situations. In most cases, when coal was mined in the vicinity of the furnace (West Virginia, eastern and western Pennsylvania, southern Ohio, etc.) small amounts of it could be added without difficulties, while larger amounts tended to reduce the temperature of the metal.

One of the most interesting operations, from a historic point of view, is that of the Mill Creek Raw Coal Furnace of Master David Grier. His furnace which measured 7 ft across the bosh and 27 ft in height, and stood on Mill Creek, three miles north of Youngstown, Ohio. It was originally built in 1825 as a charcoal furnace. A few years later, difficulties of charcoal transportation and shortage of manpower in the charmaking department induced Master Grier to burden the furnace with bituminous coal mined in the vicinity. After a short experimentation, Grier developed his own furnace practice, according to which the charcoal burden was gradually replaced with bituminous coal until iron in the hearth solidified. The furnace was then slowly blown out and the furnace contents removed. The solid metal was sold as pig, while the sponge iron from the furnace shaft was sold to local forges at a premium price.

After a few years, about 1833, even this practice proved unsatisfactory, since Grier's customers found little attraction in his slogan of *Coal Flame Superior Iron.* The furnace continued to attract sightseers because of an "enormous yellow flame burning at its mouth and visible at night for miles." The Mill Creek furnace was rebuilt to a 9-ft-diam, 30-ft-high unit equipped with hot blast apparatus in 1839, and kept producing small amounts of iron until 1855, when it was finally abandoned.

Starting in 1825, several midwestern furnaces tried peat in the blast furnace. The last and most widely publicized attempt was made by the Lake Superior Iron Company on its 9x45-ft peat furnace at Ishpeming, Mich., in 1873. This method proved uneconomical, although the furnace was known to be still in operation in 1874.

The most unorthodox approach was taken by William S. Scollard, manager of the Springfield hot blast charcoal furnace located at Springfield, Mercer County, Pa. The furnace, which measured 9 ft across the bosh and 35 ft high, was built in 1837. The furnace was burdened on several occasions with dried wood (specie unknown) to relieve the local shortage of charcoal. The exact data on this furnace



An early American coke furnace, similar to many which appeared in Pennsylvania between 1830 and 1850.

are not available, but apparently it continued to operate on the charcoal-wood burden for several years. The serious shortage of charcoal, and later on also that of high grade iron ore, brought about abandonment about 1850.

The coming of anthracite

The use of anthracite in the blast furnace was already established by the end of the 18th century. It was limited, however, to a small number of furnaces located in the anthracite region of Pennsylvania, and to rather insignificant amounts of the material, which was used together with charcoal. The proportion between charcoal and anthracite was usually maintained between 10:1 and 4:1: Amounts larger than 25 pct considerably impaired the performance of the blast furnace and caused the iron to run cold.

Numerous instances of the partial anthracite burden can be found in the literature. Among the oldest reference to *cheaters,* so called for substituting anthracite for a portion of charcoal, is a mention of the Green Mountain Iron Co.'s blast furnace manager Royal Blake, who ". . . every 14 or 16 bushels of charcoal would add a bushel or two of anthracite." Blake's furnace, located in Brandon Village, Vt., was relatively small, its dimensions being 7½ ft across the bosh and 21½ ft high. It was rebuilt around 1854 and converted to a hot blast charcoal and anthracite furnace. The conversion, however, was not successful and the furnace was finally abandoned in 1855.

One of the best known charcoal-anthracite furnaces was the Franklin charcoal furnace of the New Jersey Franklinite Co., built in 1770. It had a 6½-ft bosh and measured 20 ft in height. Small amounts of anthracite were being added in 1805. The amounts were gradually increased until they reached approximately one third of the total fuel burden in 1847 after the furnace was converted to hot blast. The Franklin furnace was used in 1854 for an experiment which was unique in the history of the American blast furnace. The metal burden of the furnace was changed to high zinc iron ore in an attempt to produce both metals from local deposits simultaneously. The experiment failed and the stack had to be rebuilt completely.

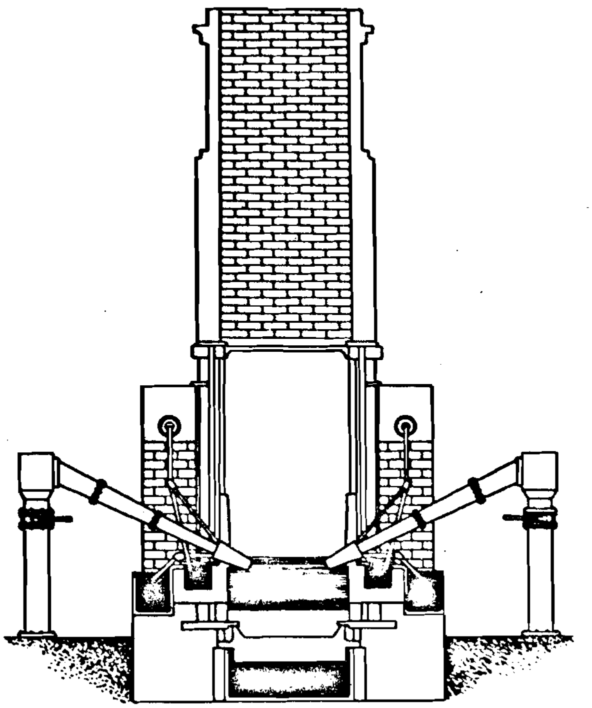
Another attempt to use anthracite was made at the Pioneer furnace owned and managed by J. W. Atkins and his brother, Samuel. The furnace which was built in 1837, was in constant trouble and a notoriously poor producer. Hanging and slipping of this furnace became a byword of the Pennsylvania ironmakers. Fortunately enough, the situation was of short duration. Beginning in 1840, the performance of this first American furnace operated along the rules established by Thomas, began to improve considerably, until by 1850, it was regarded as one of the most efficient furnaces in the country.

The increasing shortage of charcoal induced the Pennsylvania legislature to pass in 1836 an act "for the encouragement to manufacture iron by mineral fuel." The act gave the governor authority to charter companies with ample powers in regard to the stock and quantity of land which might be required. It was probably this act which stimulated the widespread investigations of the applicability of anthracite in the American blast furnace.

The earliest attempts to use anthracite for smelting of iron was made in 1820 by the Lehigh Coal and Navigation Co., which erected a small experimental furnace near Mauch Chunk, in Carbon County, Pa. Mauch Chunk was modeled after the plant at Vizille on the border of France and Switzerland. The Vizille trial was conducted under the supervision of the most famous blast furnace men of Europe, Geynard and Robin, who in 1810 concluded that in furnaces operating on cold blast, use of anthracite in the burden is usually detrimental.

At Vizille, the maximum amount of anthracite which could be charged into the furnace was established at 40 pct. Beyond this level, the furnace began to display strong tendencies to hang. At approximately 50 pct of anthracite in the fuel burden, the Vizille furnace froze entirely. The results at Mauch Chunk confirmed those of Vizille. In May of 1826, W. McDowell, manager of the furnace, recommended to George Crane that further tests be temporarily discontinued, since the furnace was solidly frozen.

The furnace was dismantled and remained inactive until 1837 when a new series of anthracite ex-



A bloomery similar to the type operated by Col. Alexander Spotswood in Virginia.

periments was started, only to be discontinued in 1839. The failures, however, did not produce a general discouragement and resignation. In fact, they became a challenge to the intelligence and know-how of the blast furnace men who had to use anthracite to survive. They took up the challenge, and created the glorious era of anthracite iron.

Hot blast

During the early decades of the 19th century, the production capacities of blast furnaces were increasing continuously, though at a comparatively slow rate. While an average American furnace was making about 18 tons per week around the turn of the century, production increased to 21 tons by 1806, and 34 tons by 1827. The increase was achieved, however, by increasing the size and blast volume of the furnaces, and by improving the quality of the ore burden. The turn of the century was a milestone of the ironmaking processes since somewhere around this time the operators began to impose stricter requirements on the quality of their ores, the first steps being manual elimination of larger lumps of rock.

English iron masters watched with growing concern the rapidly diminishing reserves of wood for production of charcoal. Experiments with mineral coal as blast furnace fuel continued, therefore, without interruptions in all major iron works of the British Isles. The solution was nowhere near, however, when it occurred to the mind of the Scotch ironmaker, James Beaumont Neilson, in 1828, to reduce the consumption of fuel in the furnace by preheating the blast. In spite of the opposition of many contemporary physicists and chemists, the idea was tried in 1829 at the Clyde Iron Works and, to the surprise of all, it worked.

The first hot blast apparatus of Neilson was very simple. The stove consisted of a rectangular wrought iron heating chamber, about 4x2 ft, and 3 ft high. The chamber was set in brickwork which was also equipped with a fireplace underneath. The top-plate of the chamber was left exposed to the atmosphere. The cold blast entered the chamber immediately over the grate and passed out from the opposite end directly into the tuyere at a temperature of about 200°F.

Each tuyere of the furnace was equipped with one heating chamber. The effect of even this moderate heat was truly astonishing. The production rate of metal increased overnight by about 100 pct without increase of fuel. Neilson became the center of attention of the European ironmakers who pilgrimaged to the Scotch plant. Neilson's idea, however, contributed little to the change of the attitude of these blast furnace men as far as construction of the furnaces is concerned. Satisfied that his invention considerably improved the productive capacity of their furnaces, they kept building in the same traditional manner. Thus, typical furnaces built from 1820 to 1850 were 45 to 50 ft high with bosh diameters from 10 to 16 ft.

In the meantime, Neilson, realizing the shortcoming of his first blast heating apparatus, kept working on improving the heating chamber. The next step was a cylindrical vessel of cast iron, bottle shaped at each end, 2 ft 9 in. in diam and 6 ft long. The chamber was fixed in horizontal position over a fireplace and wholly enclosed in brick work to reduce the heat losses. The temperature of the blast was thus raised to 280°F.

Still unsatisfied, Neilson invented a new pipe heating chamber which raised the temperature to 600°F. The new apparatus consisted of an arrangement of cylindrical cast iron pipes 18 in. in diam, fixed horizontally and united by flanges. These pipes formed a continuous length of 100 ft and offered to the blast 240 sq ft of heating surface, which was more than four times that of the bottle-type heating chamber. The grate area on each of the heating chambers measured 28 sq ft. In this apparatus the actual hot blast was first produced. The pipe stoves of Neilson showed great disadvantages, of which the most important was breakage of pipes. This occurred usually in places of contact with carbonaceous fuel resting on the grate, which could not be avoided.

Arched pipes, introduced by Neilson as the next improvement, helped only to a limited degree. In order to prevent overheating, the arch pipes were elongated into syphon-shaped tubes and removed from the proximity of the grates. Thus the pipes conducting the blast were heated by hot combustion gases produced in the separate adjoining fireplace.

Still another improvement in the blast heating apparatus found its way to the Pennsylvania iron works of the 19th century. This one was called the box foot pipestove, and consisted of a series of cast iron boxes, each of which had two sockets on top. The heating pipes were syphon shaped and were set vertically in the respective sockets of two adjacent boxes. The blast passed up one leg of pipe and down the other, and so on through the entire system. These stoves were originally built at North Staffordshire, England, around 1848. They were subsequently listed as Neilson's box foot installations at several plants of the Lehigh Valley. All of these ovens were fired by solid fuel, preferably hard coal.

Another type of stove, called the oval oven, was developed by Josiah Smith in England around 1852. Smith inserted a straight length of main between the ends of each of the semi-circular mains of the conventional box stove, thus increasing the number of the pairs of pipe from 24 to 33. This, according to data in the literature, was found to be such a great improvement over other blast stoves that another oval oven was erected in which the mains were further elongated to accommodate 36 pairs of pipe. The Parkfield furnaces near Wolverhampton and a dozen installations in nearby New Jersey and Pennsylvania were equipped with this type of blast heating apparatus.

Utilization of waste gas: 1832

The next improvement in the development of the blast furnace is rightly attributed to Fabre du Faur, who about 1832 obtained a patent on the application of the blast furnace waste gas to the preheating of the blast. Following the original experiments of du Faur in Germany, the idea was picked up by Perry at Ebbwvale, England, and found to be extremely economical. The work was described by Percy as follows:

> "At Blaina and Ebbwvale I saw the application of waste gas of the blast furnace carried out apparently to perfection. I have never witnessed any metallurgical operation with more pleasure than that of these hot blast stoves and I felt no small degree of commiseration for iron masters who still pursue the old plan of using solid fuel such as coal-slack however cheaply it may be obtained. Mr. Levich of the Blaina Iron Works assures me that the savings affected at his works by the application of waste gas of the blast furnaces to the heating of the hot blast and steam boilers is equivalent to 600 tons of coal a week".

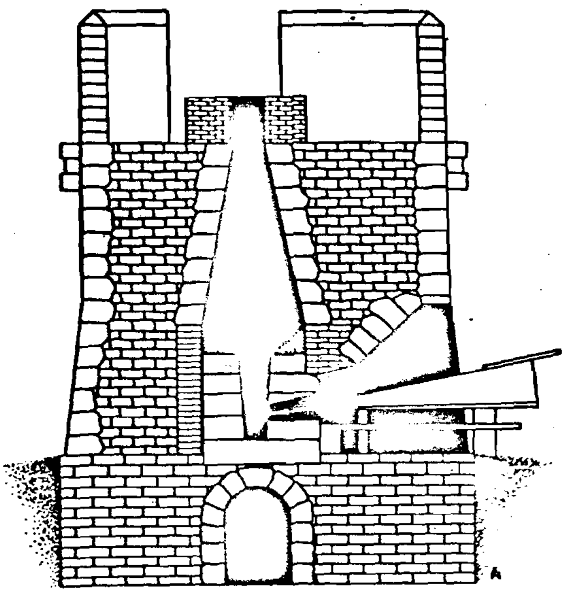
It was this type of hot blast stove which was installed between 1854 and 1856 on three coke furnaces of the Cambria Steam Hot Blast Coke Furnace Co. located at Johnstown Flat, in western Pa. The exact size of the Cambria blast stoves is not known, but it is significant that the plant was the first one in the U. S. to use one large steam blowing engine to provide blast simultaneously to three separate furnaces. It is also of interest to note that Kelly's converter process was put to test here between 1855 and 1860.

The Blaina hot blast stove was the forerunner of the Cowper stoves which eventually became the standard for the entire blast furnace industry. The gas heated blast stoves belong in fact to the period of coke furnaces. It was the coal heated blast apparatus of Neilson and Thomas which actually broke the spell of small charcoal furnaces and put the anthracite furnace in operation, thereby contributing considerably to the growth of the mightiest steel industry of the world.

The anthracite glory

The era of the American anthracite blast furnace was born in 1839 when David Thomas blew in the Pioneer furnace at Pottsville, Schuylkill County, Pa. Thomas was an Englishman who came to this country on the invitation of Mr. Erskin Hazard of the Lehigh Iron & Navigation Co. for the distinct purpose, clearly specified in his contract, of building initially one and then other anthracite furnaces for the company.

The Yniscedwin Iron Works in Wales, where Thomas worked as a young man, were on a deposit of anthracite coal, which was considered useless as far as operation of blast furnaces was concerned. Thomas thought frequently about using anthracite, and with the assistance of George Crane, the owner, proceeded to experiment with anthracite as partial fuel burden of his furnaces as early as 1820. The amount of anthracite was small and never exceeded 8 pct of the total fuel burden. According to Thomas, the furnace performed quite well under these conditions, but whenever something went wrong, the anthracite was blamed. Finally the furnace operators became prejudiced against the raw fuel and Thomas was forced to give it up. Thereafter, he repeated his experiments almost every year. In 1825, he built a separate experimental furnace for the test runs with anthracite. The furnace was 28 ft high and had a 9-ft-diam bosh. Thomas burdened this furnace with increasing amounts of anthracite, but to no avail. The furnace ran cold and the tests had to be discontinued. Thomas rebuilt the furnace in 1830. He extended the shaft to 45 ft height and widened the bosh to 11 ft diam. The experiments were much more successful than previously, but the consumption of coal was so high that they had to be abandoned.



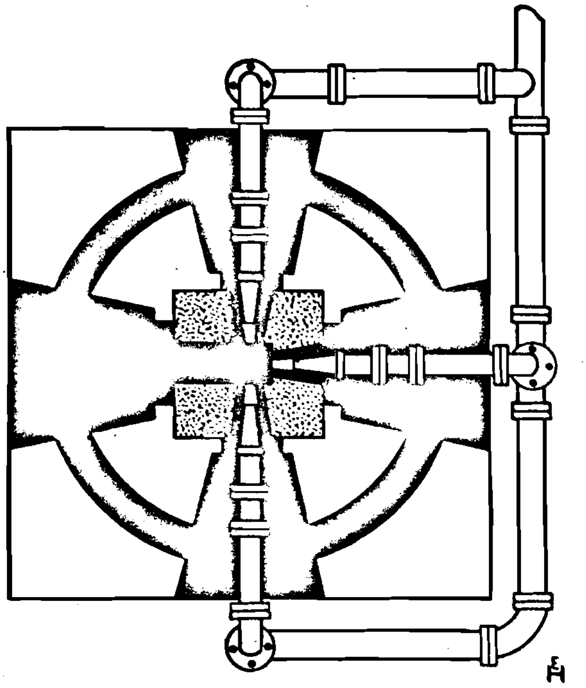
Profile of an early American charcoal furnace.

About this time experiments were also being made with anthracite at Mauch Chunk, Pa., with just about the same success.

In 1829, while the experiments were going on on both sides of the Atlantic, Neilson of Glasgow, totally unaware of Thomas' problems, obtained a patent for his hot blast apparatus. Thomas and Crane immediately recognized that Neilson's discovery might be the key to the successful utilization of anthracite in the blast furnace. Consequently, Thomas traveled to the Clyde Iron Works in Scotland to see the operation. Thomas returned to Yniscedwin with Neilson's license, now thoroughly convinced that hot blast would solve his anthracite problem.

Together with a mechanic brought from the Clyde Iron Works. Thomas built the first blast stove for an anthracite furnace, which was blown in on Feb. 5, 1837. The operation of the furnace was a complete success and the furnace produced pig iron of good quality at a satisfactory rate.

In May of the same year, a Mr. Roberts from Philadelphia came to visit George Crane, saw the furnace in operation and reported this immediately to his uncle, Josiah White of the Lehigh Coal and Navi-



Tuyere arrangement of a 19th century anthracite furnace.

gation Co. White, who previously had participated in many of the experiments on the use of anthracite at Mauch Chunk, immediately grasped the significance of Thomas' furnace and dispatched Mr. Erskine Hazard, his friend and vice president, to evaluate the development in England and to bring to this country someone who could build and operate an identical furnace in Pennsylvania. Hazard arrived in England in November 1838, found the furnace in full operation, and began negotiations with George Crane.

Hazard convinced Crane that Thomas could be more valuable in the U. S. than in England. Together, they went to see Thomas. Crane and Hazard presented Thomas a realistic picture of the blast furnace problem in America, and urged Thomas to accept the call of the new nation. It was a difficult decision; years of peaceful and satisfying life in the rural surroundings of Wales, and countrywide acclaim as inventor of the successful anthracite blast furnace assured him everything for which he dared to hope. However, the new world contained a challenge which Thomas could not refuse.

Thomas comes to the U. S.

The contract was signed on Dec. 31, 1838, and the Thomas family sailed in May 1839. Thomas arrived in Allentown, Pa., and proceeded almost immediately with the plans for the future iron works. Surveys and plan drawings were completed about August 1, and the work was started on excavations for the foundation of the wheel pit, which was to be the raceway to the water wheels, and the canal for supplying the raw materials to the furnaces.

A few weeks later, foundations for the furnace itself were started. The furnace was to be 30 ft square at the base, having a 12 ft-bosh and a height of 45 ft. The masonry was laid by Isaac McHose, whose son Samuel was subsequently builder of almost all anthracite furnaces in the Lehigh Valley. The hot blast stove of the furnace consisted of four ovens of 12 arched pipes each. The pipes measured 5 in. ID, 1½ in. in thickness in the straight sections, and were 2 in. thick in the arches. The stoves were built on the ground and fired with coal. The joints on the pipes were made with liquid cast iron, the point of junction of the arch pipes being carefully sealed to prevent the iron from running into the bed pipes. After the joints were made they were covered with salt and sal-ammoniac water which rusted them perfectly tight. The stoves were capable of heating the blast to approximately 600°F.

The arrangement for filling the furnace consisted of a water balance-type elevator in which square boxes were attached to each end of a chain. The chain in turn was wound around a wheel with a brake. While water was filled into one of the boxes, the load in the other box was lifted to the top of the furnace. As soon as this happened the water box touched a trip mechanism which emptied the water from the box and the entire procedure would be repeated.

The first American blast furnace built exclusively for anthracite was blown by a breast wheel 12 ft in diam and 24 ft long. Water falling from a height of 8 ft furnished the power. On each side of the wheel were segments geared into pinions on double tracks driving two blowing cylinders. The cylinders were 5 ft in diam and had a 6-ft stroke.

The blast from the cylinders was subsequently conducted through an 18-in. cast iron pipe to the stoves and hence to the furnace. The flow of the blast was pulsating constantly and the strokes of the cylinders could be counted as well at the furnace as at the wheelhouse. The blowing cylinders were made out of necessity in the U. S., because cargo ships refused to take aboard the huge English machines weighing several tons each.

Merrick and Towne built the cylinders and subsequently received numerous other orders from the mushrooming anthracite industry. The original cylinders which were made in England, arrived a few months later and were used in various installations as late as 1905. After many delays, the No. 1 Crane Co. furnace was blown in at 5 pm on July 3, 1840.

Use of Anthracite Expands

The Catasauqua furnace was not the first American blast furnace to operate on anthracite, for after extensive experimental runs in 1838 and 1839, the Mauch Chunk furnace was reactivated as an anthracite furnace, David Thomas helping with advice. It was not the old Mauch Chunk furnace any more; the furnace had been rebuilt in 1837 at a site about half a mile closer to the village of Mauch Chunk. The stack of this furnace was 21½ ft high, 22 ft square at the base, and 5½ ft across the bosh. The hearth had a rectangular cross section measuring 14x16 in.

Blowing apparatus consisted of two cylinders 6 ft in diam actuated by a water turbine 14 ft in diam and equipped with 36 water buckets. Design of the hot blast apparatus is not described in the literature. It was built, however, according to a drawing provided by Thomas shortly after his arrival in the U. S. The furnace was blown in on August 27 and operated continuously until Sept. 10, 1839, when the run was discontinued because of difficulties in the hot blast apparatus.

The Pottsville furnace of the Crane Co. was the scene of a similar experiment in the same year. The results indicated, however, that the basic approach of Thomas, who also designed the Pottsville hot blast apparatus, was entirely sound. The operation at Pottsville was resumed in August 1840, about one month after the blowing-in of the Crane Co. No. 1 furnace at Catasauqua, Pa.

The date is a memorable and important one because the Catasauqua anthracite blast furnace proved to be a milestone in the steel industry of the U. S. This furnace was the model for the development of the entire Lehigh Valley iron industry, which was later to give the national armies under Ulysses Grant the decisive advantage over the industrially undeveloped South.

To David Thomas must go much of the credit for this tremendous new development. By accepting a position with an unknown American organization, he gave the activities of the young and energetic people all he had—his knowhow and his love of the iron trade.

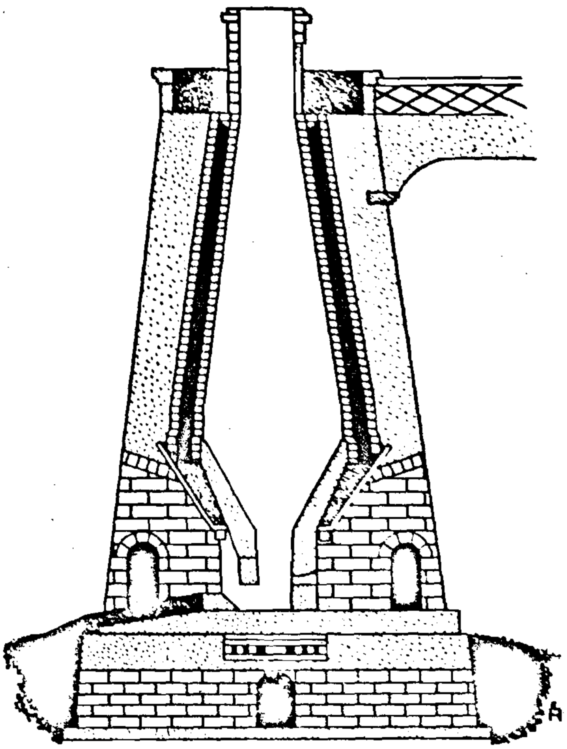
The first Thomas furnace remained on blast until it was ruined by the great flood of January 1841. In the period of the six months of operation the furnace produced 1080 tons of iron with the maximum weekly output of 52 tons. In the meantime, the ore mines had to be developed and transportation of raw materials provided. Ore mines were established in the immediate vicinity of the furnace with none of the hauls longer than 32 miles. The metallic mix was on the average 25 pct magnetite and 75 pct hematite. The No. 1 Catasauqua furnace was blown in again on May 18, 1841 and until its shutdown on Aug. 6, 1842, produced 3316 tons of pig iron.

Thomas, now famous, was highly respected throughout Pennsylvania. He was frequently consulted by enterprising men on various problems encountered in building anthracite blast furnaces. The first ones to follow in the footsteps of the Crane Co. were H. Post of Stanhope, N. J., Henry at Scranton, Firmstone at Glendane, Governor Porter at Harrisburg, and Dr. Echert at Reading. By 1846, there were 40 anthracite furnaces concentrated in clusters along the Lehigh, Schuylkill, Hudson, and Susquehanna Rivers.

Thomas was involved to a greater or lesser degree in almost every one of these installations. Usually it was only to advise and suggest. From time to time, however, he drew plans for the installations and as his time allowed, supervised construction himself. As far as could be determined, Thomas built a total of five furnaces for the Lehigh Crane Co. in the decade ending in 1850.

The anthracite iron masters were truly progressive. In 1847, a novel experiment was tried on Crane Co.'s No. 3 Furnace, by passing a strong electric current through the molten iron collected in the hearth. The thought behind this was to reduce the phosphorus content of the iron by electricity, which at that time was considered a cure for all ills. This experiment was terminated quickly when the current from a 100-cell battery caused only a severe electric shock to the blower foreman but not the slightest reduction of the phosphorus content of iron.

During 1849 and 1850 the Crane Company added two more furnaces to its famous plant. Furnaces 4 and 5 were identical and measured 18 ft in bosh diam and 45 ft in height. The blowing engines on both these furnaces were the largest made heretofore in the U. S. They had a 7-ft-diam cylinder, a 9-ft stroke and could blow under pressure up to 5½ psi, which was quite unusual in those times. After the first few months of operation it became evident that the furnaces were too short for the volume of available air (9500 cfm). Consequently, they were raised to 55 ft in 1852 and from then on, each produced on the average 300 tons of iron per week. Starting with 1857, the furnaces held the production records of all American anthracite blast furnaces, each averaging upwards of 10,000 tons of iron a year.

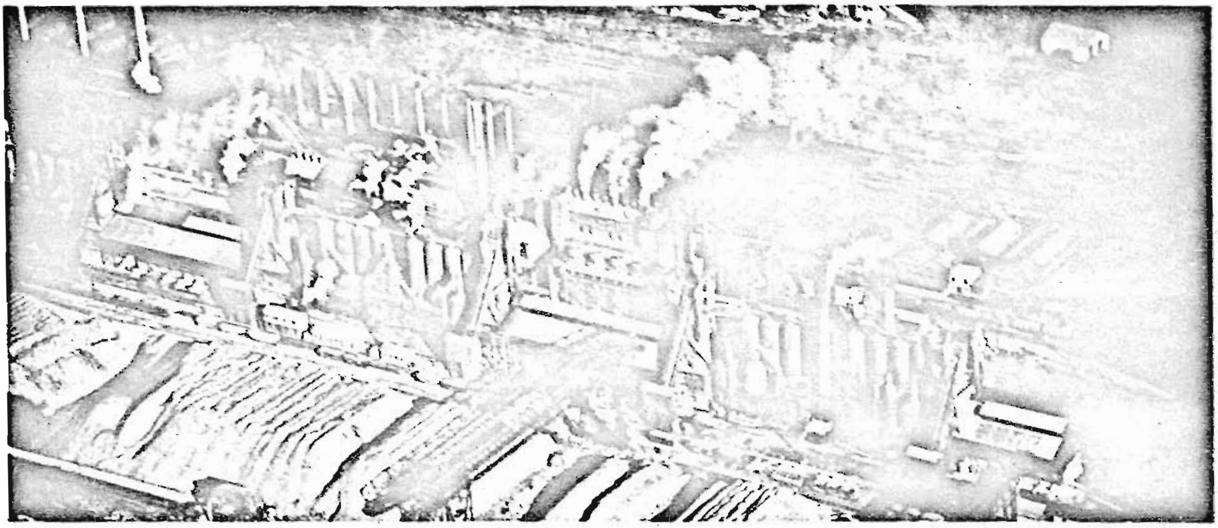


Profile view of a 19th century anthracite furnace.

Thomas left the Lehigh Crane Co. in 1854 and established his own iron and steel company with two blast furnaces at Hockendauqua, Lehigh County, Pa. The plant was located on the Lehigh River about one mile above the Crane Works. It was connected by a spur with the main line of the Lehigh Valley Railroad. The plant was only four miles from Allentown, Pa., and was managed by David Thomas and his son Samuel; it was regarded as the example of an efficiently operated plant.

Both Thomas Co. furnaces were 18 ft in bosh diam and 60 ft high. They had one common blowing machine consisting of two cylinders blowing under pressure of 8½ psi. Pig iron production of these two furnaces kept increasing gradually from 17,446 tons in 1856 to approximately 23,000 tons in 1859. Not much is known about the fate of the Thomas furnaces, except that they were abandoned like other anthracite furnaces early in the 20th century.

Production of anthracite pig iron in America increased rapidly from approximately 22,000 tons in 1842 to 393,000 in 1856, of which 306,000 tons were produced in Pennsylvania. The mushrooming iron industry contributed considerably to the changes in the living standard and social structure pattern of the young Nation. The heavily populated areas of the Eastern basin represented strong drawing points for the European immigrants to the U. S., who in turn added skill and perseverance to the industrial impetus of the growing world power.



Aerial view of the Aliquippa Works of Jones & Laughlin Steel, showing five blast furnaces.

Blast Furnace U.S.A.

III. From Falling Creek to Zug Island

Bituminous coal furnaces give way to coke, and by 1880, the American iron and steel industry was growing at a tremendous rate. In the twentieth century, the number of operating blast furnaces was cut in half while pig iron capacity more than doubled.

by M. O. Holowaty and C. M. Squarcy

Bituminous coal furnaces

Attempts to relieve the shortage of charcoal by the use of bituminous coal in American furnaces began quite early. Use of bituminous coal in the blast furnace was restricted to areas lacking anthracite deposits but rich in deposits of bituminous coal. The largest concentration of bituminous coal furnaces was in Western Pennsylvania, West Virginia and Western New York state. Other areas included Kentucky and southern portions of the states of Indiana and Illinois.

The first trials were made in Pennsylvania around 1780. Gradually several more furnaces began charging coal with their burdens as a partial substitution for charcoal. These so called *cheaters* were numerous, especially in Western Pennsylvania, which around 1810 began to expand its ironmaking capacity to catch up with the Lehigh Valley and the Schuylkill.

According to the existing references, complete bituminous coal burdens began to be used in this area only around 1840 when the ironmakers hastily adopted the hot blast apparatus introduced from England.

The majority of these furnaces were built, however, after 1844 when an extensive experimental program, carried out at the Shenango Steam and Water Hot Blast Charcoal, Coke and Raw-Coal Furnace produced favorable results, with coal containing up to 35 pct volatile matter. The furnace was located near the Shenango River on the Lackawannok Run, five miles northwest of Mercer, Pennsylvania.

It was built, owned, and operated by David Hogeland of Mercer. The first furnace was built in 1836 or 1837 as a charcoal furnace. Soon, however,

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difficulties in charcoal supply became apparent and Hogeland began experimenting with coal. The original Shenango furnace, known also as Big Bend Furnace, was 6 ft across the bosh and 28 ft high. Blast was furnished by a large water wheel.

Hogeland was a Dutch storekeeper who specialized in trade with coal miners and ironmakers of the Lehigh Valley. For unknown reasons, he abandoned his store and profession and went into partnership with Richard Shippen and Jacob Black, who jointly operated the Shippenville Charcoal Furnace at Shippenville, Pa. Hogeland learned the iron trade from Robert Montgomery, Manager of the Shippenville furnace and for many years thereafter his friend and ardent supporter. David was apparently in his fifties when he decided to investigate the iron smelting process in the blast furnace. Equipped with a keen, investigative mind he wanted answers which no blast furnace master could provide. Was screening of ore advisable? Could it be that limestone they were using was not taking out sulfur properly?, and above all—why could not bituminous coal be used for burdening the furnace?

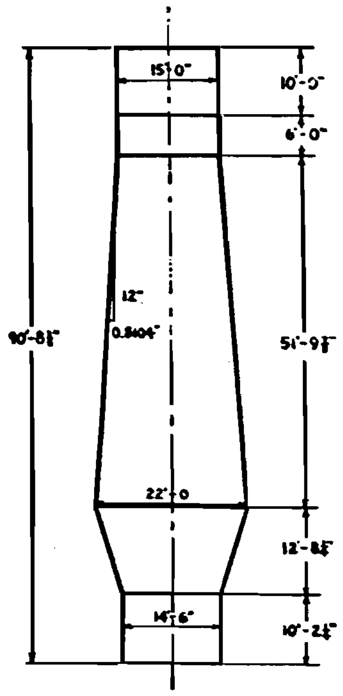
To find the answers, he finally decided to build a small furnace in Mercer County. Big Bend furnace was blown in 1837, and judging from its production records its owner was not wasting time with experimentations. Charcoal, various coals, and even the peculiar spongy fuel known as coke were tried on the furnace, only to prove that charcoal was the only fuel which could be used successfully. But Hogeland was not ready to give up.

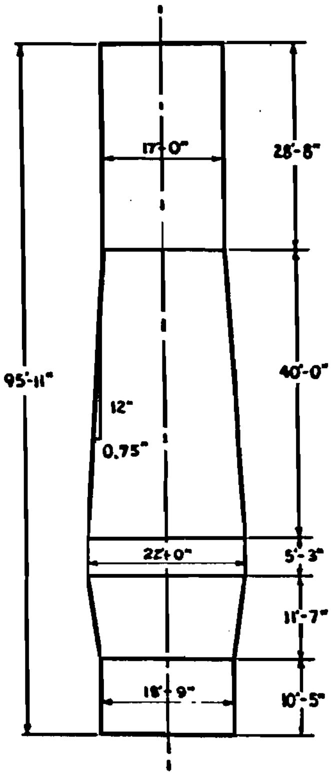
Strange stories were coming to Western Pennsylvania's coal basin that winter of 1839; an Englishman was building an anthracite blast furnace at Allentown. The neighboring furnace masters paid no attention to the new fangled hot blast idea, and even Hogeland seems to have hesitated, for he delayed the trip east until the summer of 1840. What he saw at Allentown's Thomas furnace, however, made him enthusiastic about the hot blast and his coal. Having ordered the necessary supplies and equipment, Hogeland went home and began making the required changes on his blast furnace. The hot blast equipment was installed in the spring of 1841 and water wheel was replaced by a steam blowing engine, recommended by Thomas. Hogeland also ordered several hundred tons of Eastern Pennsylvania anthracite and secured piles of various coals which he intended to investigate. Late in 1843, coke made in beehive ovens was also included in Hogeland's program, apparently because it was available from nearby Mercer.

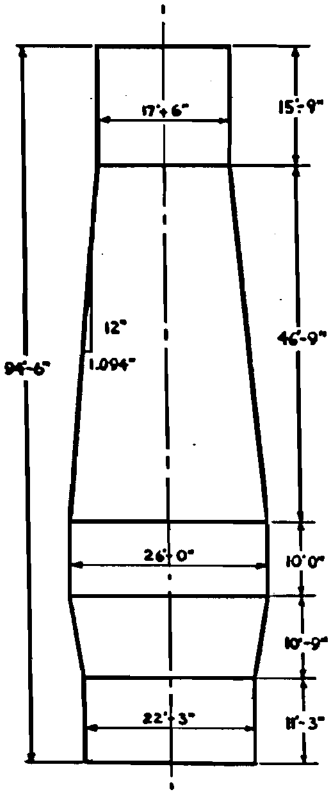
Hogeland's furnace was kept in operation until the summer of 1884 when it was torn down and rebuilt to a 7-½ ft bosh, 36 ft high unit. During various stages of Hogeland's experimentation the Big Bend blast furnace remained the center of attraction of many blast furnace men who came from far away to get expert advice and to see a real 100 pct coal furnace in operation. This explains the activity in the field of coal blast furnace construction around 1844.

Hogeland, the Pennsylvania Dutchman who made the bituminous coal furnace a reality, received the answers for which he was searching. Between 1845 and 1854, he operated his furnace just as he always thought he could—with either charcoal, coke, raw coal or anthracite or any mixture of them. The only available production record of this period shows that the furnace produced 1700 tons in 1854.

Considerable information could be gathered on the number and names of furnaces built and operated like Hogeland's Big Bend Furnace. All these furnaces were considerably larger than the original Hogeland coal furnace and consequently their pro-







ductive capacities were much higher. The average annual production ranged from 4000 to 5000 tons as compared to the record production of 1700 tons made on the Big Bend furnace.

The erection of furnaces in Indiana and Illinois was caused by the movement of the American population to the West which reached its peak between 1870 and 1880. The pioneers in the newly settled territories required iron and steel for the tools and simple machines which they had. Thus the construction of the furnaces in Indiana and Illinois was a natural solution to their iron problem, since the coal fields of these two states besides Missouri formed the Western boundary of the American coal deposits. Here about 10 furnaces were in operation in 1855. Two in Iron County, three in Francis, one each in Crawford and Franklin Counties.

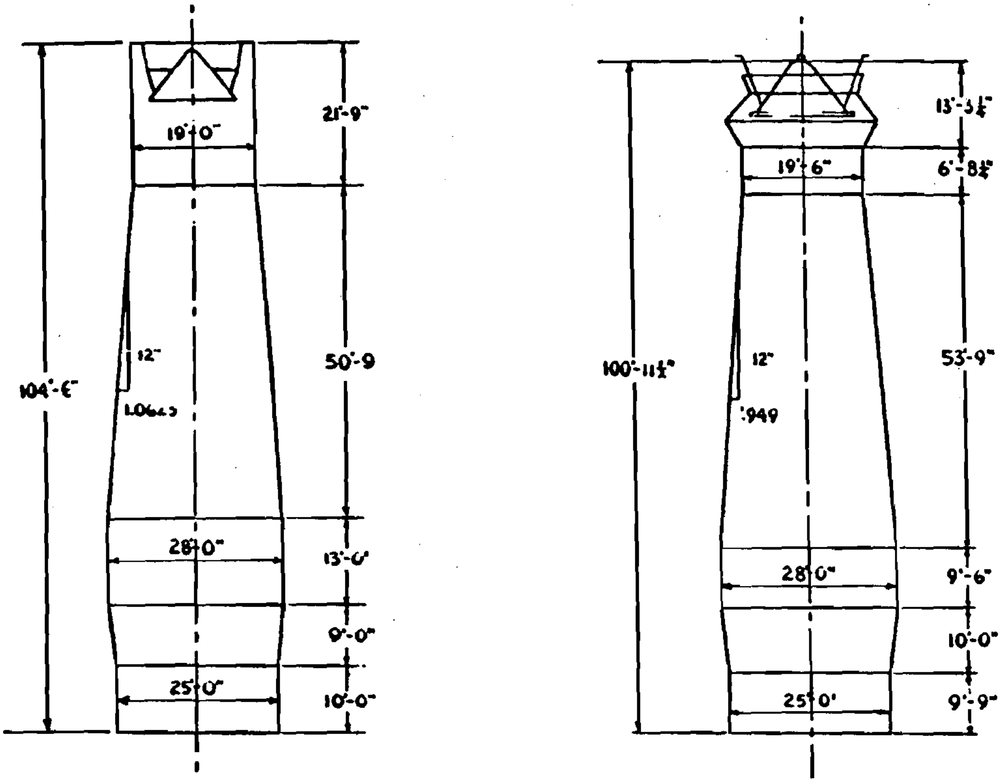
The most famous plant was the Iron Mountain Works of James Harrison, J. J. Scott and T. James who were also known as *The Three Jimmys*. Their first blast furnace was built in 1846, the second in 1850 and the third in 1854. The Iron Mountain plant was probably the most prosperous of the midwest.

The relatively short periods of existence of these furnaces does not appear unusual if one realizes the most serious drawback of their locations—the shortage of iron ore. Contrary to the iron industry of Ohio and Pennsylvania, Indiana and Illinois had no deposits of iron ore. Consequently, it had to be brought in by rail and horse wagons. The economy of these furnaces was such that they could not compete with Eastern iron which moved westward in increasing quantities as the steadily expanding network of railroads also moved west. The number of the blast furnaces in Indiana and Illinois was never large. The peak was reached in 1874 when Indiana had 12, and Illinois 11 furnaces in operation. The number kept decreasing regularly, however, and in 1890 there were only three furnaces in Indiana and four in Illinois.

The age of coke

When the Pennsylvania legislators in 1836 passed the act for encouragement of the manufacture of iron with mineral coal, they included in the bill use of "coal or coke" fuel, only after lengthy explanation by Mr. F. H. Oliphant of Fayette County, Pa. Mr. Oliphant was obviously referring to native mineral coke which was found occasionally in the coal beds of Pennsylvania and which he used quite frequently, since he and his brother purchased the Hayden furnace in 1797 or 1798. Mr. Oliphant, who was in charge of the blast furnaces at the Oliphant Brothers Iron Co., developed a strong interest in the peculiar coal that was delivered from time to time at the works. Some pieces of this coal were larger and harder than ordinary coal and were very porous. The *coak* coal did not ignite easily; Oliphant found that the best way to ignite it was by burning it with coal, and then it did not burn with the long yellow flame of coal but rather glowed intensely for a long time. Oliphant began to charge coke into his charcoal furnace sometime around the turn of the century. As far as could be deduced, only small amounts of coke were mixed with the charcoal burden. This is because only small amounts of coke were available and even those were regarded as nuisance rather than an asset to the blast furnace operations.

Oliphant and probably many other blast furnace men of that time were happy about being able to dispose of it in the blast furnace without decidedly unfavorable results. In 1835, Oliphant smelted a small amount of iron exclusively with coke. The coke iron and the raw materials used in its produc-



The contour lines of modern coke furnaces, showing the gradual increase in height and diameter. With furnaces such as these, U. S. pig iron production soared while the total number of operating furnaces decreased.

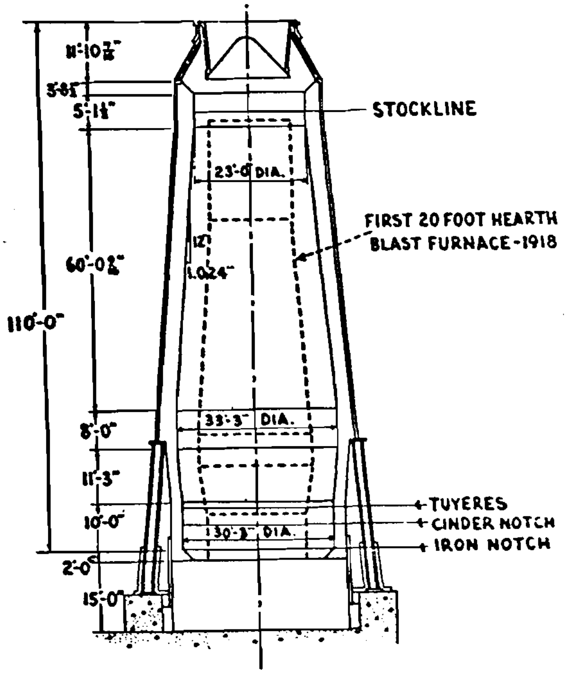
tion were sent to the Franklin Institute in Philadelphia where they were exhibited for a number of years.

The Oliphant Furnace was, however, not the first one to attempt production of coke iron on a commercial scale. The Lucy-Salina furnace of the Longdale Iron Company of Longdale County, Pennsylvania is reported to have been burdened with coke in 1828. The furnace was originally built in 1827 for exclusive use of charcoal. Gradually, however, small amounts of coke of uncertain origin were being added for trial purposes only. The original cold blast furnace was converted to a hot blast unit in 1842 or 1843 and gradually amounts up to 50 pct of coke fuel were being added. The furnace, which was rebuilt again in 1873 to 11 ft bosh diam and 44 ft height, operated after that time exclusively on coke.

The first major attempt to use 100 pct coke burden was made by William Firmstone at the Mary Ann Furnace in Huntington County, Pennsylvania in the spring of 1835. It was followed closely by the experiment of Frank Oliphant who also reported similar results.

During 1835, 1836, and 1837 blast furnaces were built at Carthouse and Ferrandsville on the west branch of the Susquehanna River and at Frozen Run near the Lycoming River. The Carthaus furnace produced several hundred tons of iron which, partly because of its high sulfur content and partly because of the superstitions of the old foundry men, proved unsoluble. The furnace was subsequently converted to charcoal.

The furnace at Ferrandsville was unfavorably placed in regard to the iron ore, which had to be brought over distances of 20 to 100 miles. The coke which was considered for this installation proved also to be of extremely poor quality, since it tended to "plug up the furnace and make it run cold". This was because the coals available were of poor coking characteristics and did not produce strong, hard coke. It appears that the coal in question was splint coal mined in the Ferrandsville area. The operations of this blast furnace were terminated in 1840 or 1841. The Ferrandsville plant practice, however, indicated clearly that the coke was being made from coal. This appears to be one of the first commercial coking operations in the United States.



Comparison of the contour lines between a 1918 furnace with 20 ft hearth, and blast furnace A of Great Lakes Steel Corp. at Zug Island.

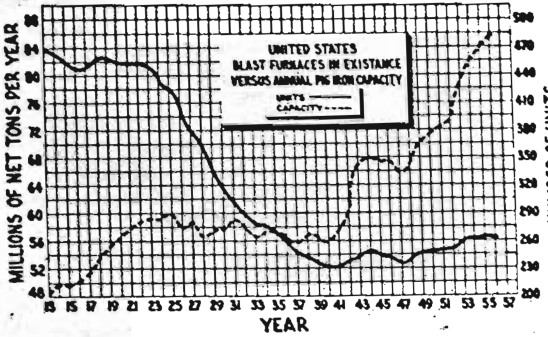
No better was the fate of the Frozen Run Furnace which, though located near the ore body, suffered under extremely poorly coking coals.

Tonnage spirals upward

Significant progress in the American iron industry began in 1880. The Struthers furnace of Ohio was one of the first which became famous for the amounts of iron it produced. It was 54 ft-9-½ in. high, had a diameter of 16 ft at the bosh, 9 ft 1-½ in. in the hearth. The fuel was raw coal (semi-anthracite). This furnace made 1627 tons of iron in December, 1871, and 1668 tons of iron in January, 1872. The best production week was 406 tons. In March of 1872 the production increased to 2064 tons.

There is a report about the Isabella furnace #1 near Pittsburgh, which was also famous in the iron industry. The dimensions were: height—75 ft, the bosh diameter 20 ft, and the capacity 15,007 cu ft. The furnace was in operation from January 1876 until May 1880 and made a total of 119,486 tons or an equivalent of 2,300 tons per month, with a consumption of 3153 lb of coke, blast temperature of 540 to 590°F and 0.6 to 0.9 lb pressure. The Lucy Furnaces of the Carnegie Phipps & Co. were also outstanding in their production. The dimensions of the furnace were: total height 75 ft, 20 ft at the bosh and 9 ft ¼ in. at the hearth, and total volume 15,395 cu ft. Mr. Curey who was the manager of the plant stated to Mr. Gayley that the contour lines were largely responsible for the excellent results obtained on this furnace which produced on the average 3338 tons per month in 1878 with a coke rate of 2749 lb per ton and made shortly thereafter 834 tons of iron in one week. The furnace was blown in September of 1877 but was shut down again shortly because of difficulties in the construction.

The blast furnace *A* of the Edgar Thomson Works was originally a charcoal blast furnace at Escanaba, Michigan. It was dismantled there and brought to the Thomson Works in 1879 and reconstructed. The dimensions were as follows: height 64 ft 11½ in., bosh diameter 12 ft-11⅞ in. hearth 8½ ft. The furnace operated with six tuyeres located at 5½ ft above the bottom of the hearth and measured 3-15/16 in. diam. The average ore burden to the furnace contained 54.5 pct iron. In March of 1880 this furnace produced 2806 tons of iron, with a coke rate of 2269 lb per ton. The blast volume was set at 15,007 cfm. which was almost double the average volume used on most American blast furnaces of the day. The experiences obtained with the *A* blast furnace at the Edgar Thomson Works were incorporated in the design of the second blast furnace whose dimensions were: height 79 ft 11-⅞ in., bosh diam 20 ft, hearth diam 10 ft-11-⅞ in., volume 17,867 cu ft. The selection of the hearth diameter was based on the results obtained by the Crane Iron Company in the Lehigh Valley, who was regarded as a top producer of iron. The production data show that from May of 1880, when the furnace produced 3777 tons at a coke rate of 2535 lb, the production increas-



Pig Iron Production Capacities by Furnaces and Districts in the U. S. A., 1955

District	No. of Furnaces		Total Annual Capacity, Net Tons
Eastern	54	(a)	17,690,000
Pittsburgh-Youngstown	95	(b)	30,495,350
Cleveland-Detroit	25		10,001,700
Chicago	48		16,830,500
Southern	12	(c)	6,427,080
Western	12		4,040,600
Total	261	(d)	85,485,230

(a) Includes 384,000 tons ferro-alloys capacity.
(b) Includes 322,800 tons ferro-alloys capacity.
(c) Includes 103,000 tons ferro-alloys capacity.
(d) Includes 809,800 tons ferro-alloys capacity.

Blast Furnace Dimensions

	Great Lakes *A*	Haven's 1940 Prediction
Hearth Diam	30 ft-3 in.	30 ft
Bosh Diam	33 ft-3 in.	32 ft-9 in.
Stockline Diam	23 ft	21 ft-6 in.
Bell Diam	16 ft-6 in.	16 ft

ed to 4798 tons per month in October of the same year with a coke rate of 2692 lbs. Another blast furnace was built in 1885-86 at the Thomson Works. The height and hearth diameter of previous blast furnaces was retained, but the diameter of the bosh was increased to 23 ft. The bell measured 12 ft. The total working volume was 19,774 cu ft. The furnace was put into operation in October 1886 and produced gradually increasing amounts of iron: in November of 1886, 6843 tons, 1874 lb of coke per ton, December, 7614 tons at 2072 lb of coke, and January, 1887, 8532 tons at a coke rate of 1905 lbs.

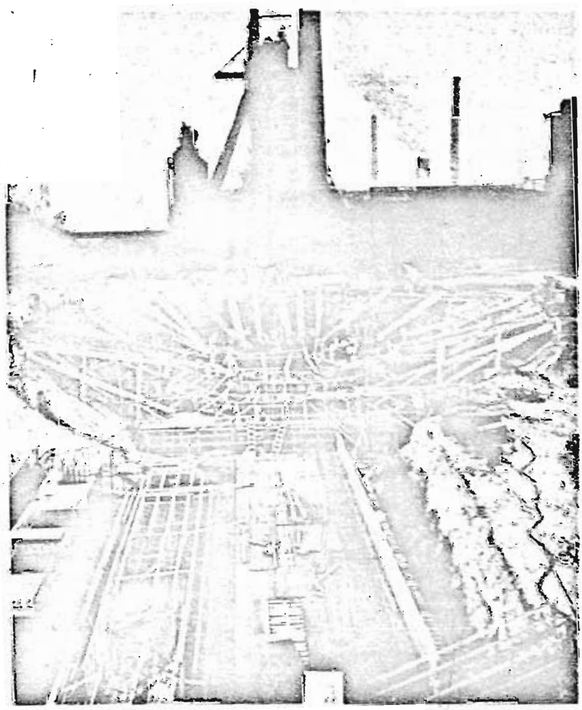
If production figures seemed high in the 1800's, they certainly outstripped all expectations by the 1900's. At this time a very significant change in the basic blast furnace design occurred when the height of the bosh was lowered from 20 ft to 12 ft on the Edgar Thomson *D* furnace. Because of the success of this radical change, it has remained with us today. The furnace was capable of averaging about 463.4 tons per day with a coke rate of 2227 lb per ton. According to George E. Rose, "Legend seems to ascribe this pulling down of the hearth of the mantle making the lower bosh possible to Pig Iron-Jim Gayley."

The next improvement was the increasing of hearth diameter. Certainly one of the factors involving this change was a natural reluctance on the part of blast furnace designers to develop a non-penetration area at the tuyere zone. Gradually this reluctance was overcome as success in the form of greater production followed the increased hearth diameter. Possibly this non-penetration was avoided, at least in part, because maintaining the almost universally successful 12 ft high bosh at the same time gradually increasing hearth diameter naturally resulted in a similar gradual increase of the steepening of the bosh angle. For example in 1905, the bosh angle was 76° and by 1927, South Works No. 7 furnace had a bosh angle of 80° 33″. The average daily output for this furnace in 1929 was 679.6 tons with an average coke practice of 1839 lbs.

Hearth diameters continued to increase, but when 18 ft 9 in was no longer enough, 22 ft hearth diameters became necessary. The point at which the 22 ft bosh diameter had to retreat was when the gradually increasing hearth diameter itself finally reached 22 ft. Then, in order to have a bosh at all, the bosh diameter had to be increased to 26 ft. Departure from this tradition took place at Gary No. 9 in 1927. The average daily production was 880 tons with a coke rate of 1845 pounds. The total production for three years was 939,000 tons.

Although the era of the new big 1000 tpd furnace was initiated by the Ohio Works No. 2 in 1929, it was not until the first depression years that several others began to be built. Inland's No. 5 was built in 1937 with a bosh and hearth diameter of 28 ft and 25 ft respectively, similar to Ohio Works' No. 2 of 1929. Choice of these dimensions undoubtedly was influenced by the *ideal* blast furnace profile recommended by the Blast Furnace & Coke Association of the Chicago District, whose findings were published about that time

Furnaces continued to grow in size and their auxiliary equipment in proportion, but since the breakaway from the 22 ft bosh, no significant new structural changes were made. Great Lakes *A* Furnace at Zug Island was completely rebuilt in 1934



Laying of the foundation for Kaiser Steel's fourth blast furnace at Fontana, Calif. Scheduled for operation early in 1958, the furnace is expected to push Kaiser's output close to the goal of 3 million tons a year.

and represents the giant or size. Hearth diameter is 30 ft 3 in., bosh diameter 33 ft 3 in. The total working volume is almost 65,000 cu. ft.*

William A. Haven predicted dimensions for a 30 ft furnace approximately 15 years before the furnace was constructed. The furnace had 24 tuyeres and a blowing engine capable of 125,000 cfm at 35 psi.

No history of blast furnaces in the United States would be complete without a mention of the recent westward development. Henry Kaiser's plant, built in 1942, was the first successful unit to operate on the west coast. Certainly the existence of the war hastened this move. *Bess* was blown in on December 31, 1942 and produced 2,012,266 tons on her first 5-½ year campaign. Today three 25½ ft furnaces are successfully operating at this site, with a fourth under construction.

Perhaps another result of World War II was the introduction of high pressure at the furnace tops. The first furnace where this technique was used was the D.P.D. No. 5 furnace at Republic Steel Corporation in Cleveland, Ohio. The inventor was Julian M. Avery. At this writing, there are 28 furnaces installed with high pressure tops. Some controversy exists over the ideal top pressure, however, 7 psi top pressure seems to be the accepted figure.

One of the most interesting facts to come to light in a study of history of blast furnaces is not so much the simple growth of the structure itself as the increase in tonnages figures, all out of proportion to actual increase in size unit-wise.

From 1810 to 1898, the total annual pig iron production increased from 60,377 net tons to 13,186,806. Today there are 60 pct fewer blast furnaces than fifty years ago, but technical progress in blast furnace construction and operation has increased the total blast furnace capacity of the country from 12 million to about 84 million net tons.

In the past, tonnage capacity was increased by adding units and by increasing the size of units. As demand for iron increased, construction costs have soared, so that now every effort is being brought to bear on the greatest possible utilization of the present equipment along with every technological improvement in handling or processing raw materials.

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* Since this writing, two larger furnaces have been built in England, both having a hearth diameter of 31 ft.

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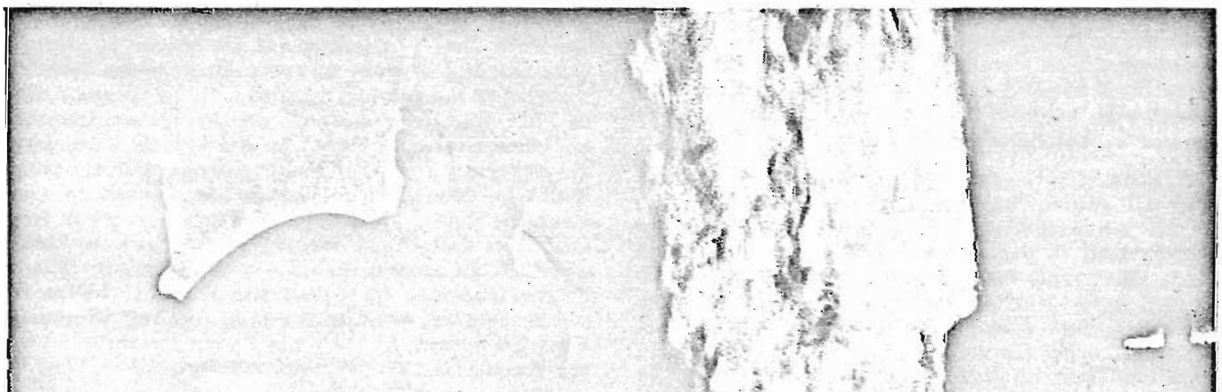


STERLING, RINGWOOD, AND GREENWOOD

Sterling Lake

by R. W. Shearman and F. Weston Starratt

A new center for mining and metallurgical research is developing at Sterling Forest, N. Y., under the auspices of Union Carbide Corp. Here is to be located the Union Carbide Nuclear and Ore Research Laboratories. In truth, history has repeated itself; the Sterling Forest area in the days of the Revolutionary War, and for many years thereafter, was the mining and metallurgical center of the US. For in these Ramapo hills along the New York-New Jersey border, iron ore was mined, pig iron was cast, and the weapons of war and the plowshares of peace were forged.

Before embarking on an historical pilgrimage to yesteryear—a brief description of Sterling Forest. Located in Orange County, N. Y., near Tuxedo, immediately north of the New York-New Jersey State line, and just west of the Erie Railroad and the New York State Thruway, Sterling Forest is approximately 35 mi from New York City. Title was acquired in 1956 from the Harriman family by City Investing Co. Its President, Robert W. Dowling, has established himself as a city planner, having conceived such projects as Pittsburgh's Gateway Center and Philadelphia's Penn Center.

A unique, self-contained community is planned that will contain light industry and centers for research and engineering. Colonies of homes will be interspersed throughout the 20,000 acres of forest land, lakes, and rolling hills. Culture will not be neglected, for Sterling Forest will be the new home for the annual Empire State Music Festival. The Sterling Forest Gardens, 125 acres of landscaped woodland and streams, will become the "world's largest permanent floral showplace." The Sterling Forest International Research Building was opened earlier this year, and designed to provide all facilities needed by small growth research companies. The first major company to acquire land to construct research buildings at Sterling Forest is Union Carbide.

1763 . . . Discovery of iron ore

In turning back the pages of history, a fascinating story can be told of special interest to the metallurgist, the mining engineer, and perhaps even the sociologist. For, where new communities are planned today, older communities had been born, matured, and died. In these hills had lived the iron miners, the blacksmiths, the lumbermen, the masons, and the teamsters that had given America its start in heavy industry. This was the area where the forests were crisscrossed with many wood roads that brought logs to the charcoal pits, and iron ore to the furnaces.

Men make history. Our story brings forth many names of men known as ironmasters, or as industrial leaders—Hasenclever, Faesch, Erskine, Townsend, Ryerson, Parrott, Cooper, Hewitt, Jay Cooke, and Harriman.

The name *Sterling* is derived from a Scotch Lord, the Fifth Earl of Stirling (in its earlier spelling). Lord Stirling was one of seven Englishmen granted a patent of land in the Ramapo hills by Queen Anne in 1707, known as the *Cheesecock Patent*. He sent an agent, Cornelius Board, to America in 1730, with the express purpose of looking for copper deposits. While he found no copper in his travels up and down the Ramapo Valley, he did find iron ore in two localities: first, in the vicinity of what is now Ringwood, N. J.; second, five miles to the north. There he constructed a forge and furnace at the edge of a lake in 1736, naming the land *Stirling Property*, after his patron. In 1740, the Ogden family in Newark bought land from Board at Ringwood and began smelting of iron in 1741.

The Ringwood story

Soon, a genius in the person of Peter Hasenclever appeared on the scene. He was attracted by an advertisement in the *New York Mercury* for March 5, 1764, in which David Ogden of Newark offered

A MAP of part of the STATES of

NEW-YORK and NEW-JERSEY:

Laid down, chiefly from *Actual Surveys*, re-ceived *from the Right Hon.ble* Lᵈ STIRLING *&* *others*, and Deliniated for the use of *His Exce.y* GEN.L WASHINGTON, by *Robᵗ Erskine* F.R.S. 1777.

Fig. 1—Ringwood and "Stirling" ironworks were about 35 miles northwest of New York. Shown here is the northeast quadrant of an original map drawn in 1777 by Robert Erskine, Surveyor General to the Army of the United States, and Ironmaster at Ringwood, 1771-1780. Other ironworks mentioned in the article—Long Pond, Charlotteburg, Pompton, and Cortland—can be found on the map. Greenwood, developed later, was a few miles northeast of Sterling. (Map reproduced by permission of the Pierpont Morgan Library.)

various mining properties for sale, including "a well-built furnace, good iron mines near the same, two forges, one with 3 and the other with 2 fires; a saw mill, several dwelling houses and several tracts of land adjoining; carts, wagons, utensils and tools proper for the works."[2] For £5000, Hasenclever purchased the then dilapidated Ringwood Mines and reorganized them.

Peter Hasenclever was a German. His career began in iron works at age 14. He traveled throughout Europe, learning several languages. He had served as a financial consultant at the Court of Frederick the Great, had been a partner in a mercantile business in Cadiz, Spain, and then went to England where a stock company was formed, officially known as *Proprietors of the New-York and New-Jersey Iron Works.*[3] Unofficially it became known as *The American Company* and sometimes as *The London Company*. From its capitalization of £40,000, Hasenclever financed the Ringwood purchase. From Germany he transported 535 persons, "miners, founders, forgemen, colliers, carpenters, masons, and labourers with their wives and children."[4]

Hasenclever soon realized that extensive forest lands for charcoal would be required to operate his furnaces. A sum of £10,000 was expended to acquire forests extending to Greenwood Lake.

Under Hasenclever's management, Ringwood became an important part of the large-scale development of the iron industry in America. He also was responsible for iron works at Charlottenburg (Charlotteburg), Long Pond (Greenwood Lake), and Cortland, New York. Hasenclever is credited with several advances in iron-making. He built dams to supply a continuous source of power for his furnace draft. He introduced a method for recovering iron from old cinder banks. Perhaps the first man to improve furnace refractories, he adopted slate as a lining for his furnace.[5]

Hasenclever himself has described some of his problems and achievements:

> "The working of so many mines was not only a very expensive, but also a laborious and vexatious work. The disappointments were incredible; in some places we found abundance of ore, but it proved *cold-shear*, *copperish*, and *sulphureous*, and of arsenical quality, so that it could not be used, and out of 53 mines, seven only proved good.[6]

As so often true with men who are primarily promoters, "Baron" Hasenclever enjoyed living in a grand style. At his manor house at Ringwood, he is reputed to have dined from gold plates while serenaded by a brass band. When his expenses totalled £54,000, the London partners, weary of receiving no dividends, discharged Hasenclever and sent Jeston Homfray to take his place. However, the partners did acknowledge that Hasenclever's iron was the best "that ever made its appearance in the London market from America; it has been tried and found of exceeding good quality."[7]

John Jacob Faesch, successor to Jeston Homfray, was a very competent ironmaster. His origin was Swiss and he possessed the faculty of being able to berate the German workmen in their native tongue, to the benefit of maximum production.

Faesch remained at Ringwood for about two years, while The American Company looked for a permanent manager to send to America. Later, he moved on to Morris County, N. J., where he developed the Mt. Hope Mine, in operation to this day.

Robert Erskine, of Scotch ancestry, was selected to be the permanent manager. Although a qualified engineer and draftsman, he knew little about iron manufacture. Following his appointment as manager at Ringwood, he toured the Welsh mines to study their methods of mining and smelting. Incidentally, he had earlier been elected a Fellow of the Royal Society and was sponsored by Benjamin Franklin.

Erskine arrived in America in 1771, and found Ringwood in poor condition. Erskine's efforts to put the properties on a paying basis were carried out under difficulties. A request in 1773 to The American Co. for additional working capital was ignored. An effort to sell the enterprise brought no bidders. Erskine succeeded in borrowing cash from a New York banking firm, later repaying the loan.

Upon outbreak of hostilities between England and the colonies, Erskine wrote to his stockholders that he intended to help the rebels as much as possible, but would look after the Company's interests. Erskine raised the first company of soldiers in northern New Jersey, and equipped them at his own expense. The Continental Congress commissioned him a Captain with instructions to keep his company at Ringwood to protect the iron works.

At outbreak of the Revolution, General Washington was handicapped by having only previously-drawn British maps, often inaccurate. Erskine's abilities as a qualified topographic engineer had come to the attention of General Washington. This resulted in Erskine's commission in 1777 as Geographer and Surveyor General to the Army of the United States. In this capacity, he supervised the making of over 200 maps for the Army, mainly for Washington's Jersey campaigns.

At Ringwood, the first chain across the Hudson to keep out the British was forged. This chain stretched across the river from Fort Montgomery to St. Anthony's Nose, slightly north of the present Bear Mountain bridge. Unfortunately the British found it to be no obstacle; they captured Fort Montgomery, and took the chain with them when they sailed downstream. Apparently the British had a high regard for the chain, for they used it for many years at Gilbralter to protect their warships riding at anchor.[8]

Robert Erskine died in 1780 at an early age. Thanks to him, the operations at Ringwood were improved, and the Company's finances rehabilitated.

Erskine is credited with inventing the first magnetic separator.[9] It consisted of an oak log serving as a drum with magnets driven into it. As it slowly rotated, the crushed ore was poured on the drum. The rock passed by, and the ore, after being brushed off on the far side, fell into a bin.

Robert Erskine's widow remarried a year later. Her second husband, Robert Lettis Hooper, Jr., was not an ironmaster, and steps were soon taken to dispose of the property. As the real title was still theoretically vested in the London stockholders, the New Jersey Legislature enacted a Special Confiscation Act, under which the property could be seized by the Commissioners of Forfeited Estates.[8] The *power of agency* was vested in Hooper and his wife, with authority to manage the estate. In 1795, a sale was negotiated with James Old, an ironmaster from Pennsylvania. However, as payments were not met, the Sheriff of Bergen County (now Passaic County), advertised the property for sale for back taxes in 1803. In 1807 the property was acquired by Martin John Ryerson.

Martin John Ryerson was well known as an ironmaster, and had successfully operated an iron works for many years at nearby Pompton Lakes. In fact, his ancestors had been in the iron business for nearly 100 years. Ryerson was responsible for producing shot and shell for the US Army during the War of 1812. His operations at Ringwood were most successful.

After the death of Martin Ryerson in 1832, his sons succeeded in the management. Jacob M. Ryerson served as manager, but failed to make the property pay, due in part to the reduction of the tariff on iron, and in part to permitting workmen to overdraw accounts at the Company store. The Ringwood iron furnace was blown out in 1848, after operating for 106 years. The Ringwood property was sold at a Sheriff's sale in 1853 to Peter Cooper.

However, the Ryerson name has not been lost. Today, the Ryerson family is distinguished as the oldest in the iron and steel business in America.

Peter Cooper is probably the most famous proprietor of Ringwood. He is known as the founder of Cooper Union, celebrated technical school in the city of New York. He is credited as the inventor of the locomotive *Tom Thumb*. With Cyrus K. Fields, he promoted the first trans-Atlantic cable. In his early years Cooper had served an apprenticeship as a carriage-builder, operated a furniture shop, then a grocery shop, and at the age of 33, purchased a glue factory. His fortune was based on his virtual monopoly in glue and isinglass.

Peter Cooper was also an ironmaster. He had manufactured charcoal iron near Baltimore in 1830 and operated a rolling mill in New York City in 1836. In 1845, this activity was moved to Trenton. The successful business required sufficient iron ore, and hence, the purchase of various mines in northern New Jersey.

The Ringwood property was run by Cooper's son, Edward Cooper, and his son-in-law, Abram S. Hewitt.

Peter Cooper received the Bessemer Gold Medal of The Iron and Steel Institute of Great Britain in 1879 for his services in the development of the American iron trade.

Abram S. Hewitt—Partnership between Abram S. Hewitt and Peter Cooper was effected in 1844 with the formation of The Trenton Iron Co. Cooper was president, and Hewitt, secretary. At Trenton the first iron beams for buildings in the US were rolled in 1854. After 1870, the firm was known as Cooper, Hewitt & Co.

Ores from Ringwood were profitably shipped after discontinuance of the furnaces until the 1890's. After that, high-phosphorus Ringwood ores found it difficult to compete with Lake Superior ores.

What about Abram Hewitt? In 1874 he changed his legal residence from Ringwood to New York City, and in 1887 was elected Mayor. In 1890 he also was awarded the Bessemer Gold Medal for his contributions in the field of metallurgy.

Ringwood in the Twentieth Century—The Ringwood story since 1900 is not a happy one. The mines continued in operation sporadically until 1931, when they were shut down for lack of ore. The property was operated under the name Ringwood Co. by Abram Hewitt's son Erskine Hewitt, and his heirs.

With the heavy demand for iron ore during World War II, the US government purchased the Ringwood mines outright in 1942 as an auxiliary source of ore. A sum of almost $4 million is reputed to have been expended in reconditioning the mines and constructing a modern concentrating plant, but V-E Day intervened. Alan Wood Steel Co. did the work for the Government.

A private operator, Patrick Moran, president of Ringwood Mines, Inc., purchased the property in 1947 from the War Assets Administration for $1,275,000.[9] His hope to produce 1000 tons of iron ore per day was not successful. A total of 46,900 tons was produced before the property reverted to the Government.

The most recent attempt at operating the Ringwood property was made in 1952. The newly organized syndicate of Ringwood Iron Mines, Inc., headed by Colonel Lewis Sanders, president and general manager, purchased the mines from the General Services Adminstration for $1.5 million.[10] Their aim was to produce powdered and pelletized iron.

Two workable mines remain today at Ringwood, the Cannon mine, 480 ft in depth, and the Peters mine, 2700 ft in depth, with 17 levels. Total production for the Ringwood District to 1931 was about 2,671,000 tons.[11] Drilling has indicated that at least 5 million tons of ore remain in the known ore bodies below ground.[12]

The Sterling furnace story

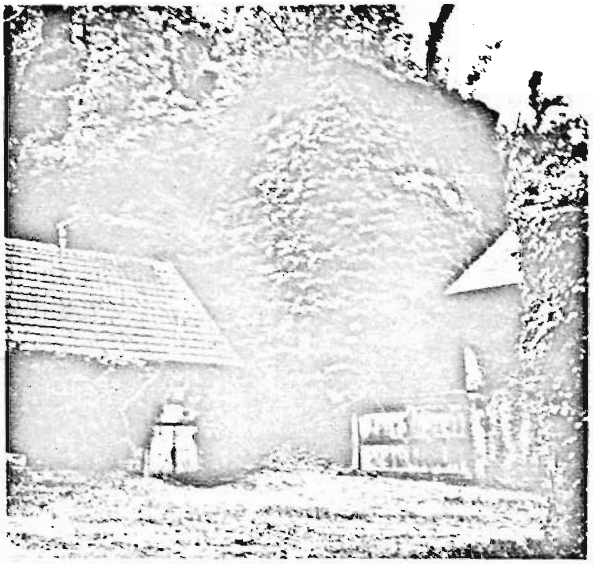
We return now to Sterling Lake, N. Y., 5 mi to the north of Ringwood, and to the year 1750. William and Albert Noble purchased the mines at Sterling Lake, and in 1751 constructed a furnace. During the Revolution, a partnership was formed under the name of Noble, Townsend & Co.

In addition to cannonballs, the partnership received the prime contract to supply the second chain across the Hudson River, stretching from West Point to Constitution Island. Here a bend in the river required ships to tack. With so little momentum, the British ships were unable to break the

Table I. Analyses of Ore From the Sterling Lake District[a]

Mine	Fe, Pct	P, Pct	S, Pct
Crawford	57.66	2.004	0.178
Lake	57.25	1.205	0.088
Redback	52.93	0.028	3.603
Sterling	61.01	0.284	0.371
Tip Top	54.03	1.751	0.173

[a] Adapted from information contained in *The Magnetic Iron Deposits of Southeastern New York* by R. J. Colony.[13]



chain. (Was this the reason for success, or was it superior metallurgy?) The links in the chain were 2.5 to 3 ft long and weighed from 140 to 150 lb each, 186 tons total. It was made and delivered in six weeks.[12] For this job, the Government paid £400.

Other products of the Sterling forges were cannons, and massive iron anchors for the frigates *Constellation*, *Constitution*, and *Congress*.

In 1798, the Nobles sold their interest to the Townsend family, who continued in ownership until 1865, under the name Peter Townsend & Co. In that year, control passed to the well-known financier, Jay Cooke, and his syndicate. Ownership was under the name of the Sterling Iron & Railway Co.

In 1893, a considerable share of the stock was acquired by E. H. Harriman, prominent railroad financier, and reorganizer of the Union Pacific Railroad. Two years later, Harriman acquired full control. After his death, ownership passed to his sons, E. Roland Harriman, and Averell Harriman, former Governor of New York.

The Midvale Steel & Ordnance Co. leased the property in 1917, organized the Ramapo Ore Co. Inc. to work the lease, and spent approx $4 million on improvements at Sterling (including a $100,000 schoolhouse in conformity with the laws of New York State). Ore was shipped to blast furnaces at Coatesville, Pa. After acquiring Midvale, Bethlehem Steel Co. was in charge of operations briefly until the mines were finally closed in 1921. Title to the land was acquired from the Harrimans by City Investing Co. in 1956, and renamed *Sterling Forest*.

Sterling Mines—The Sterling mines consist of some 22 mines and prospect pits. Of them, the Lake, Scott, and Cook, were operated until 1921.

The ore discovered in 1750 was a large outcrop of magnetite on the north slope of the hill at the south end of Sterling Lake. This became the Sterling mine, named after Lord Sterling, proprietor of the land. Here the first blast furnace in New York State was erected. The mine, which extended under Sterling Lake, was closed in 1902.

The nearby Lake mine is wholly under Sterling Lake. Output from this mine up to and including 1917 was 1,254,283 tons of magnetite.[13]

After the Sterling and Lake mines, the Scott and Cook mines were the largest. Total production from these mines was 1,900,000 tons of ore. Table I gives analyses of ore from the Sterling Lake district.

Fig. 2—Yesterday and today—Greenwood Furnace No. 2 was the center of a little Pittsburgh. The above photo (courtesy of W. A. Lucas, Hawthorne, N. J.), taken about 1870, shows the furnace in operation; at left is the same furnace as it appears today.

Sterling Furnaces—The Sterling Works operated two furnaces, which together produced 25 tons of pig iron per day.[14] These were the Sterling Lake furnace and the Southfields furnace.

The original Sterling Lake furnace was built in 1751, and torn down in 1804. The most recent furnace was operated from 1847 to 1890. In later years, anthracite replaced charcoal. Its remains are preserved today, and the City Investing Co. has covered the furnace with a roof, of appearance similar to the Jefferson Memorial in Washington. Pigs made at Sterling were stamped with a horse head emblem, the family coat of arms of the Sterlings.

Construction of the Sterling Mountain Railway in 1865 gave direct access to the New York and Erie Railroad for mine and furnace products. Connection was made near Sloatsburg, 8 mi away, and over heavy grades and around sharp curves. Remains of the rusted track, abandoned since 1921, are visible today.

Southfields furnace, built about 1830, was modernized in 1839, and produced pig iron until 1887. A direct rail connection was made with the New York and Erie Railroad, 0.5 mi distant. Pigs were shipped to Cornwall on the Hudson, and from there by water to the West Point Foundry at Cold Spring, New York. Here the famous Parrott guns and shells were constructed. They proved their worth during the Civil War (Fig. 3).

The Greenwood story

On the periphery of the Sterling Forest area is one additional furnace of historic interest, still standing today. This is the Greenwood furnace, at Arden, N. Y. Just a few hundred yards east of the Erie Railroad and the parallel New York State Thruway, it is visible to the traveler if he knows where to look and has sufficient interest! (Fig. 2.)

The Greenwood furnace was part of the Greenwood Iron Works at a time when Arden was known as *Greenwood*. During the Civil War this area was a miniature Pittsburgh, with a population of 2000. Ore was mined nearby, charcoal was produced from the neighboring forests, and pigs and blooms were smelted and shipped.

The first Greenwood furnace, built in 1811, was located in a ravine, where the Arden Brook supplied power for a saw mill and a stamping mill. At the latter, ore was broken into small pieces prior to smelting.

In 1838, the property was acquired by the Parrott Brothers, Peter P. and Robert P. Peter became manager of the Greenwood property, and Robert, the superintendent of the West Point Foundry at Cold Spring. He acquired the secrets of rifled cannons of the Krupps in Germany, and by the outbreak of the Civil War, had patented the Parrott gun and the expanding projectile to be used with it. His gun had longer range with accuracy than any previous artillery piece.

In 1854, Greenwood Furnace No. 2 (also known as *Clove furnace*) was constructed. As the New York and Erie Railroad had been completed in 1841, anthracite rather than charcoal was used from the beginning, due to its availability.[15] (See Table II.)

The Greenwood furnaces, as was the case with the nearby Southfields furnace, shipped a large percentage of their product to the West Point Foundry. It has been said that what Sterling furnace was to the Nation in the American Revolution, Greenwood furnaces were during the Civil War.[16]

Greenwood could not survive the Mesabi competition. In 1871 the Greenwood charcoal furnace ceased operation; in 1885, the Greenwood anthracite furnace closed down.

Early iron making—a summary

The early iron furnaces, like modern steelworks, were products of economic conditions of the day. Ore was available, for the Ramapo Hills where New York and New Jersey meet are well supplied with magnetite. For charcoal smelting the ore, wood was available in abundance. Power was present in the form of lakes and streams. The Sterling Forest area was ideal for carrying out all metallurgical operations from mine to finished shapes. Finally, transportation in the form of the nearby Hudson River, carried finished goods to communities on the eastern seaboard.

Fig. 3—Southfield furnace, as it looks today, produced iron for the famous Parrott guns used in the Civil War.

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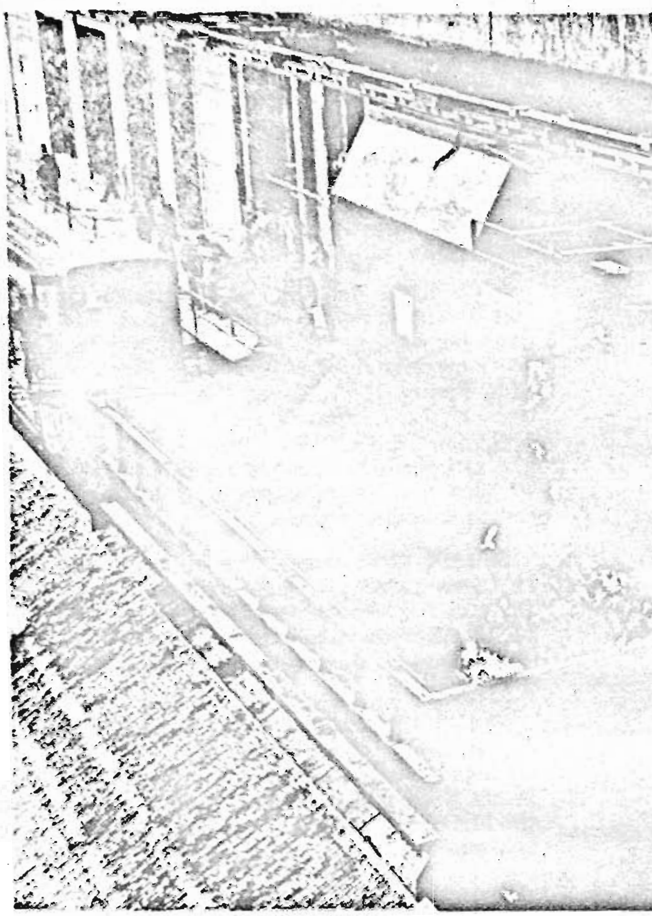
Table II. Pig Iron Furnaces of Sterling Forest Area in 1859[a]

Name	Owner	Year Built	Type	Dimensions	Production
Sterling No. 2	Peter Townsend & Co.	1847	Hot-blast charcoal	13 ft wide at bosh; 48 ft high	2520 tons in 48 weeks of 1857
Southfield	Peter Townsend & Co.	About 1800; rebuilt 1839	Hot-blast charcoal	12 ft wide at bosh; 40 ft high	6353 tons from Oct. 11, 1850 to July 3, 1853, with 62 days stoppage
Greenwood No. 1	Robert P. & Peter P. Parrott	1811, enlarged 1825	Hot-blast charcoal	11 ft wide at bosh; 42 ft high	1500 tons in 1856
Greenwood No. 2	Robert P. & Peter P. Parrott	1854	Anthracite	18 ft wide at bosh; 54 ft high	5000 tons in 1855

[a] Chart prepared from information in *The Iron Manufacturer's Guide to the Furnaces, Forges and Rolling Mills of The United States* by J. P. Lesley.[17]

HISTORY OF THE COKING INDUSTRY IN THE UNITED STATES



I—Early Coke Processes

by C. S. Finney and John Mitchell

There is no field of human thought or endeavor which does not owe much to the past. Yet, surrounded by the prodigious scientific and technological achievements of our day, it is all too easy to forget the extent to which we have stood *on the shoulders of giants.*

The coking industry of the United States is now a little more than one hundred years old. As with the American nation itself, the earliest beginnings of the industry owe a great deal to British influences, and its development owes much to those influences of continental Europe. No serious contribution to the history of coking in the United States can be written, therefore, which does not mention the work of the pioneers of the Old World.

It is believed that the use of metallurgical coke dates back to antiquity. The fact that certain coals would soften under the influence of heat to yield a porous solid was known to the ancients of China and India, where a very crude coking operation was carried out by simply setting fire to piles of coal. After active combustion had started, turf or wet straw was used to seal off the pile. The coke obtained was used to forge iron and steel implements and weapons.

Perhaps the earliest reference to the coking phenomenon is to be found in the writings of Theophrastus, pupil of Aristotle. In his *History of Stones,* which was written in or about the year 371 B.C., there appears the following observation. "But the Lipara stone empties itself, as it were, in burning and becomes like the pumice, changing at once both its colour and density; for before burning it is black, smooth and compact. . . . Certain stones there are about Tetras, in Sicily, which is over against Lipara, which empty themselves in the same manner in the fire." The first comparatively modern reference to coke is to be found in a recommendation for carbonization made in 1584 by Julius, Duke of Braunschweig-Luneberg, owner of the Hohenbuchen mine in the Harz district of Germany. In 1587, Sir Francis Willoughby of Wollaton, England wrote:

"There are twenty rooks broughte into charcoal and laid up in store." A rook of coal was equivalent to some 25 tons, and the coking would probably have been carried out in a manner similar to that used for the production of charcoal. In 1589, Thomas Proctor attempted to carbonize coal, and in the year 1590 an English patent was granted to John Thornborough, Dean of York, in order that he might "purify pit coal and free it of its offensive smell". Sir Robert Cecil (1595), Robert Chantrell (1607), Simon Sturtevant (1611) and John Rovenzon (1613) were all granted patents for the use of coal or coke

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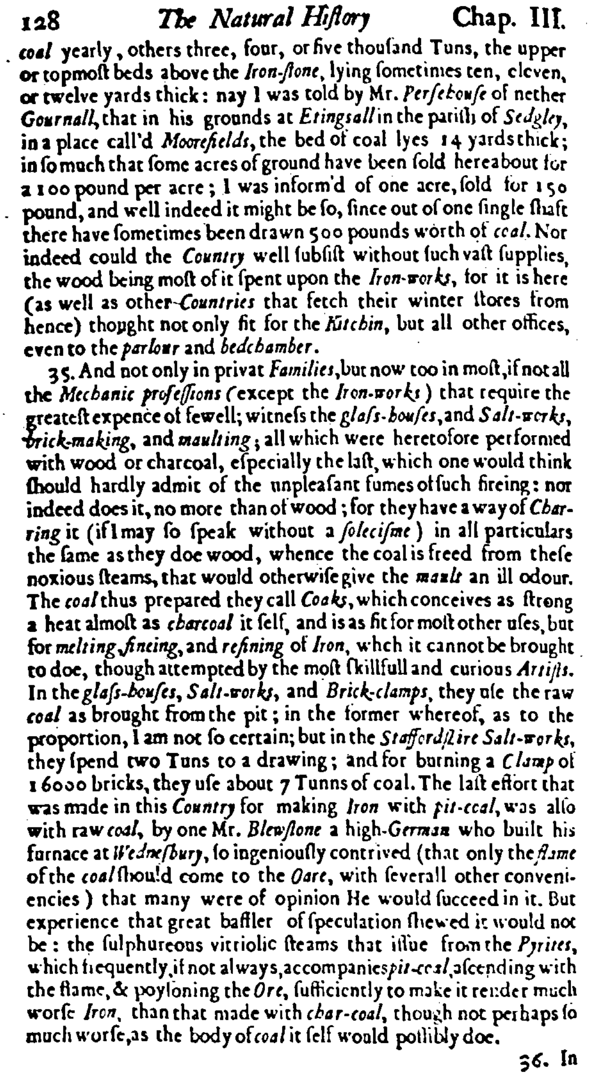
in iron making, and in 1620 a patent was given Sir William St. John "to chark or otherwise to converte into charkcole, within our said realms of England and Ireland and dmion of Wales, or anie or eyther of them, all manner of seacole, stonecole, pitcole, earthcole, turf peate, brush flagg, cannell, and all other fewell or combustable matter of what nature or qualetie soever". In 1651 Jeremy Back was granted a patent to make iron with stone-coal, pitcoal or sea-coal without charking. It may thus be inferred that *charking* or coking was quite well known and practiced in England prior to that time. The word *chark* meant to burn to a black cinder, and *to char* meant to burn wood to black cinders. In *The Natural History of Staffordshire*, written by Dr. Robert Plot, "Professor of Chymistry in the University of Oxford", and published in 1686, it is recorded that coal was *charred* in exactly the same way as wood, the treated coal being then known as *coaks*. Being capable of producing just as great a heat as charcoal, it could be substituted for most purposes, but not, says Plot, "for melting, fineing, and refining of iron, which it cannot be brought to doe though attempted by the most skillfull and curious artists". Obviously, however, a *most skillfull and curious artist* by the name of Thomas Chetle of Berrow Hill in Worcestershire still lived in hope, for on December 20, 1695, he obtained a patent for smelting iron "with pitt coales or sea-coales charked".

Despite the ancient origins of coke and a fairly widespread familiarity with its preparation and properties over the centuries, the birth of the modern coking industry undoubtedly took place in England in the early years of the eighteenth century. Its founder was Abraham Darby, (1678-1717) who, for the first time, successfully used coke for the smelting of iron at Coalbrookdale in Shropshire. Abraham Darby was the son of a locksmith and farmer of the Wrens Nest, Dudley, Worcestershire, and spent his youth in apprenticeship to a malt-mill maker in nearby Birmingham. On the completion of his apprenticeship in 1699, Darby went to Bristol and there set up his own business for the making of malt-mills. There can be little doubt that his connections with the malt industry gave Darby considerable familiarity with the use of coke. The center of the malt making area at that time was the town of Derby, where coke making was first practiced on any scale and where appreciable quantities were used for the drying of malt. The making of coke in England was not, of course, restricted to the Derby district or indeed to malt making. It was beginning to be used in copper smelting, for example, where a charge of two-thirds coke and one-third coal was employed. And while referred to as *coaks* in Staffordshire, it was known as *cinders* in Scotland and Newcastle, *cowks* in Derby, *couk* in Lincolnshire, and *pitt-coale charr'd* in South Wales.

When Abraham Darby went to Coalbrookdale in 1708, therefore, coke was no new or novel material. Indeed it would seem probable that its use was known in the Coalbrookdale area itself. The making of clay pipes had been carried out for a hundred years or more at Brosely, where a *cynder* fire was used for drying the pipes. It seems probable that Darby used exactly the same methods for making coke as were practiced by the maltsters at Derby, who in turn had adopted the techniques by which charcoal had been made for centuries. In charcoal burning, large circular mounds of carefully arranged logs were prepared, some sort of flue being left at the center. The spaces between the larger logs were filled with smaller pieces of wood, and the whole pile covered with turf, dirt, wet straw and leaves, etc. After burning-wood or charcoal had been pushed down the central shaft, the latter was sealed off and other vent holes made nearer the circumference. With careful control, smoldering could be made to travel outward from the middle of the heap and thus convert the whole mass of wood into charcoal. The *charking of cole* was carried out in an identical fashion. Piles of coal was built up in mounds similar to the *meilers* of the charcoal burners. In one of the first known descriptions of the procedure at Derby in 1693 it is stated that, "the collier sets six or eight waggon loads of coal in a



Extract from *The Natural History Of Staffordshire*, by Dr. Robert Plot, 1686.

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coal yearly, others three, four, or five thouſand Tuns, the upper or topmoſt beds above the *Iron-ſtone*, lying ſometimes ten, eleven, or twelve yards thick: nay I was told by Mr. *Perſehouſe* of nether *Gournall*, that in his grounds at *Etingsall* in the pariſh of *Sedgley*, in a place call'd *Moorefields*, the bed of coal lyes 14 yards thick; inſomuch that ſome acres of ground have been ſold hereabout for a 100 pound per acre; I was inform'd of one acre, ſold for 150 pound, and well indeed it might be ſo, ſince out of one ſingle ſhaft there have ſometimes been drawn 500 pounds worth of *coal*. Nor indeed could the *Country* well ſubſiſt without ſuch vaſt ſupplies, the wood being moſt of it ſpent upon the *Iron-works*, for it is here (as well as other *Countries* that fetch their winter ſtores from hence) thought not only fit for the *Kitchin*, but all other offices, even to the *parlour* and *bedchamber*.

35. And not only in privat *Families*, but now too in moſt, if not all the *Mechanic profeſſions* (except the *Iron-works*) that require the greateſt expence of fewell; witneſs the *glaſs-houſes*, and *Salt-works*, *brick-making*, and *maulting*; all which were heretofore performed with wood or charcoal, eſpecially the laſt, which one would think ſhould hardly admit of the unpleaſant fumes of ſuch fireing: nor indeed does it, no more than of wood; for they have a way of *Charring* it (if I may ſo ſpeak without a *ſoleciſme*) in all particulars the ſame as they doe wood, whence the coal is freed from theſe noxious ſteams, that would otherwiſe give the *mault* an ill odour. The *coal* thus prepared they call *Coaks*, which conceives as ſtrong a heat almoſt as *charcoal* it ſelf, and is as fit for moſt other uſes, but for *melting*, *fineing*, and *refining* of *Iron*, whch it cannot be brought to doe, though attempted by the moſt ſkillfull and curious *Artiſts*. In the *glaſs-houſes*, *Salt-works*, and *Brick-clamps*, they uſe the raw *coal* as brought from the pit; in the former whereof, as to the proportion, I am not ſo certain; but in the *Staffordſhire Salt-works*, they ſpend two Tuns to a drawing; and for burning a *Clamp* of 16000 bricks, they uſe about 7 Tunns of coal. The laſt effort that was made in this *Country* for making *Iron* with *pit-coal*, was alſo with raw *coal*, by one Mr. *Blewſtone* a high-*German* who built his furnace at *Wedneſbury*, ſo ingeniouſly contrived (that only the *flame* of the *coal* ſhould come to the *Oare*, with ſeverall other conveniencies) that many were of opinion He would ſucceed in it. But experience that great baffler of ſpeculation ſhewed it would not be: the ſulphureous vitriolic ſteams that iſſue from the *Pyrites*, which frequently, if not always, accompanies *pit-coal*, aſcending with the flame, & poyſoning the *Ore*, ſufficiently to make it render much worſe *Iron*, than that made with *char-coal*, though not perhaps ſo much worſe, as the body of *coal* it ſelf would poſſibly doe.

36. In

round heap upon the ends, and as pyramidal (large at the bottom and small at the top) as they will stand". Originally, large sized lumps of coal were used in an attempt to construct a primitive flue system in the pile. Later, kindling wood was built into the heap to support the flues. Still later, vertical wooden posts were utilized. On removal of the posts from the newly built heap, holes were left into which burning coal could be dropped for ignition purposes. At about this same time wet coke breeze was being used to seal the pile instead of dirt or wet straw and leaves. By 1768, the first brick flue had appeared, for in that year John Wilkinson put up a chimney in the center of the pile. Naturally the coke yields obtained by these early pioneers of carbonization were not high. A figure of 33 pct is mentioned as being typical.

The exact year in which Abraham Darby achieved successful use of coke alone as a blast furnace fuel seems to be open to some doubt. R. A. Mott, after some of the most thorough and detailed historical research so far carried out into the subject, concluded that in 1709 Darby made more than 200 tons of coke, and that during this same year he produced the first iron to be successfully smelted by coke only. Since Darby died in May 1717, and was apparently sick for the preceding year-and-a-half, the date of his success must lie in the years 1709 to 1715.

To his daughter-in-law Darby was *a religious good man*, and this was surely virtue enough. History, however, will regard him as a great man; for truly he was the father of an industry.

From charcoal to coke in US

In America, as in England, it was the demand of a growing iron industry for blast furnace fuel which led to the establishment and development of the coking industry.

The presence of iron ore in the New World had first been discovered by members of an expedition fitted out by Sir Walter Raleigh. In 1585 the expedition landed on Roanoke Island, off the coast of what is now North Carolina. Thomas Hariot, servant of Sir Walter Raleigh, recorded that "wee founde neere the water side the ground to be rockie, which by the triall of a minerall man, was found to hold iron richly. It is found in manie places of the countrey else". Iron ore was of no interest to the expedition, however; silver and gold were what they had hoped to find.

The first iron to be made from American ore was smelted in England. The ore was taken from deposits found near to the James River in Virginia, a colony (the first permanent one in the New World) having been founded in 1607 at Jamestown by the Virginia Co. of London. Seventeen tons of metal were produced and were sold to the East India Company for £ 4 per ton.

In 1619 the Virginia Co. sent out to Virginia one hundred and fifty settlers. Included in that number were ironworkers whose task was to *set up three iron works*. Work was commenced in 1619 at Falling Creek, a tributary of the James River, some 66 mi above Jamestown, but progress was impeded by the death of three of the master artisans in charge of the project. In any event iron never was made at Falling Creek. On March 22, 1622, at which time the works must have been almost completed, hostile Indians led by Opitchapan massacred one-hundred and fifty men and women, and totally destroyed what had been so painfully and patiently accomplished.

The next attempt to manufacture iron in the colonies seems to have been made in Massachusetts. Here, in 1644, at a small village named Hammersmith, near Lynn on the western bank of the Saugus River, was established what is thought to be the first successful iron enterprise in America. It was founded by John Winthrop, Jr. and eleven other English gentlemen who formed *The Company of Undertakers for the Iron Works*. Using local bog ores, and charcoal as a fuel, about 8 tons of pig iron a week were produced.

Like many other developments, the iron industry in America gradually moved inland and westwards from the Atlantic coast. The first blast furnaces were built along the coast of Massachusetts and Rhode Island, but they were soon to spread through the states of Connecticut, New York, and New Jersey, and on into the valleys of eastern Pennsylvania. To the south, the iron industry in Virginia was revived in 1716 by the governor, Colonel Alexander Spotswood. In Maryland, a company first known as Joseph Farmer and Co. and later to become the Principio Co. blew in a blast furnace in 1724, at the mouth of Principio Creek which runs into Chesapeake Bay near the mouth of the Susquehanna River.

The fuel used in these early blast furnaces was, of course, charcoal of which abundant supplies were available from the heavily timbered country. By the end of the 18th century, however, although wood for charcoal making was still available, it was being brought to the smelting furnaces from increasing distances. The point was being reached, in fact, where it was cheaper to buy imported rather than domestic iron. In England, the scarcity and cost of charcoal a century before had forced the iron industry to search for and use a less expensive fuel, coke, and by 1796 charcoal blast furnaces in Britain were few and far between. In America a different remedy, the use of anthracite, was applied.

The use of anthracite as a blast-furnace fuel was first attempted in the latter years of the 18th century, small quantities being used to replace part of the normal charge of charcoal. Only minor percentages could be substituted in this way, otherwise furnace performance would suffer, and the iron run cold. In 1835 the Franklin Institute of Philadelphia offered a gold medal "to the person who shall manufacture in the United States the greatest quantity of iron from the ore, during the year, using no other fuel than anthracite, the quantity to be not less than twenty tons". This would seem to indicate that prior to 1835 anthracite had not been successfully used for iron ore smelting. No record exists of the award of the medal to any of the men who made it possible to produce pig iron with anthracite. Included among these was the Rev. Dr. Frederick W. Geissenhainer, a Lutheran clergyman of New York City. In a letter written to the Commissioner of Patents in November, 1837, he declared, "I can prove that, in the month of December, 1830, and in the months of January, February, and March 1831, I had already invented and made many successful experiments as well with hot air as with an atmospheric air blast to smelt iron ore with anthracite coal in my small experimenting furnace here in the city of New York". It is probable that the Reverend Doctor knew that in 1828 James B. Neilson of Scotland had been granted an English patent for the use of hot air in iron smelting. On December 19, 1833, a United States patent was granted to Geissenhainer for " a new and useful improvement in the manufacture of iron and steel by the application of anthracite coal". In August and September 1836 he actually succeeded in making pig iron with anthracite exclusively at the Valley furnace on Silver Creek in Schuylkill County, Pennsylvania. The real founder of the anthracite iron industry in America, however, was David Thomas, a Welshman from Glamorgan. Arriving in the United States on June 5, 1839, he started to build an anthracite blast furnace in the same year at Catasauqua for the Lehigh Crane Iron Co. The furnace was blown in on July 3, 1840, and produced good quality iron at the rate of 50 tons per week until 1879 when it was demolished. It was certainly the most successful of the early anthracite furnaces.

The fact that anthracite alone could be used as a blast furnace fuel was rapidly made use of, not only in the valleys of eastern Pennsylvania but also in New York, New Jersey, and Maryland. In 1842, twelve anthracite furnaces produced 15,000 tons of pig iron in Pennsylvania. This may be compared with the 98,350 tons which 210 charcoal furnaces in the state turned out. By April, 1846, forty-two anthracite smelting furnaces with an annual capacity of 122,720 tons were at work in Pennsylvania and New Jersey. In 1856, 393,000 tons of anthracite iron were made, and one-hundred and twenty-one furnaces in the country were either in operation or were capable of being operated; ninety-three were in Pennsylvania, fourteen in New York, six in Maryland, four in New Jersey, three in Massachusetts, and one in Connecticut. The influence of anthracite practice was also felt as far south as Birmingham, Ala., and to the west in Ohio and Wisconsin.

The effect which the introduction of the new fuel had on the iron industry, and indeed on the industrial life of the whole country, was profound. The manufacture of iron was now possible in areas where timber shortages had previously restricted it. Greater production and a measure of competition led to lower prices, which in turn served to stimulate demand. In 1864 more than 1 million tons (1,135,996 tons) of pig iron were made, 684,018 tons being produced with anthracite. Only in the year 1875 did the quantity of iron produced by coke (947,545 tons) first exceed that of anthracite iron (908,046 tons); and not until 1908 was there a really sharp reduction in the amount of anthracite iron smelted, 355,009 tons being made in that year compared with 1,371,554 during 1907. In 1921 the net tonnage of anthracite pig iron was a mere 15,392 tons, and in 1922, for the first time, no iron of that type was produced. In 1923 a slight and temporary revival occurred, 14,258 tons being made. By the end of that year, however, anthracite smelting had been abandoned.

It is rather surprising that from the time Abraham Darby established the use of coke as a successful blast furnace fuel during the years 1709-1715, more than a century was to pass until serious efforts were made to follow his example in North America. J. M. Swank, in his *History of the Manufacture of Iron in All Ages,* published in 1884, considered that the reasons for the delay were as follows: transportation facilities for bringing coke and iron ore together were lacking; of the known deposits of bituminous coal, not all were suitable for coke manufacture; the process of coke manufacture was not well understood; plentiful supplies of timber existed for the production of charcoal; charcoal pig iron was more highly regarded than any other. Cogent as these reasons may appear, they do not fully explain the late beginnings of the coking industry in America.

Early coke production in the US

One of the earliest references to the manufacture of coke in the United States is contained in a letter sent by a Mr. D. M. Randolph to Harry Heth, a mine operator in the coal fields of Richmond, Va. Randolph had been sent to England by Heth in order to look into the use of steam engines for hoisting and pumping at the mines. The letter was written from London and dated August 22, 1808. It contained the following paragraph: "I shall explain to you, how, by turning Deep Run fine coal in Coak, to make great profit from what has heretofore been useless. You will do well to ascertain the price and amount of demand for this article throughout the U. States among brewers and manufacturers. I know how also to make every bushel of such fine slaty coal, fetch as much as any of the best grate coal by turning it into Coak: and that too, after paying all expenses of the process". The knowledge gained by Randolph was evidently ahead of the times, for his suggestions were never made use of.

In the Pittsburgh *Mercury* dated April 8, 1813, there appeared an advertisement by an enterprising Englishman named John Beal who claimed the knowledge "of converting stone coal into Coak". It seems that Beal was anxious to reveal his knowledge "to proprietors of blast furnaces", no doubt on a satisfactory cash basis. His services as a consultant do not appear to have been in any great demand by the ironmasters of the day. In 1817, however, coke *made on the ground* was used by Colonel Isaac Meason in his iron works at Plumpsock, Fayette County, Pa. This was the first rolling mill west of the Allegheny Mountains to puddle iron and roll iron bars. Coke was used in the refinery. Meason's executors offered the works for sale in the summer of 1818, when the following advertisement appeared in the Pittsburgh Gazette of June 5.

"Plumpsock Iron Works, with about 350 acres of land belonging thereto. It is situated in Fayette County, nine miles east of Brownsville, and the like distance of Connellsville, five miles northwest of Uniontown. This establishment consists of a forge, rolling mill, grist and saw mills. Bar iron is made in this forge by rolling, instead of hammering, of a superior quality. Stone coal is the only fuel used in making it, an inexhaustible pit of which is within one hundred yards of the forge. Three men with a horse and cart are sufficient to raise, coke and haul to the forge all the coal necessary for keeping the works in full operation." In 1819 a blast furnace built near Lawrenceburg, Pa., was intended as a coke furnace. Owing to the weakness of the blast, among other things, it was unsuccessful and had to be taken out of operation after making 1 or 2 tons of iron. This experiment was doubtlessly one of many trials with coke which were being carried out at the time, for the records of the day indicate that considerable attention was being given to the use of coke as such, or mixed with charcoal, anthracite, and bituminous coal in the blast furnace.

The fact that successful blast furnace operation with coke had not been achieved by 1825 is evident from a letter of instruction which William Strickland received from the Acting Committee of The Pennsylvania Society for the Promotion of Internal Improvement. The letter is dated March 18, 1825. The committee were evidently much concerned by the state of the iron industry in the Commonwealth of Pennsylvania, for in their own words, "No improvements have been made in it within the last thirty years, and the use of bituminous and anthracite coal in our furnaces is absolutely and entirely unknown. Attempts, and of the most costly kind, have been made to use the coal of the western part of the state in the production of iron. Furnaces have been constructed according to the plan said to be adopted in Wales and elsewhere; persons claiming experience in the business have been employed; but all has been unsuccessful. In large sections of our state, ore in the finest quality, coal in the utmost abundance, limestone of the best kind, lie in immediate contiguity, and water power is within the shortest distance of these mines of future wealth.

"The prices which are obtained for iron on the western waters are double those of England, the demand is always greater than the supply, and thus nothing but the art of using these rich possessions is wanted.

"We desire your attention to the following inquiries on the subject of the manufacture of iron:

(1) What is the most approved and frequent process for coking coal, and what is the expense per ton or caldron?

(2) In what manner are the arrangements or buildings, if any, constructed for the coking of coal, obtaining drawings and profiles thereof?

(3) Are there different modes for coking coal; and if they have any difference in principle, what are they?

(4) In what manner are the most approved furnaces for the smelting of ore constructed? Drawings and sections of the same to accompany the information that may be obtained upon this inquiry." William Strickland journeyed to England, where he carried out his commission faithfully and intelligently. His report to the committee contained detailed plans of ovens used for coke making.

On March 4, 1834, there was read in the Senate of Pennsylvania a report containing the following statement: "The coking process is now understood, and our bituminous coal is quite as susceptible of this operation, and produces as good coke, as that of Great Britain. It is now used to a considerable extent by our iron manufacturers in Centre County and elsewhere." It is certain that the coke referred to was made on the ground and not in any type of oven. It is also extremely doubtful whether such coke was used other than as an experimental addition to the normal charcoal charge, or alternatively for melting pig iron as practiced by Colonel Isaac Meason. The fact that the Committee on Premiums and Exhibitions of the Franklin Institute in Philadelphia felt able, in 1835, to offer a gold medal to "the person who shall manufacture in the United States the greatest quantity of iron from the ore, during the year, using no other fuel than bituminous coal, or coke, the quantity to be not less than twenty tons", makes it most unlikely that coke alone had been used as a blast furnace fuel to any extent.

The rewards for successful blast furnace operation with coke were, of course, likely to be very much greater than any attractions which the Franklin Institute could offer. Nevertheless, the proposed award of a gold medal doubtless focused attention upon the problem of coke smelting, and coincidence or not, successful iron smelting with coke was achieved during the year in which the offer was made. The feat was accomplished by William Firmstone at the Mary Ann furnace in Huntingdon County, Pa. Firmstone was an Englishman who emigrated to the United States in the spring of 1835. Using coke made from Broad Top coal, he produced gray forge iron of good quality for a period of about 1 month. The coke had not been produced for smelting purposes, but was intended for use in the *run-out* fires at the forge. Whether Firmstone was aware of the Franklin Institute's offer, is not known. However, he made no attempt to claim the medal, which was, in fact, never awarded. Possibly it was the work of Firmstone that was being referred to when Isaac Fisher of Lewistown, Pa., stated in April, 1836, that "successful experiments have lately been tried in Pennsylvania in making pig iron with coke".

It was F. H. Oliphant who next produced any quantity of coke pig iron. In or about the year 1837 some 100 tons or more were made at his Fairchance furnace near Uniontown in Fayette County, Pa. Evidently difficulties in the use of coke were encountered, for after a short time it was replaced by charcoal. J. M. Swank asserts that Oliphant did know of the gold medal which had been offered by the Franklin Institute, and that he wrote of his success in a letter to the Institute dated October 3, 1837. According to Swank the letter was accompanied by a box containing specimens of pig iron, together with samples of the raw materials from which it had been produced. No trace of Oliphant's letter can be found in the archives of the Franklin Institute, but it is somewhat unlikely that such a late claim to the medal would have been considered.

Despite the success of Oliphant and of Firmstone, and despite legislation passed by the Commonwealth of Pennsylvania on June 16, 1836, "to encourage the manufacture of iron with coke or mineral coal", the use of coke for iron smelting developed slowly indeed. Many of those who did attempt it suffered disappointments and losses. For example, a Boston company spent $500,000 at Farrandsville, near Lockhaven, Pa., in an effort to establish iron and mining enterprises and to smelt the local ores by means of coke. From 1837 until about 1839 some 3500 tons of iron were made. The costs were so high, however, that further attempts to produce iron with coke were abandoned. Again, the Clearfield Coal and Iron Co. of Karthaus, Pa., produced coke iron during 1839, but in this case also operations were abandoned before the year was out, although lack of proper transportation facilities has been reported as the main reason. According to Joseph D. Weeks (*Report on the Manufacture of Coke,* Volume X of the Tenth Decennial Census: 1880), successful use of coke in the blast furnace for any considerable period was first achieved in Maryland. In 1837 the George's Creek Coal Company built the Lonaconing furnace, 8 mi northwest of Frostburg. By June, 1839, this furnace was apparently producing about 70 tons of iron per week using coke made in open pits.

Even by the year 1849 there was not a solitary blast furnace running on coke in the whole of Pennsylvania. There were, to be sure, four furnaces owned by the Brady's Bend Iron Co. which were classed as coke furnaces, but they did not produce iron in 1849. In his book *The Manufacture of Iron*, published in Philadelphia in 1850, Frederick Overman was able to write, "But few blast furnaces work coke in this country, and even these, as far as we know, are not in operation at the present time". Also, "as there is but little prospect of an addition to the number of coke furnaces which now exist, we shall devote but a limited space to this subject". Overman's prediction was wrong. By 1856 there were twenty-one furnaces in Pennsylvania and three in Maryland that were either using coke or were capable of so doing. In the Census Year of 1850, four coke-making establishments were listed. By 1860 the number had increased to twenty-one, and after the middle sixties coke began to occupy an increasingly important position as a blast furnace fuel.

Early coking processes in the US

The coke used in the earliest American blast furnaces to utilize it was undoubtedly produced by coking piles of coal. The quality is reported to have been excellent, although uniformity of the product was not good. Naturally the yield was low. This description of coking in piles or mounds appeared in Report L of the Second Geological Survey of Pennsylvania, published in 1876.

"The coke yard is prepared by leveling a piece of ground and surfacing it with coal dust. The coal to be coked is then arranged in heaps or pits, with longitudinal, transverse and vertical flues; sufficient wood being distributed in these to ignite the whole mass.

"Beginning on a base of 14 feet wide, the coal is spread to a depth of 18 inches, A. On this base the flues are arranged and constructed as shown in the plan—the coal being piled up, as shown in section B. The flues are made of refuse coke and lump coal, and are covered with billets of wood. When the heap is ready for coking, fire is applied at the base of the vertical flues C, igniting the kindling wood at each alternate flue.

"As the process advances, the fire extends in every direction, until the whole mass is ablaze. Considerable attention is required in managing this mode of coking, in diffusing the fire evenly through the mass, in preventing the waste of coke by too much air at any place, and in banking up the heaps with fine dust as the operation progresses from base to top.

"When the burning of the gaseous matter has ceased, the heap is carefully closed with dust or duff, and nearly smothered out in this way. The final operation is the application of a small quantity of water, down the vertical flues, which is quickly converted into steam, permeating the whole mass. This gives coke with the least percentage of moisture, if carefully applied.

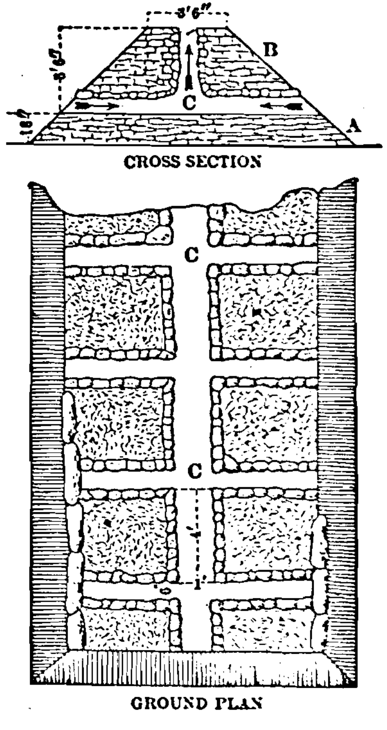
"The time necessary for coking a heap, with the Bennington coal, is from 5 to 8 days—depending mainly on the state of the weather."

A coke yield of 59.1 pct is given for mound coking as carried out at the Bennington yard, and this tallies well with a recovery of 59.6 pct quoted for the process at Holidaysburg. However, A. W. Belden (Technical Paper No. 50, issued by the Bureau of Mines in 1913) commented that yields of almost 60 pct could only have been achieved by taking special pains to produce the highest possible quantity of good coke, and that 50 to 55 pct would have been more representative of the average mound coke producer.

Frederick Overman, to whom reference has already been made, was a great champion of coke made in the open air, and saw little virtue in that which was produced in ovens. The following passages have been taken directly from his book, *The Manufacture of Iron, In All Its Various Branches*, (1850).

"The manufacture of coke for blast furnace purposes is generally carried out in the open air, either in round heaps or rows; the latter mode is generally preferred. Coke burned in ovens will answer for that which is used in the furnace of locomotives, or for the purpose of generating steam; it is even useful in a foundry cupola oven; but in the blast furnace, or even in the refining fire, it ought not to be applied, for reasons we shall presently explain.

"Cases may occur where coking in ovens may be permitted even for blast furnace coke; as for instance, where a very brittle coal, but free of sulphur, is to be charred. But these cases are rare, at least in the coal fields at present worked; for all our coal, when compared to the coal which is employed in the blast furnaces in Europe, may be considered more or less sulphurous. However that may be, coke ovens are practicable; at least, they are at present in general use in the Pittsburgh coal fields. All the coke used in cupola ovens and refining fires in the Western states is made in ovens. Coke ovens of various forms have been erected, sometimes with regard to quality, but most generally to quantity; and for the latter purpose they have been brought to great perfection. In our case, quantity is of secondary consideration; the obtaining of coke, free of bitumen



Coke mound or pile.

and sulphur, is the object at which we aim. All the various coke ovens are constructed mainly upon one principle; that is, they are built in the form of a common bake oven, and generally of capacity sufficient to receive a charge of two or three tons of coal at once. Some are round; others egg-shaped; and at the Clyde Iron Works, in Scotland, the hearth is square. *Ure's Dictionary of Arts and Manufactures* contains a description of an excellent arrangement for coking coal, erected for the use of the locomotive engines of the London and Birmingham Railway Company, but we doubt the utility of such ovens in iron establishments for we cannot believe that the large quantity of coke yielded is of quality sufficiently good for the manufacture of iron. In Germany and France, coke ovens have been built of admirable construction, as far as the saving of fuel is concerned, but iron masters who require a good article burn coke in the open air.

"As we have previously remarked, there is but little prospect of seeing coke furnaces in successful operation in the United States. Nearly every state in the Union has good raw coal in sufficient quantity, as well as of proper quality to supply its furnaces."

Overman's *preferred* method of coking in rows or long heaps is described thus: "These rows are sometimes one-hundred feet long, seven or eight feet wide, and three feet high. To coke in rows, a yard is to be levelled sufficiently large to hold as much coal as is required to keep the furnaces in operation. Along, or all around, this yard, it is advisable to have a ditch dug, which will hold a regular supply of water throughout the year; this water ought not to fail during the driest seasons. A row is started at that end of the yard most convenient for the transportation of the raw coal, and directed in a straight line towards a point on the opposite side of the yard. Should there be a deep covering of coke dust all over the yard, a kind of ditch, as broad as the coal pile is designed to be, may be prepared by scraping the dust from the middle, and drawing it towards the spaces between the rows. This ditch will indicate the direction in which the coal is to be laid, and will bring it close to the moist ground. The scraped coke dust is afterwards used for covering the heap. The coal is arranged as in the above case (authors' note: coarse coal at the bottom and in the center). Due attention should be paid to placing air-channels, or draft holes, at the bottom, and to throwing the coarse coal in the centre. At a distance of seven or eight feet from each other, tapered posts seven or eight inches in diameter, are fastened in the ground, around which the coarsest coal is arranged. These posts or poles are removed before the heap is fired, and are designed to form chimneys, for the free vent of gaseous matter, and the increase of draft. When the pile extends twenty feet or more, and it is covered with small coal, slag, or coke dust, fire may be put to the heap at different places near the air holes; and the row may then be continued. In this way it will happen that coke is drawn at one end of a row, and coal is set at another. After fire is kindled, and the heat extended to the center, the pile may be covered more closely, with due attention to leaving some air-holes near the top; and in case these holes are shut by the expansion of the coal, they should be re-opened by means of iron bars run down to the center of the pile, or at least to the fire. When the white flames of carburetted hydrogen cease to be visible, the heap and air-holes may be closely covered by coke dust, and the coke left to cool. This method of making coke for the blast furnace has, thus far, been preferred to any other method. For this preference the following reasons may be assigned: the small body of coal in fire at one time; the large surface of ground it covers, thus presenting unequalled facilities for the circulation of watery vapors through the hot coke; and the chance it affords of retaining the heat till the advantages of steam are produced. For these reasons a water ditch around a coke yard is required to keep the ground moist; besides, water is frequently needed to choke the fire where it continues too long in the heap, and thus to drive the steam through the hot coke. For the same reason, a yard does not make good coke if it is covered too thickly with coke dust."

Development of the Coke Industry During the 19th Century

Year	Number of Establishments	Year	Number of Establishments
1850	4	1889	252
1860	21	1890	253
1870	25	1891	243
1880	149	1892	261
1881	197	1893	258
1882	215	1894	260
1883	231	1895	265
1884	250	1896	341
1885	233	1897	336
1886	222	1898	341
1887	270	1899	343
1888	261	1900	388

Overman's theory of carbonization placed great emphasis on the benefits to be derived from "the circulation of watery vapors through the hot coke". "Good coke", he writes, "ought to be silvery white and compact; it ought to sound like good crockery ware and should be free of bitumen, hydrogen, and sulphur." Water quenching he was not at all in favor of. "In some establishments, workmen have been advised to sprinkle water over the red-hot coke, which may be done from the nose of a watering-pot, partly with the object of expelling the remaining sulphur, and partly with the object of extinguishing the fire. This is a bad habit; it inures the coke, makes it rotten, and seriously impairs its utility in the blast furnace." To the reader of today, Mr. Overman's views upon coke and coking sound quaint indeed. Perhaps we should not judge him too harshly, however, and even the most critical tends to find himself mollified by a preface which disarmingly states that, "This work contains imperfections for which we cannot consistently ask the indulgence of the reader. It may even embody errors; these, on the ground of human frailty, may be deemed, by the kind-hearted reader, excusable."

Open-air coking was, of course, wasteful and lacking in control, and the next step in the development of carbonization practice was no doubt the use of rectangular brick enclosures which were left open at the top. The side walls of these precursors to the oven were between 5 and 8 ft tall and contained holes provided for the entry of air. The method of coking was identical to that followed when coking in mounds. From this it was a logical development to provide the walls with a roof to make a fully enclosed oven. The original shape may have been suggested either by the dome-shaped mound used for coking or by the form of the charcoal kiln.

HISTORY OF THE COKING INDUSTRY IN THE UNITED STATES

II—The Beehive Oven Era

by C. S. Finney and John Mitchell

The introduction of ovens for the production of metallurgical coke is believed to be due to L. L. Norton who operated an iron foundry in the vicinity of Connellsville, Pa. Persuaded by his foreman, an English immigrant named Nickols from Durham, L. L. Norton put up a 12-ft square oven which produced coke in 1833. The coal used was taken from a local mine at Mounts Creek. The oven seems to have been used in conjunction with the customary method of coking in mounds. It was in the Connellsville district also, in 1841, that two carpenters, Provence McCormick and James Campbell, formed a partnership with John Taylor, a stone mason, for the manufacture and sale of oven coke. The task of the mason was to construct the ovens, while the carpenters were to build the arks by which the coke could be taken by water to the market at Cincinnati. The following account of the enterprise was given by McCormick: "James Campbell and myself heard in some way that I do not now recollect that the manufacturing of coke might be made a good business. Mr. John Taylor, a stone mason, who owned the farm on which the Fayette coke works now stand, and who was mining coal in a small way, was spoken to regarding our enterprise, and proposed a partnership—he to build the ovens and make the coke and Mr. Campbell and myself to build a boat and take the coke to Cincinnati, where we heard there was a good demand. This was in 1841. Mr. Taylor built two ovens. I think they were about 10 feet in diameter. My recollection is that the charge was 80 bushels. The ovens were built in the same style as those now used, but had no iron ring at the top to prevent the brick from falling in when filling the oven with coal, nor had we any iron frames at the mouth where the coke was drawn. The top and mouth had to be repaired when they fell in. In the spring of 1842 enough coke had been made to fill two boats 90 feet long—about 800 bushels each—and we took them to Cincinnati down the Youghiogheny, Monongahela, and Ohio, but when we got there we could not sell. Mr. Campbell, who went with the boats, lay at the landing some two or three weeks, retailing out one boatload and part of the other in small lots at about 8 cents a bushel. Miles Greenwood, a foundryman of that city, offered to take the balance if he would take a small patent flour mill at $125.00 in pay, which Mr. Campbell did. He had it shipped here. We tried it, but it was no good, and we sold it to a man in the mountains for $30.00, and thus ended our coke business."

So successful did the coke subsequently prove to be in use that the three partners were asked to deliver more. Evidently they had had enough of the coke business, however, for they refused to have anything more to do with it. Few ovens were built between 1841 and 1855, and it is reported that in the latter year, "there were only 26 coke ovens along the river above Pittsburgh". Successful coke makers of these years included Mordecai Cochran, Richard Brookius, and Colonel A. M. Hill. It was the use of coke in 1859 in the Clinton furnace erected by Graff, Bennett and Co. in a plant on West Carson Street, Pittsburgh, that brought the real beginning of the coke-iron era in America. Here the successful use of Connellsville coke as a blast-furnace fuel was demonstrated beyond all possible doubt, and from the year 1859 the coking industry expanded tremendously.

The era of beehive coke ovens

During the latter half of the nineteenth century and the early years of the twentieth, the major percentage of metallurgical coke produced in the United States came from beehive ovens. It was not until 1893 that the first battery of by-product ovens came

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Beehive coke ovens in 1893.

into operation (at Syracuse, N. Y.), and only in 1919 did the total production of by-product coke first exceed that from beehive ovens. Peak output of beehive coke occurred in 1916 when 35,464,224 tons were produced as opposed to the 19,069,361 tons carbonized in by-product ovens.

The Connellsville district of Pennsylvania was not only the birthplace of the oven coking industry in the US, it was in this region also that the most extensive growth of beehive coking operations took place. There were two reasons for the rapid development of the coke industry at Connellsville. First, enormous quantities of excellent coking coal were readily available from the Pittsburgh seam of the Connellsville basin. Secondly, adequate rail and water transportation facilities allowed the coke to be shipped as far west as California, south to New Orleans, and to such eastern cities as New York and Baltimore.

In the special report on the Coke Manufacture of the Youghiogheny River Valley issued in 1875 as part of the Second Geological Survey of Pennsylvania, the Pittsburgh Coal Bed in the Connellsville Basin was described as occupying a trough 3 mi wide and 50 mi long, and giving from 8 to 9 ft of workable coal that was soft, easily and cheaply mined, and yielded a coke of unusual excellence. At the time of the Survey, the coal could be mined, coked, and loaded on cars at the ovens for $0.0275 per bushel, or $1.37 per net ton.

A typical analysis of the Pittsburgh coal then mined at Connellsville was given as: Moisture—1.3 pct; Volatile Matter—30.1 pct; Fixed Carbon—59.6 pct; Ash—8.2 pct; and Sulfur—0.8 pct.

Owing to its columnar structure and friable nature, Connellsville coal was readily broken during mining and handling, and thus arrived at the coke plant in comparatively small, uniform pieces. Since it was also free from any considerable impurities, it could be charged to the beehive ovens without any form of preparation.

As already noted, the development of the Connellsville coking industry was materially assisted by its favorable location with respect to transportation. By means of the Youghiogheny, Monongahela, Ohio and Mississippi rivers, the celebrated coke of Connellsville could be marketed in cities such as Cincinnati, St. Louis, and even New Orleans. In addition to this great river network, however, the coke region was served by four railways; the Pittsburgh, Washington and Baltimore (Pittsburgh and Connellsville) main line ran along the north bank of the Youghiogheny, Pittsburgh being 57 mi and Baltimore 287 mi from the town of Connellsville; the South West Pennsylvania Railroad connected with the Pennsylvania Railroad at Greensburg, 24 mi north of Connellsville; and short branch lines 10 and 9 mi in length, respectively, linked Connellsville with the coke works south as far as Uniontown and north to Mount Pleasant. Thus it was that from this small area of undulating country in Westmoreland and Fayette counties in southwestern Pennsylvania, Connellsville coke went out to Ohio, Milwaukee, Chicago, Omaha, Salt Lake City, and California in the west; to the Gulf Coast in the south; and to New England, New York City, Philadelphia and Baltimore on the Atlantic coast.

By 1875 there were 3578 beehive ovens in the Connellsville Basin, capable of producing 26,000 tons or 1,302,600 bushels of forty-eight hour coke when operating full time. Details for the four districts comprising the Connellsville region are as follows:

District	No. of Works	No. of Ovens	Weekly Shipments in Cars of 600 Bushels
Fayette County Branch of Pittsburgh & Connellsville R.R.	7	646	375
Mount Pleasant Branch of Pittsburgh & Connellsville R.R.	21	1349	860
Pittsburgh Connellsville R.R.	8	953	562
South West Pennsylvania R.R.	9	630	374
Total	45	3578	2171

The beehive coking industry was not, of course, confined to the state of Pennsylvania, much less to

Table I. Analysis of Coals of Various Areas at the Close of the 19th Century

Appalachian Coals

State	Moisture, Pct	Volatile Matter, Pct	Fixed Carbon, Pct	Ash, Pct	Sulfur, Pct
Pennsylvania—East	1.73	23.89	67.03	6.69	0.66
Pennsylvania—West	1.70	39.15	46.66	10.52	1.97
Ohio	1.58	41.86	51.44	5.12	2.64
West Virginia—East	1.52	19.81	72.71	5.20	0.76
West Virginia—West	1.52	37.86	53.37	6.03	1.22
Kentucky	1.80	33.00	60.10	5.10	0.65
Tennessee	1.50	32.51	59.33	5.82	0.84
Alabama	1.65	32.48	60.15	4.82	0.90
Eastern[a] and Western[b] Interior Coals					
[a]Illinois	2.08	37.10	52.17	7.02	1.63
[a]Indiana	2.98	40.98	50.70	3.48	1.88
[b]Kansas	3.25	40.96	43.98	10.71	1.10
[b]Missouri	6.50	37.71	42.17	10.56	3.06
Rocky Mountain[c] and Pacific Coast[d] Coals					
[c]Colorado	0.82	37.25	55.72	6.00	
[c]Montana	1.02	38.01	48.20	11.87	Not
[c]New Mexico	6.66	40.13	45.56	7.65	Given
[d]Washington	3.26	35.36	57.58	3.80	0.10

Table II. United States Coke Production During 1896

	Coke Production, Net Tons
Appalachian Region	
Pennsylvania (includes New York)	7,356,502
West Virginia	1,648,755
Alabama	1,479,437
Tennessee	339,202
Virginia	268,081
Ohio	80,868
Georgia	53,673
Kentucky	27,107
Total	11,254,625
Eastern Interior Region	
Wisconsin	5,332
Indiana	4,353
Illinois	2,600
Total	12,285
Western Interior Region	
Indian Territory	21,021
Kansas	4,785
Missouri	2,500
Total	28,306
Rocky Mountain Region	
Colorado	343,313
Montana	60,078
New Mexico	24,228
Utah	20,447
Wyoming	19,542
Total	467,608
Pacific Coast Region	
Washington	25,949
Grand Total	11,788,773

the Connellsville district. By the close of the 19th Century, beehive ovens were at work in the following areas: the Appalachian region in the coal fields of Pennsylvania, Virginia, West Virginia, Ohio, Tennessee, Georgia, Alabama and eastern Kentucky; the Eastern Interior region in the fields of Illinois, Indiana and western Kentucky; the Western Interior region in Kansas, Missouri and Oklahoma; the Rocky Mountain province, including Colorado, Montana, Utah and New Mexico; and the Pacific coast province in the fields of Washington.

Typical analyses for the coals of these regions were given by John Fulton in his book *Coke* published in 1905 and are listed in Table I. Important as they may have been locally, the coke-producing areas other than the Appalachian region were of limited national significance. Either, as in the case of the Eastern and Western Interior regions, the coals were much less well suited to beehive operations than the strongly coking Appalachian coals; or alternatively, as in the case of the Pacific coast fields of Washington, coking coals were only found in small areas.

From Table II which illustrates the coke production in the US during the year 1896, it can be seen that of a total output of 11,788,773 net tons (including 83,038 tons of by-product coke) 11,254,625 tons were produced in the Appalachian region, Pennsylvania alone being responsible for more than 7 million tons. The total output for all the other coke-making regions combined was only 534,148 tons.

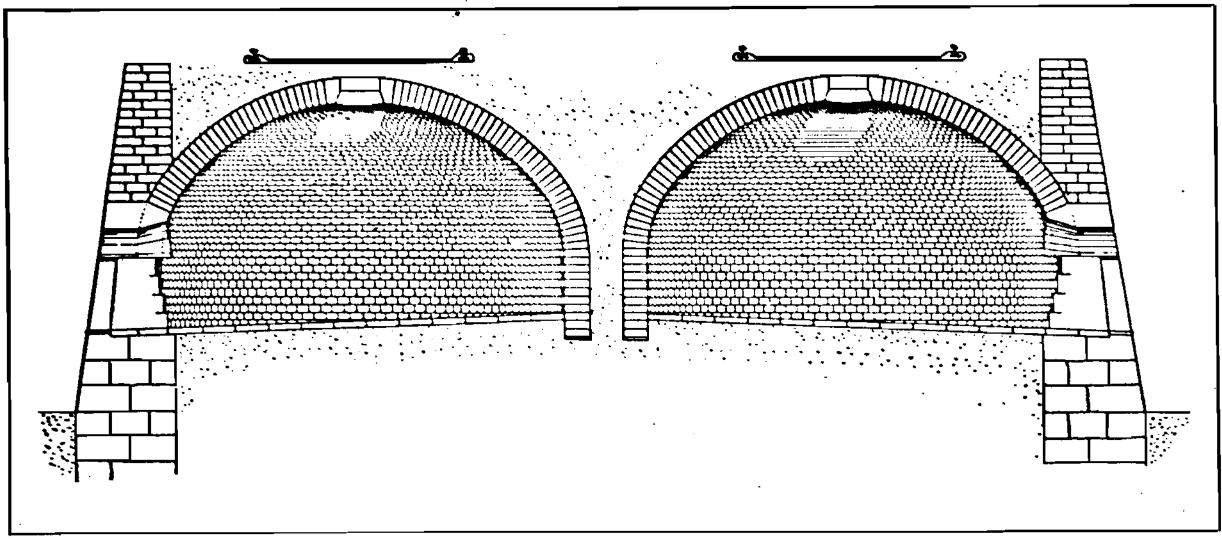
The quality of Connellsville coke always stood pre-eminent. An indication of how highly it was regarded may be gained from a statement made by R. W. Raymond, President of the American Institute of Mining Engineers, at a meeting of the Institute held in Pittsburgh in October 1872. "I saw in the neighborhood of Salt Lake City, Utah, last summer several carloads of Connellsville coke costing, when delivered, about $33.00 per ton and that price was more economical than charcoal as a smelting fuel."

Even as late as 1915 Connellsville coke was considered the standard coke of the country, its quality being the yardstick against which cokes from all other areas were judged. As far as the other districts of the Appalachian region were concerned, excellent beehive coke was also made in Virginia, West Virginia, and from some of the Alabama coals. The cokes of Kentucky, Ohio, Tennessee, and Georgia were less highly rated.

A characteristic feature of beehive coking is, of course, the production inside the oven of the heat necessary for carbonization. The earlier ovens were made of masonry, firebrick, and tile, and were simple, dome-shaped structures about 12 ft in diam and 7 or 8 ft in height. The floor was constructed of flat tiles, and the domed roof provided with a charging port which also served as a vent for the combustion gases. An arched door built into the side of the oven enabled the air for combustion to be admitted, and also allowed leveling of the coal charge and quenching and withdrawal of the coke after carbonization had been completed. The ovens were built in single rows or banks, and in double rows with ovens back to back or in an interlocking or staggered formation.

The first step in preparing for beehive operations was to start a fire of wood and coal in the oven, the side door being partially bricked up so that only adequate air for combustion was allowed to enter. When the oven reached temperature, the side door brickwork was removed, the chamber cleaned, and the door re-bricked again, a suitably-sized hole for leveling of the coal charge being left. Five or six tons of coal were then charged through the roof and leveled off to a depth of some 2 ft. Under the action of the heat stored in the oven walls, volatile evolution occurred, and combustion took place mainly above the coal charge. Coking proceeded downwards, and the carbonization time varied between 48 and 72 hrs.

Control over the quantity of air admitted to the oven was of considerable importance in beehive operations, and the area of the opening in the side door through which the air entered had to be regulated throughout the coking period if the best results were to be obtained. From a maximum at the time of greatest volatile evolution, the air supply



Cross-sectional view of beehive coke ovens.

was decreased as coking proceeded and the liberation of combustible gases diminished. During the latter stages of the carbonization process, considerable restriction of the air supply was necessary if severe losses due to combustion of the coke were to be avoided.

After the completion of coking, the charge was quenched in the oven and withdrawn for the next cycle to be commenced.

Naturally, the cost of making coke in the beehive oven varied according to the local conditions in any particular producing area. A cost of $1.6735 per ton has been quoted as applying to Connellsville beehive ovens in the year 1899.

As with any other industry, the early days of beehive coking were characterized by simple structures and crude methods. Charging and leveling of the coal were carried out manually, as was raking out of the coke; air regulation was obtained by the rough-and-ready method of inserting or removing bricks in the side door as appropriate; and of course no attempt was made to recover the sensible heat of the waste gases or the heat of combustion of the unburned gaseous or liquid decomposition products. As time went on, however, more sophisticated methods of oven building, operation, and materials handling emerged. Shaped firebrick for the charging ports, domes, and doors came into use, as did the adoption of silica for the roof. Annular air admission passages were provided on some ovens, perforations being used in an effort to obtain equal air distribution above the level of the charge. It was claimed that such an arrangement gave an increased coke yield. Machinery for withdrawing the coke was devised. An English machine patented in 1891 by Thomas Smith of the Thorncliff Iron Works, Sheffield, was put into use near Latrobe, Pa., where in 1895 the Latrobe Coal and Coke Co. started up a plant of 30 Newton Chambers beehive ovens. The Smith coke-drawer consisted of two trucks coupled together and running on a track parallel to the ovens. One truck carried the extractor itself, while its companion carried a small, upright boiler of 9 hp which supplied steam for propelling the trucks and operating the coke-puller. The extractor consisted of a steam engine by means of which a wedge-shaped shovel was pushed under the coke and then withdrawn bringing the coke with it. The machine was said to be capable of drawing four ovens per hour at about one-third the cost of hand labor. The Newton Chambers beehive ovens at Latrobe were also notable for the fact that they were built for by-product recovery. After a short period, however, attempts to recover gas, ammonia compounds, and tar were abandoned.

Another mechanical extractor, the Hebb coke-drawer invented by Mr. J. A. Hebb of Hopwood, Pa., utilized a hoe on a rack which was actuated by a motor-driven pinion. Mounted on rails in front of the oven doors, the machine was equipped with an integral turntable which allowed the hoe to reach all parts of the oven floor. Because of the circular shape of beehive ovens, coke-pullers were only partially successful, and drawing had to be finished off by hand.

Efforts to utilize waste heat for steam generation were made. At the Pratt mines of the Tennessee Coal, Iron, and Railroad Co., two waste heat boiler plants were installed, each of which took the heat from its individual battery of 12-ft bank beehive ovens. Each steam-raising plant consisted of two batteries of 46 in. x 26 ft boilers. The waste gases from the ovens were delivered by short 12-in. diam connecting flues into a 3½-ft diam main flue which was built in contact with the rear walls of the ovens. It is stated that the quantity of coal required for steam raising at the mines was reduced from 1500 to 300 tons per month, and that the savings which resulted from the adoption of waste heat recovery were $18,000 per year.

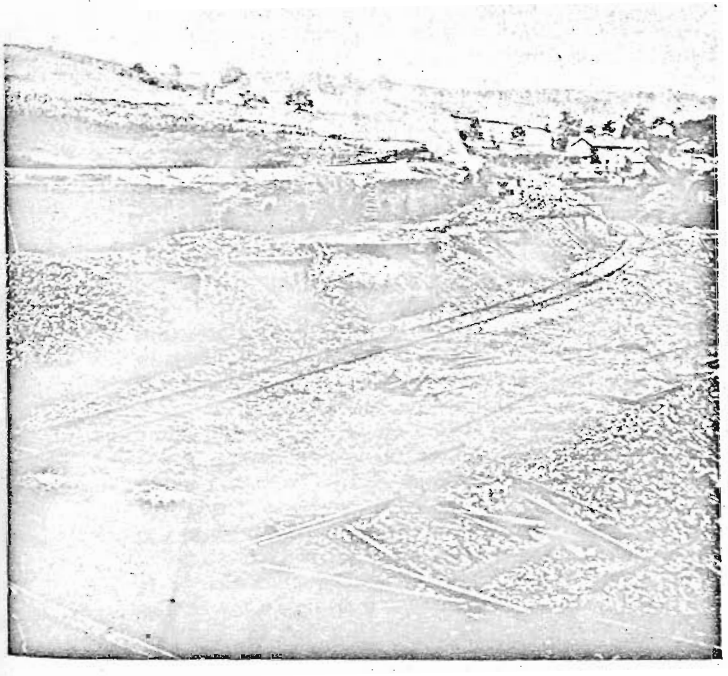
Another method of waste heat utilization was that exemplified by the Ramsay Patent Beehive Oven in which the decomposition products were taken off from the top of the oven, traveled down through external, vertical flues, and on into horizontal combustion flues located below the hearth before being vented through individual stacks.

Adaptations of the beehive oven to allow for mechanical withdrawal of the coke appeared in the old Welsh drag-oven, and later in the Thomas oven. The former was built as an arched chamber 12 ft in length, 7 ft in breadth, and 6 ft high. One end of the oven was walled up and had a flue for gas discharge. The opposite or front end was provided with doors through which the coke was taken out by means of an iron drag-bar which was positioned on the oven floor before charging with coal. At the end of the coking cycle an engine-driven winch pulled the drag-bar across the floor, thus removing the whole coke mass which was then quenched outside the oven. The Thomas oven was very similar to the Welsh oven but was considerably longer and had doors at both ends. It was thus unnecessary to place the drag in position before charging. As with the Welsh oven, external quenching was practiced. In both cases the principle was that of beehive coking, and in neither quality nor yield did the product differ greatly from that obtained from the older ovens. The *longitudinal oven*, on the other hand, which was yet another modification of the beehive, was claimed to give an increased yield and better coke at a lower operating cost. Originally developed in England, ovens of this type allowed complete mechanization of the modified beehive oven to be attained. Charging was carried out from larry cars running on tracks above the ovens, and the coal was mechanically leveled. Discharging was done by means of a mechanical pusher which delivered the coke to conveyors and then into coke cars.

Excellent metallurgical coke was made in the beehive oven, and for many years after the introduction of by-product ovens, opinion, in England and America especially, was that only in beehive installations could a really first-class coke be produced. Because of its operating characteristics, however, the beehive oven was somewhat selective in the type of coal that could be used, and could not successfully be employed to carbonize the less strongly coking coals. Comparatively low initial oven temperatures, together with the fact that the charge is, in effect, heated from the top only, combine to give a slow rate of heat penetration, and accordingly much of the charge is at a low temperature for a considerable period. While this slow initial heating makes for the formation of a well developed cell structure, it also makes mandatory the use of a coal with strong coking properties. Beehive coke is dense and hard with a silvery, glossy sheen. It is produced in large, rather long pieces. A typical analysis of coke produced from Pittsburgh seam coal in the Connellsville area at the turn of the century was: Moisture—0.5 pct; Fixed Carbon—87.5 pct; Ash—11.3 pct; Sulfur—0.7 pct; and Phosphorus—0.03 pct.

Although coke yields of up to 65 pct from beehive ovens were quoted in the literature of the day, not all authorities agreed that such efficiencies were being generally attained. One of the most trenchant critics of the way in which beehive ovens were being operated was A. W. Belden of the Bureau of Mines (*Metallurgical Coke*, US Bureau of Mines Technical Paper No. 50, 1913). Belden considered that the process of coking had not greatly altered since the evolution of the beehive oven began with the ovens of McCormick, Campbell, and Taylor in 1841, and attributed the higher efficiencies of later years mainly to improvements in the ovens and better coal preparation. "To this day", wrote Belden, "the burning of coke, except in a few instances, is left in the hands of unskilled laborers, and technical knowledge of coking processes is woefully lacking. Until 1896, when the by-product coking industry began to grow appreciably, little was heard of any technical study or deep thought being applied to coke making." After commenting that, "The determination of the coking properties of any coal was generally decided by the report of practical coke burners from the Connellsville region", Belden tartly reminded his readers that, "The very fact that Connellsville coal produces coke of excellent quality no matter how inefficiently the ovens are handled, should preclude the use of such evidence." Skeptical of the percentage coke yields which were being reported at the time, Belden noted that, "The handling of the modern beehive oven, as practised in all parts of the country, undoubtedly gives a lower yield of coke than might be obtained, but the matter of increased yield, even when brought to the attention of those in authority, is most often passed over with the remark, 'We are doing well enough and making money, so why should we make any change?' One reason why it is so hard to impress the importance of greater efficiency on the mind of the coke manufacturer is that he does not know what yield he is getting. He is satisfied to use figures that show the amount of coke produced if they come anywhere near what he thinks he ought to obtain. The 1911 returns to the Division of Mineral Statistics of the United States Geological Survey show the average yield of coke in beehive ovens for the country to be 64.7 pct, but if figures showing the actual tonnages of coal charged and coke produced were obtainable, the yield would probably more nearly approach that in mounds or piles, namely 59 pct. There is no doubt that with proper supervision of the burning of coke this figure could be increased 3 to 5 pct. A conservative estimate of the direct loss from the 27,703,644 tons of coke produced in this country in bee-hive ovens in 1911 is 1,154,318 tons worth over $3,266,350. The gratifying increase in by-product coke production, the output being 22.07 pct of the total production in 1911, shows that the country is waking up to the necessity of curtailing this enormous waste. . . . The fact that the country's best coking coals are rapidly becoming

Beehive coke ovens between Greensburg and Mount Pleasant in the Connellsville District of Pennsylvania.



exhausted makes the scientific study of the process of coking more imperative, and it is only the by-product oven that can give the proper answer to the many questions asked."

There can be little doubt that Belden's strictures were well merited by large sections of the beehive industry. Then, as now, human inertia and resistance to the adoption of sound technological principles allowed rule-of-thumb methods to persist long after these had been proved inadequate. Admittedly, the mechanism of the coking process was a subject about which almost nothing was known, and the industry had been forced to depend on the application of practical skills rather than of scientific knowledge. There were, however, no mysteries about the need for and benefit from such ordinary practices as proper leveling of the coal charge, or careful air regulation over the whole carbonization period. Yet all too often such matters were neglected or ignored to the detriment of both coke quality and yield.

It is likely that beehive oven managers often had trouble in maintaining good operating procedures because of the nature of the work involved. The operation of beehive ovens was hot, dirty, and arduous, especially before the introduction of mechanical methods of leveling, or coke drawing. Only unskilled labor was likely to be attracted to such tasks, and intensive supervision must have been required to obtain consistently good results. The immediate supervisor of the labor force was the foreman or *yard boss*, who was responsible to the superintendent for ensuring that the plant was properly run. "He must keep a record of each oven drawn and charged each day. He must see that the charges are not too large or too small for the 48-hour or the 72-hour coking periods, and that no ovens are drawn until the coke in them is properly coked. The drawers, chargers, levelers, daubers, ash boys, and laborers are under his direct charge, and he must see that they report for duty at the time specified for the days run to begin and that there are no unnecessary delays about a coke plant, as they occasion expenses and loss of coke by retarding the charging of the ovens beyond the regular time for quitting work for the day.

"The coke boss must further see that neither too much nor too little water is used in watering the coke, that the supply of railroad cars arrives at the plant at the proper time, that the coke is loaded properly, that the cars are properly carded for shipment, the yards kept clean, that the water supply is at all times in good shape, and that the ovens receive the necessary repairs, as they deteriorate from constant use. He must also watch the entire plant to see that at all times it is kept in first-class working shape, and that all persons employed at the plant do their work properly and at the right time, as the matter of having certain work done at certain times, and on certain days, is a very important matter connected with the successful manufacture of coke."

Table III. Beehive Coking During the Last Two Decades of the 19th Century

Year	No. of Ovens	Coke Production, Net Tons
1880	12,372	3,338,300
1881	14,119	4,113,760
1882	16,356	4,793,321
1883	18,304	5,464,721
1884	19,557	4,873,805
1885	20,116	5,106,696
1886	22,597	6,845,369
1887	26,001	7,611,705
1888	30,059	8,540,030
1889	34,165	10,258,022
1890	37,158	11,508,021
1891	40,057	10,352,688
1892	42,002	12,010,829
1893	44,189	9,464,730
1894	44,760	9,187,132
1895	45,493	13,315,193
1896	46,784	11,705,735
1897	47,388	13,027,072
1898	47,863	15,752,764
1899	48,583	19,762,035
1900	57,399	19,457,621

A good foreman had to be especially watchful for what a contemporary account refers to as *coke drawers' tricks.* To the hot and toilsome task of pulling coke there were evidently those who applied a measure of cunning as well as a lot of brawn. Thus, "Men who pull coke from the ovens are paid so much per oven and not by tonnage; hence, it is an object to them to have as little coke as possible to draw. Each man is given a block of six ovens; thus he will have three ovens daily to pull. When one oven is being watered down, another oven, if it has the bricks of the door pulled down, can have its coke burning up, so that when it comes time to water the oven a large quantity of coke has been consumed and there is not so much to draw. During the time the coke has been thus burning the oven has also been cooling off; and when it has been watered and left standing without proper attention it is further cooled off with the result that poor coke will be had from the next drawing. To hasten the coking of the coal in an oven, an occasional brick may be knocked out from the door; the increased quantity of air admitted by this means will cut the coke out very fast, and as it is difficult to chink up such holes the ovens must be banked as soon as coking is finished, for otherwise it will cool as well as burn up coke."

Manifestly, the job of yard boss was no sinecure. Indeed, good foremen were, as they still remain, the very backbone of any enterprise. Yet one sees few testimonials to the loyalty and skill of such men, who, standing between management and organized labor, often neglected by one and suspected by the other, contributed much to their company and industry.

The last two decades of the nineteenth century were marked by a steady expansion of the beehive coking industry. By the year 1900 almost 20 million tons of coke were being produced from 57,399 ovens.

In 1910, there were 100,362 beehive ovens in existence, from which 34,570,076 net tons of coke were produced, but the threat of the seventeen-year-old by-product industry was becoming very evident. As the twentieth century opened, some 5 pct of the total coke made in the United States came from by-product oven; by 1910 the percentage had increased to 17.1.

The heyday of beehive coking lay between 1900 and 1920. In only two of these years (1900, 1919) was production less than 20 million tons, and in 1916 an all-time record was reached when 35,464,224 tons of beehive coke out of a national total of 54,533, 585 tons were made. After the first World War, however, the beehive industry lost its position as the major producer of metallurgical coke. Since that time it has been a marginal source of supply, useful in times of national emergency but contributing in only a minor degree toward the demands of blast furnace or foundry.

HISTORY OF THE COKING INDUSTRY IN THE UNITED STATES

III—Emergence of By-Product Coking

by C. S. Finney and John Mitchell

The decline of the beehive coking industry was inevitable, but it had filled the needs and economy of its day. A beehive plant required neither large capital investment to construct nor an elaborate and expensive organization to run. The ovens were built near mines from which large quantities of easily-won coking coal of excellent quality could be taken, and handling and preparation costs were thus at a minimum. The beehive process undoubtedly produced fine metallurgical coke, and low yields were considered to be the price that had to be paid for a superior product. Few could have foreseen that the time would come when lack of satisfactory coking coal would force most of the beehive plants in the Connellsville district, for example, to stay idle; and if there were those like Belden who cried out against the enormous waste which was leading to exhaustion of the country's best coking coals, there were many more to whom conservation was almost the negation of what has since become popularly known as the spirit of free enterprise. As for the recovery of such by-products as tar, light oil, and ammonia compounds, throughout much of the beehive era there was little economic incentive to move away from a tried and trusted carbonization method simply to produce materials for which no great market existed anyway.

With the twentieth century came changes that were to bring an end to the predominance of beehive coking. Large new steel-producing corporations were formed whose operations were *integrated* to include not only the making and marketing of iron or steel but also the mining of coal and ore from their own properties, the quarrying of their own limestone and dolomite, and the production of coke at or near their blast furnaces. As the steel industry expanded so did the geographic center of production move westward. By 1893 it had moved from east-central to western Pennsylvania, and by 1923 was located to the north and center of Ohio. This western movement led, of course, to the utilization of the poorer quality coking coals of Illinois, Indiana and Ohio. These coals could not be carbonized to produce an acceptable metallurgical coke in the beehive oven, but could be so treated in the by-product oven.

By World War I the technological and economic limitations of the beehive oven as a coke producer were being widely recognized. After the war the number of beehive ovens in existence dropped steadily to a low of 10,816 in 1938, in which year the industry produced only some 800,000 tons of coke out of a total US production of 32.5 million tons. The demands of the second World War led to the rehabilitation of many ovens which had not been used for years, and in 1941, for the first time since 1929, beehive ovens produced more than 10 pct of the country's total coke output. Production fell off again after 1945, but the war in Korea made it necessary once more to utilize all available carbonizing capacity so that by 1951 there were 20,458 ovens with an annual coke capacity of 13.9 million tons in existence. Since that time the iron and steel industry has expanded and modernized its by-product coking facilities, and by the end of 1958 only 64 pct of the 8682 beehive ovens still left were capable of being operated.

Because beehive ovens are cheap and easy to build and can be closed down and started up with no great damage to brickwork or refractory, it is likely that they will always have a place, albeit a minor one, in the coking industry. The future role of the beehive oven would seem to be precisely that predicted forty years ago by R. S. McBride of the US Geological Survey. Writing with considerable prescience, McBride declared: "A by-product coke-oven plant requires an elaborate organization and a large investment per unit of coke produced per day. Operators of such plants cannot afford to close them down and start them up with every minor change in market conditions. It is not altogether a question whether beehive coke or by-product coke can be produced at a lower price at any particular time. Often by-product coke will be produced and sold at less than cost simply in order to maintain an organization and give some measure of financial return upon the large investment, which would otherwise

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remain entirely unproductive. As a natural consequence of this relationship of investments in the two types of plants, it may be expected that in the future most of the fluctuations in production will occur in the beehive branch of the industry. In other words, the beehive ovens will serve the purpose of standby equipment and the by-product ovens will be the normal operating agents in the supply of metallurgical fuel."

Development of by-product coking

The by-product coking industry of the United States began in 1893, but its European origins reach back to the seventeenth century. On August 19, 1681, an English patent was granted to Johann Becher and Henry Serle for "a new way of makeing pitch, and tarre out of pit coale, never before found out or used by any other". This seems to be one of the first patent references dealing with the possibility of recovering the by-products of coal carbonization. It was not until the middle of the eighteenth century, however, that the first real efforts were made to reclaim by-products. De Gensanne, a French metallurgist of the day, has described a plant which may very well have been the first by-product installation ever constructed. Built in 1766 at Sulzbach near Saarbrücken by the *Kohlenphilosoph* Johann Kaspar Staudt, the plant consisted of nine ovens which were simply muffle furnaces heated by means of coal burned on external grates. The capacity of each oven was about 1 ton of coal, and coking was carried out over a period of three days. The installation was intended to remove the sulfur from coal so that the coke might be used to make iron, but oil, tar, lampblack, and sal ammoniac were collected by Staudt. "Coal thus coked exhales not the slightest odour in burning, and it has the advantage of lasting twice as long in the fire as wood-charcoal, instead of which it may be used for all purposes without fear of the least inconvenience. This is not all; the oils and bitumens obtained in this operation almost pay the expense of it." Staudt and his ovens have the distinction of being mentioned in Goethe's autobiography *Dichtung Und Wahrheit*. As described by Goethe, who visited the plant in 1771 while a student at the University of Strasbourg, Staudt apparently had a good deal to be philosophic about. Worn and haggard, wearing a boot on one foot and a slipper on the other, he was in charge of an enterprise which was on the verge of being abandoned because (despite the glowing economic picture of the quotation above) it did not pay. In Goethe's words, "all failed together on account of the many ends in view".

Coking Industry During the 20th Century

	No. of Ovens In Existence		Production, Million Net Tons			
				By-Product		
Year	Beehive	By-Product	Beehive	Quantity	Percentage of Total	Total
1900	57,399	1085	19.4	1.1	5.2	20.5
1905	84,405	3103	28.8	3.4	10.7	32.2
1910	100,362	4078	34.6	7.1	17.1	41.7
1915	93,110	6268	27.5	14.1	33.8	41.6
1920	75,298	10,881	20.5	30.8	60.0	51.3
1925	57,587	11,290	11.4	39.9	77.9	51.3
1930	23,907	12,831	2.8	45.2	94.2	48.0
1935	13,674	12,860	0.9	34.2	97.4	35.1
1940	15,150	12,734	3.1	54.0	94.6	57.1
1945	12,179	14,510	5.2	62.1	92.3	67.3
1950	17,708	14,982	5.8	66.9	92.0	72.7
1955	10,104	16,039	1.7	73.6	97.7	75.3
1956	9,549	15,923	2.5	72.0	96.0	74.5
1957	9,519	15,897	2.1	73.9	97.2	76.0
1958	8,682	16,244	0.6	53.0	98.9	53.6
1959	7,448	15,993	1.1	54.6	98.0	55.7

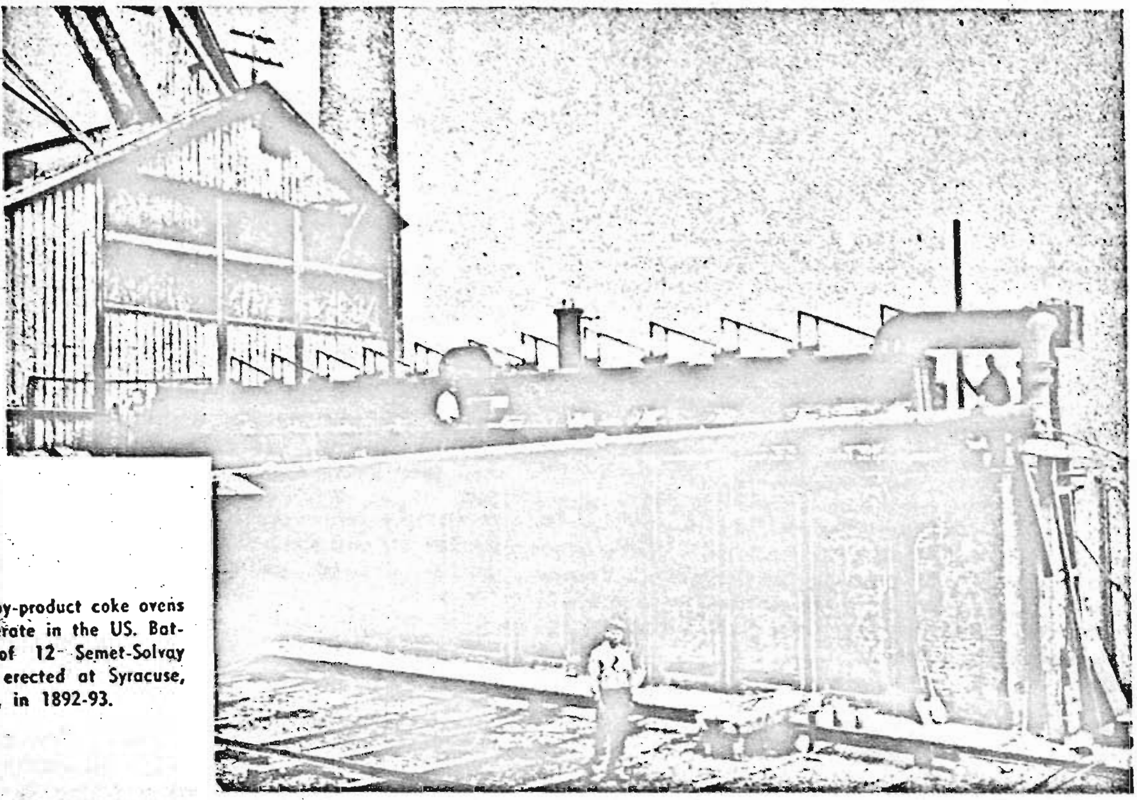
Despite the granting of a patent (No. 1291 of April 30, 1781) to Sir Archibald Cochrane, Earl of Dundonald, —"that indefatigable inventor" as Professor George Lunge has described him—for "A method of extracting or making tar, pitch, essential oils, volatile alkali, mineral acids, salts, and cinders from pit-coal", by-products were not recovered on any considerable scale until the beginning of the nineteenth century and the development of the coal-gas industry.

There seems to be some doubt as to who first distilled coal gas and used it as an illuminant to any extent. Dr. Stephen Hales, Vicar of Teddington, in his *Vegetable Staticks* published in 1727 recorded that by distilling 158 grains of Newcastle coal he had been able to obtain 180 cu in. of inflammable gas, but he made no attempt to carry out further work on a larger scale. Another ecclesiastic to examine the distillation products from coal was Dr. Richard Watson, Bishop of Llandaff. In 1767, from 96 oz of Newcastle coal, Bishop Watson obtained 28 oz. of gas, 12 oz of tar, and 56 oz of what he described as "a light spongy mass, in appearance, and, indeed, in quality resembling a substance prepared from pit-coal, as an article of trade, and which is usually called coak or cinder". Of the gas which he collected, Watson wrote: "The air which issued with great violence from the retort was inflammable, not only at its first exit from the distillatory vessel, but after it had been made to pass through two high bended glass tubes and three large vessels of water". Like Hales, Dr. Watson confined his work to small-scale experiments.

The first successful manufacture of gas and its utilization for lighting on a practical scale has been claimed for the Englishman, George Dixon; the Dutchman, Jean Pierre Minkelers; the French engineer, Phillipe Lebon; and William Murdoch of Scotland. Dixon is said to have lighted a room of his house with coal gas in 1779, while Minkelers is supposed to have used gas to light his lecture room from 1783 onwards while Professor of Philosophy at the University of Louvain. Lebon certainly obtained an illuminating gas by carbonizing sawdust, and obtained a patent in 1799 for a *most beautiful* light which he could produce with his *thermolamp*. He also experimented with coal, but only in a minor way. Whatever success the others may have had on a limited scale, it was undoubtedly Murdoch who, in conjunction with his famous collaborator Samuel Clegg, laid the foundation of the coal-gas industry. In 1792 William Murdoch, who at the time was employed by Boulton and Watt as their manager in the Duchy of Cornwall, England, lit his house and offices at Redruth, Cornwall, with coal-gas generated in an iron retort in his backyard. He also carried bladders of gas to light himself home at night. In 1798 Murdoch built an apparatus at the Soho works (Birmingham) of Boulton and Watt, for making, storing, and cleaning gas, which was used to light parts of the factory. And in 1802, to celebrate the Peace of Amiens, two *Bengal Lights* were put up at the works as a public display of the new gas-lighting.

World's first gas company

In 1812, largely due to the efforts of that remarkable character, Frederick A. Winsor, the world's first



First by-product coke ovens to operate in the US. Battery of 12 Semet-Solvay ovens erected at Syracuse, N. Y., in 1892-93.

gas company, the Gas Light and Coke Co. of London, was chartered. Born Winzer (or Winzler) in Zhaim, Moravia, he was a dauntless, if rash and flamboyant advocate of the budding industry. To further his vision of a public gas supply, he did not spare either his own energies or the pockets of any who would listen to him. Neither did he spare their sensibilities, if the following jingle attributed to him can be taken as typical of his publicity methods:

"Most mortals on earth with smoke live in strife
And many a beauty is smothered alive.
Great London itself, th' empor'um of the world
In clouds of black smoke is constantly furl'd.
Smoke begot chimneys, chimneys beget smoke,
Soot, fires, and filth all prevented by coke."

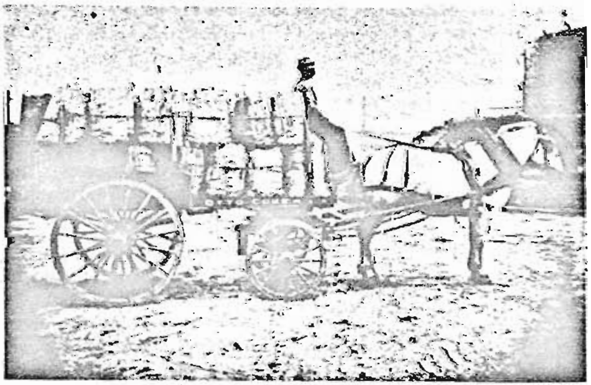
Poet, experimentalist, entrepreneur, Winsor was many things to many men. He died in France in 1830, very little the richer for his pioneering. Although never a modest person, it is likely that even Winsor had no idea that his contributions to the founding of an industry would bring him such fame. The dignified words of Samuel Clegg's son in 1841 might well have formed his obituary. "He was not cast in the same mould as Mr. Murdoch, and it is therefore unfair to measure him, as some have done, by such a standard. One was a philosophical investigator—the other an impetuous schemer. Each had his own sphere of action; each was great in his own way; each deserves to be, and will be, kept in remembrance."

The establishment of the Gas Light and Coke Co. in 1812 was rapidly followed by the building of public gas-works in Paris in 1815, in Baltimore in 1816, Boston in 1822, New York in 1825, and Berlin in 1826. The liquor and tar which were produced during the manufacture of city gas were at first a source of much trouble and embarrassment to the gas companies. They were of no commercial value, a nuisance to store, and could not be indiscriminately dumped. At the Glasgow gas-works attempts were made to use tar, for example, in the heating of the retorts, while in Paris it was sold in small amounts for medicinal purposes. In 1845, however, A. W. Hoffmann recognized and proved the presence of benzene in coal tar, and the method of obtaining it in quantity from tar was developed in Hoffmann's laboratory by his pupil, Charles Mansfield. In 1856, W. H. Perkin discovered mauve, the first of the aniline colors, and thus founded the coal-tar-dye industry. Perkin was trying to make quinine from aniline. Instead of quinine he was left with a black powder. The latter, when extracted with *methylated spirits of wine* gave a solution which "when distilled left the mauve as a fusible bronze-coloured mass". The presence of napthalene in coal-tar was discovered by both Garden and Brande in 1819, and investigated in detail by Lawrent in 1832. In the same year Dumas proved anthracene to be a constituent of tar, and in 1869 Graebe and Liebermann synthesized the dyestuff alizarin from the compound. Coincident with these developments was the work of Liebig, the great German chemist, and Lawes and Gilbert, founders of the Rothamsted Experimental Station in England, upon plant nutrition. This led to a wider understanding of the value of artificial fertilizers in assisting crop growth, with the result that the ammoniacal liquor which in earlier times had been such a nuisance to the gas industry could henceforth be profitably utilized in the production of ammonium sulfate.

Early oven design

The progress of the city gas industry and the development of markets for the by-products must have been watched with considerable interest by the manufacturers of metallurgical coke. However, neither in Europe nor in America did the coking industry at first show much enthusiasm for modifying its operations to allow by-product recovery. This indifference may have stemmed from the fact that for metallurgical purposes the quality of gas-works coke was much inferior to that obtained from the beehive oven. The inference drawn was that a good blast furnace coke could not be made in ovens from which by-products were recovered, and this conclusion seemed to be sustained by the poor coke produced from the new, closed, retort-type ovens that were being developed on the continent by such men as Knab, Coppée, Appolt, Carvés, and Francois-Rexroth. In the first designs no attempt was made to recover ammonia or tar, but the gas was utilized to heat the ovens instead of being wasted. Knab, in 1856, at Commentry, Dept of Allier, France, built a group of ovens which were narrow, vertical chambers 23 ft long, 6 ft, 6¾ in. high, and 3 ft, 3¾ in. wide. The combustion flues were located below the oven base. The quality of the coke was not impressive, but the yield, at 63 pct of the coal charged, was quite good. In 1862 Knab was joined at Commentry by Carvés, who greatly improved the heating system of the Knab oven by using side flues in addition to the original bottom flues. Better temperature distribution and faster carbonization were thus obtained. Carvés also extracted tar and ammoniacal liquor from the gas before returning it to the oven, an exhauster being used to take it off from the ovens and pump it through the by-product recovery train. The Knab-Carvés ovens gave the following yields: Large coke—70.00 pct; Breeze—1.50 pct; Dust—2.50 pct; Graphite —0.50 pct; Tar—4.00 pct; Ammoniacal liquor—9.00 pct; Gas—10.58 pct; Losses—1.92 pct. In 1881 Henry Simon of Manchester, England, added a recuperator to the Carvés oven so that the air required for combustion in the side-wall flues could be preheated by the waste gases. Simon-Carvés ovens were built at Bear Park, Durham, in 1883, and achieved a coking time of 48 hr.

The Appolt oven was another early design in which by-product recovery was limited to use of the gas for heating the oven. This was a vertical-type oven consisting of a series of upright, rectangular retorts enclosed in a large, vertical combustion chamber. The retorts were wider (4 ft x 1 ft 6 in.) at the base than at the top (3 ft 8 in. x 13 in.) to facilitate coke discharge, and were 13 ft high. Each retort held about 13 tons of coal, and the coking time was 24 hr. The Appolt oven was expensive to build and maintain, and coke quality was variable.



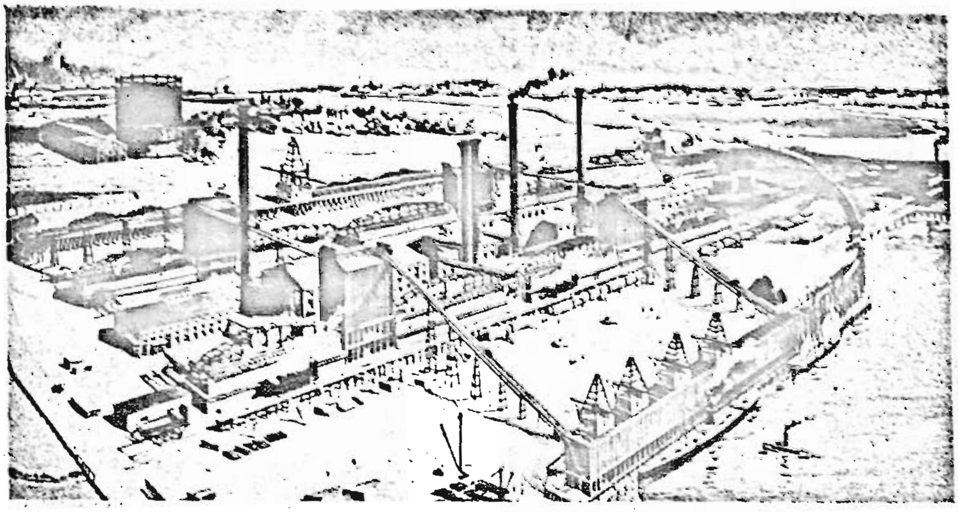
Retail delivery of Otto Coke in 1903.

The ovens designed by Francois-Rexroth were, like the Knab and Simon-Carvés ovens, of the horizontal type. Unlike the latter, however, they incorporated vertical instead of horizontal heating flues, and may thus be regarded as the prototype of the modern by-product oven. Some 26 ft long, 5 ft high, and about 35 in. in width, the Francois-Rexroth oven had a taper of 2 in. Gas and air were supplied to the vertical flues at various points below the top of the oven, and the waste gases were subsequently discharged to the stack by means of bottom flues underneath the oven. Three tons of coal per oven could be carbonized in 48 hr.

In 1861 the Francois-Rexroth oven was modified and improved by E. Coppée of Belgium. Coppée combined the rather high, narrow coking chambers used previously by Smet, with the vertical heating flues introduced by Francois-Rexroth, the result being an oven 30 ft in length, 15 to 18 in. wide, and 4 to 5 ft high. Each of the 28 vertical combustion flues was provided with a separate air control-damper. Heating could thus be more accurately controlled, and refractory life was much improved compared to earlier ovens. The first Coppée ovens to be built in Germany were constructed in the Ruhr by Dr. C. Otto in 1876. They were 24 in. wide, 68 in. high, and about 30 ft long; the carbonizing time was 48 hr. The length of the later Coppée ovens was increased to 33 ft, the height of 68 in., and the width of 24 in. being retained. The number of combustion flues was increased from 28 to 32. A 72 pct coke yield could be obtained, and oven capacity was 7 to 8 tons of coal. The sensible heat of the waste gases was recovered by means of waste heat boilers.

Although by 1881 considerable progress in the recovery of by-products from coke ovens had been made in France, little work on a commercial scale had been done in Germany. The attempt was made in 1881 by Albert Hüssener of Essen, who built 50 coke ovens at Gelsenkirchen of a type similar to those used by Knab and Carvés. About 15 pct of the coke produced was used to heat the ovens, and the principles used in gas-works practice were employed to recover by-products. Designed to make blast furnace coke from a high-volatile gas coal, the ovens were at first a complete failure. When charged with a lower volatile coal, however, good metallurgical coke was obtained, together with a favorable yield of satisfactory by-products. Thus encouraged, Hüssener put up a second battery of 50 ovens in which improved combustion arrangements allowed the use of coke for heating purposes to be dispensed with, and a small amount of surplus gas to be obtained. Hüssener's success did much to correct the belief that acceptable blast furnace coke could not be made in by-product ovens.

In 1882 Dr. Th. von Bauer of Germany recommended the use of the Siemens regenerative principle for coke-oven operation, and in 1883 Gustav Hoffman patented the idea. The German patent (No. 18,795) was bought by Dr. C. Otto and Co., who applied it to the Otto-Coppée oven, and the first Otto-Hoffmann type plant was built near Wanne in 1883. Improved ovens of this type rapidly gained popularity in Germany, and by 1894 more than 1200 of them had been built on the Continent. They produced good metallurgical coke at yields of 70 pct and better, and considerable quantities of tar and ammonia products were obtained. At the time of Otto's death in 1897 more than 10,000 Otto



Otto-Hoffmann ovens at the Everett Coke Plant in Massachusetts. Circa 1898.

oven had been constructed in Germany alone. Many of these were not by-product ovens, but in that particular year some 7 million gallons of tar, 400,000 gallons of benzole, and 14,000 tons of ammonia products were produced in plants operated by Dr. C. Otto and Co. Plainly the by-product coking industry of continental Europe was now firmly established.

By-Product coke ovens in the US

Blessed with abundant quantities of such celebrated coking coals as those of Connellsville, Durham, and South Wales, American and British coke makers had not been forced to develop (and were little inclined to adopt) the coking methods required to treat the poorer coals of Belgium, France or Germany. Furthermore, in both the United States and in Britain, the superiority of beehive coke was accepted as an article of faith long after the iron masters of Europe had overcome their prejudice against coke made in the by-product oven. In October of 1891, in a paper given at the Franklin Institute of Philadelphia, Dr. Bruno Terne declared that "If you will visit our coal region today, you will find the nightly sky illumined from the fires of the coke ovens, and every one of the brilliant fires bears testimony that we are wasting the richness of our land in order to pay the wiser European coke manufacturer, who saves his ammonia and sends it to us in the form of sulfate of ammonia; and who also saves his tar, which, after passing through the complex processes of modern organic chemistry, reaches our shores in the form of aniline dyes, saccharin, nitrobenzol, etc.

"As far back as 1768, tar had been produced as a by-product of the coke industry by a chemical process at Fishbach, in the coal district of Saarbrücken on the Rhineland. (Authors' note: this seems to be a reference to the work of *Kohlenphilosoph* Staudt.)

"The general opinion of the consumer there was then, and most likely will be here at the present time, that the coke produced will be of inferior quality. Against this opinion of the practical coke men, it has always been held by technical chemists, that the process can be so conducted as to yield all the by-product and still make a first class coke."

In England, even as late as 1893, no less a person than Sir Isaac Lowthian Bell felt able to write of the by-product oven that "My own firm has spent large sums in pursuit of a plan of obtaining ammonia, etc., and the firm of Messrs. Pease and Company are continuing the process with perfect success as regards the by-products, but they, or their customers, find, as we found, the coke not so suitable for blast-furnace work as that burnt in the old-fashioned beehive oven".

The first by-product coking plant to be constructed in the United States was associated with the chemical industry. In 1882 the first ammonia-soda plant for the production of soda ash had been built at Syracuse, N. Y. by the Solvay Process Co., founded by Ernest Solvay of Belgium. The son of a salt manufacturer, Solvay had observed the reaction of ammonium bicarbonate on brine in 1861, and had subsequently established a successful process for the production of sodium carbonate. This process involved the use of ammoniacal liquor and coke. The former was the source of ammonia, and the coke was employed to obtain carbon dioxide by burning limestone in vertical kilns. In association with Semet (a relative who was employed at the Brussels Gas Works), Ernest Solvay had developed the Semet-Solvay coke oven to provide the necessary raw materials, and in 1892 the erection of 12 of these ovens, the first by-product ovens in America, was commenced at Syracuse.

Like the Carvés oven, the Semet-Solvay oven was of the horizontal-flue type, but each oven was designed with its own individual heating flues which were separated from those of the adjoining oven by a robust firebrick wall. The Syracuse ovens were 30 ft long, 16½ in. in width, and 5½ ft in height. A charge of 4.4 tons of coal could be carbonized in 24 hr. The cost of the Syracuse installation has been given as $88,014.

Because the by-product train installed was large enough to handle the output from 25 ovens, the total cost per oven was rather high at $7334. During 1893 the 12 ovens at Syracuse produced 12,850 tons of coke.

The success of the Solvay Process Co.'s pioneering venture did much to establish the respectability of by-product coking in the United States, and the day for which the conservationists such as Belden had hoped, was rapidly arriving. It was not long before the suppliers of capital came to realize that here was a promising field for investment, and coke users to appreciate that the unattractive, dull, grayish-black coke that they had scorned to accept could, in fact, compete with the lustrous, silvery-gray, beehive product as a metallurgical fuel. In 1895 two more batteries, each containing 25 Semet-Solvay ovens, were constructed for the American Manganese Manufacturing Co. at Dunbar, Pa., followed by 90 ovens at Ensley, Ala., for the Tennessee Coal, Iron and Railroad Co. in 1898, and a further 30 ovens at the same place in 1899. During 1898 and 1899 90 Semet-Solvay ovens were also constructed near Wheeling, W. Va., for the National Tube Co. The capacity of the later ovens was enlarged from the original 4.4 tons to 7 to 9 tons by increasing the length to 35 ft and raising the height to as much as 9 ft. The standard width of 16½ in. was maintained.

Naturally the Semet-Solvay Co. (a subsidiary of the Solvay Process Co.) had competitors in the business of building by-product ovens. Their success in Europe with the vertical-flue Otto-Hoffmann oven had led Dr. C. Otto and Co. to consider whether they might not enter the American market, and Dr. F. Schniewind was commissioned to investigate the possibilities. As a result of Schniewind's activities, the Otto Coke and Chemical Co. was formed, and this was rapidly enlarged into the United Coke and Gas Co. with W. L. Elkins, Jr. of Philadelphia as president, and Schniewind as vice-president. Elkins and Schniewind managed to interest the Cambria Steel Co. of Johnstown, Pa. in the Otto-Hoffmann system of carbonization, and in the summer of 1893 the steel company sent John Fulton to Germany to investigate whether Connellsville coal might be successfully coked in such a plant. Fulton reported that as a result of oven tests carried out on some 18 tons of Connellsville coal, a 71 pct yield of large coke was obtained which was of excellent metallurgical quality. A contract was accordingly signed for the construction of two batteries of 30 ovens each, together with a full by-product recovery system, and during 1894 work on the first by-product plant to be erected for the specific purpose of supplying blast furnace coke was begun at Johnstown.

The next move by the enterprising managers of the United Coke and Chemical Co. was to attract the attention of the iron and steel industry at Pittsburgh. A site at Glassport, near McKeesport, was therefore selected as a suitable location for the construction of by-product ovens which could carbonize the readily available Pittsburgh seam coal, and from which the blast furnaces of the area could be supplied with coke. In 1897 120 ovens and an associated by-product recovery plant were built for operation by the Pittsburgh Coke and Gas Co. The ovens were arranged in four batteries; they were 33 ft long and 6 ft high, had a taper of 22 to 19 in., and held about 6 tons of coal. A laboratory was provided, and provision was also made for oven tests on carload lots of coal. Gas was supplied to McKeesport.

The largest single installation of by-product ovens during the ebb of the nineteenth century was the contract for eight batteries of 50 Otto-Hoffmann ovens each at Everett (near Boston), Mass. for the New England Gas and Coke Co. The latter company was organized in 1897 by Henry M. Whitney. During the early 1890's Whitney had become associated with the local gas utility business in Boston, and he had also developed interests in the Dominion coal fields at Cape Breton, Nova Scotia, which had been discovered in 1896. The coal from Cape Breton was a high-volatile coking coal which could be landed in Boston at low cost, and the construction of a by-product coking plant gave an expanding Boston the gas it needed and assured Nova Scotia of a market for its coal. Work was begun in 1898 on 299 acres of land in the Everett and Chelsea districts, and production commenced in 1899. The ovens were almost identical with those of the Glassport installation, and incorporated the *rich and poor gas system* which Schniewind had developed for the latter. Coke production was 1400 long tpd, half of which was supplied to such railroads as the Boston and Maine, and the New Haven and Hartford, as a locomotive fuel. Of the remainder, 25 pct was sold to steam generating plants, and 25 pct was marketed for domestic purposes. Often sold in half-bushel paper bags through grocery stores, etc., the domestic coke was publicized in the following terms: "Otto coke is the new domestic coke, better than hard coal, and costs about $2.00 less per ton. It's made from coal by burning off smoke and dirt . . . all the things you don't want . . . and leaving a firm, smokeless fuel" The housewives of Boston also discovered the *Otto coke* to have a further property not possessed by hard coal; it gave rise to considerable clinkering troubles. The gas produced at the Everett plant was sold to various local gas companies. The first contract called for the delivery of 12 cp unpurified gas at a price of $0.14 per mcf, but after four or five years the price had to be raised to $0.23 per mcf and by 1917 it was up to $0.295 per mcf. The candlepower of the gas was also increased from 12 to 16, and subsequently to 18.

As the following tabulation shows, by 1902 (that is, 10 years after construction was commenced on the Semet-Solvay ovens at Syracuse) the by-product coking industry had expended tremendously.

The First Ten Years of By-Product Coking

Year	Ovens in Existence at End of Year	Ovens Being Built	Production Net Tons
1892	—	12	—
1893	12	—	12,850
1894	12	60	16,500
1895	72	60	18,521
1896	160	120	83,038
1897	280	240	261,912
1898	516	500	294.445
1899	1,016	65	906,534
1900	1.081	1,096	1,075,727
1901	1,161	1,533	1,179,900
1902	1,669	1,346	1,403,588

The figure of 1669 for ovens in existence at the end of 1902 has been taken from the Bureau of Mines Circular 7996, *Coke Plants in the United States on December 31, 1959*. John Fulton in his book *Coke* published in 1905 quotes a figure of 1663, however, which is in agreement with that used for many years in earlier publications by the Bureau of Mines. Included in this total of 1663 were 525 Semet-Solvay, 1067 Otto-Hoffmann, 15 Schniewind, and 56 Newton Chambers ovens. Of the 1346 ovens under construction, there were 210 Semet-Solvay, 664 Otto-Hoffmann, 412 Schniewind, and 60 Retort Coke Co. ovens. The Schniewind oven was a modification of the Otto-Hoffmann oven. Designed to allow accurate and uniform distribution of fuel gas to the combustion chambers, it had a further advantage in that the regenerators were built independent of the oven structure and could not therefore affect the latter by expansion.

HISTORY OF THE COKING INDUSTRY IN THE UNITED STATES

IV—Development of Modern By-Product Ovens

by C. S. Finney and John Mitchell

The growing popularity in the United States of the vertical-flue oven was emphasized when in 1905 the United States Steel Corp. chose the Koppers oven as the type which best suited their requirements. Heinrich Koppers was born on November 23, 1872, at a small farm in Walbeck near Geldern on the lower Rhine. When young Koppers was eight years old, however, the family moved away from the farm to the industrial city of Bochum in the Ruhr. Here Koppers attended public school and subsequently served an apprenticeship to a tinsmith before taking a job as a lathe operator with a local steel company. He had ambitions to be much more than a machinist, however, and used his week-ends and evenings to improve his theoretical background by taking courses at a vocational-training school in Bochum. After winning the highest honor the school could bestow (the silver *Staatsmedaille*), Koppers went on to continue his education at the Rheinisch-Westfälische Hüttenschule in Duisberg. One of his teachers there, Fritz Wüst, who later became a professor at the Technische Hochschule at Aachen, recognizing Koppers' unusual abilities, predicted for him a great future.

In 1894 Heinrich Koppers joined the firm of Dr. C. Otto and Co. in Dahlhausen, and in 1899 while superintendent of the Mathias Stinnes mine he built his first battery of ovens for Hugo Stinnes, the German industrialist. Two years later he started his own organization, and in 1902 he made Essen his headquarters. It was to Essen that a group of engineers from the United States Steel Corp. went in 1906 with an invitation to Koppers to design and supervise the construction of four batteries of ovens at the Joliet works of the Illinois Steel Co. Each battery was to consist of 70 ovens. Arriving in the United States in 1907, Koppers established a branch of his firm in Joliet, and construction began. The first battery was fired on July 27, 1908. Rugged and simple, these ovens incorporated basic design features which were to make the Koppers oven and its future modifications the choice of a very large segment of the by-product coking industry of America.

The 280 ovens at Joliet were 35 ft long, 8¾ ft in height, and tapered from 21 to 17 in. The total daily capacity of the four batteries was 2240 tons of coke. The ovens were of the new *cross-regenerative* type; that is, instead of longitudinal regenerators serving an entire battery, as in the older Koppers ovens, cross regenerators for each separate oven were employed. Fuel gas was supplied from the side of the battery through ducts in the brickwork known as *gun flues*, which reached to the center of the battery under the vertical heating-flues. Removable, ceramic gas-nozzles fitted at the top of each gun flue helped to insure good control over the distribution of the fuel gas, and uniform heating conditions were also promoted by regulating the air supply to, and the suction in, each heating flue. A different refractory was used for each battery. One was built of American silica brick, one of American quartzite, and two of imported German quartzite.

The installation at Joliet proved to be very successful, and in 1911, 490 additional Koppers ovens were built for the Illinois Steel Co. at the great new steelworks at Gary, Ind. By 1912 the H. Koppers Co. had established its headquarters in Chicago and was rapidly extending its business to include construction for such iron and steel companies as the Woodward Iron Co. at Woodward, Ala. (80 ovens in 1912); the Tennessee Coal, Iron and Railroad Co. at Fairfield, Ala. (280 ovens in 1912); the Inland Steel Co. at Indiana Harbor, Ind. (86 ovens during 1913 and 1914); and the Republic Iron and Steel Co. at Youngstown, Ohio (68 ovens in 1913).

In 1914 a group of men in Pittsburgh bought a major shareholding in the H. Koppers Co., and moved the headquarters of the organization from Chicago to their own city. Under its new management the company was highly successful in obtaining a large share of the contracts for by-product installations built during World War I. In 1917 the remaining German interests in the company were

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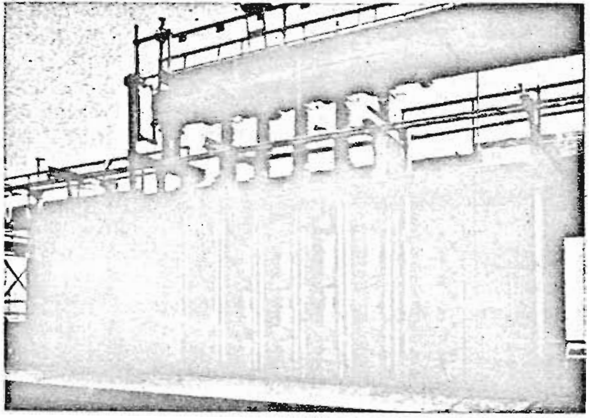
taken over by the Alien Property Custodian, and subsequently passed into American hands. The Koppers Co., Inc. as it became, was to develop into the largest designer and builder of by-product ovens in the United States.

The Koppers cross-regenerative oven was not without faults, and difficulties were experienced, for example, with the single, horizontal flue (or bus flue) through which combustion gases passed from the heating flues to the downflow flues. Because this common flue handled the entire volume of combustion products from the battery, it had to be quite large. With the construction of greater capacity ovens and an increasing use of such lean fuels as blast-furnace gas or producer gas, the gas volume became such that an adequately sized horizontal flue could no longer be built without dangerously weakening the structure and seriously affecting the coking process.

The problem of the horizontal flue was solved by designing an entirely new heating system by which gas was burned in all the flues of one wall at the same time. The combustion products then passed over the top of the oven by means of several crossover flues, down through vertical flues on the other side, and thence to the stack by way of the regenerators and waste gas flue. The new design, for which US Patent 1,374,546 was granted on April 12, 1921 to J. Becker as assignor to the Koppers Co., Inc., allowed ovens to be built of up to 50 pct greater capacity than had been possible with the original heating system. Joseph Becker was born in Essen, Germany, on October 1, 1887. As the son of a local policeman, there were all too few opportunities for him to pursue his education beyond the age of 14, and he therefore took a job as an office-boy in a law office. It seems that young Becker had little interest in the law, for less than a year later he took another and very different job at a colliery which operated a battery of by-product coke ovens. It was there that he gained an early familiarity with carbonizing and recovery plant, and there also that he attracted the attention of Heinrich Koppers who in 1906 offered him a position as a chemist in the Koppers laboratories at Essen. Capable and energetic, his first really big opportunity came in 1910 when he was sent to Joliet in the United States as chief chemist for the Koppers organization. Two years later, Becker was appointed as superintendent of all Koppers operations in the US, with headquarters in Chicago. As the company expanded so did Joseph Becker move up in the organization. In 1944 he became vice-president and general manager of the engineering and construction div. of the Koppers Co., Inc., and in 1950 he was made a member of the Board of Directors.

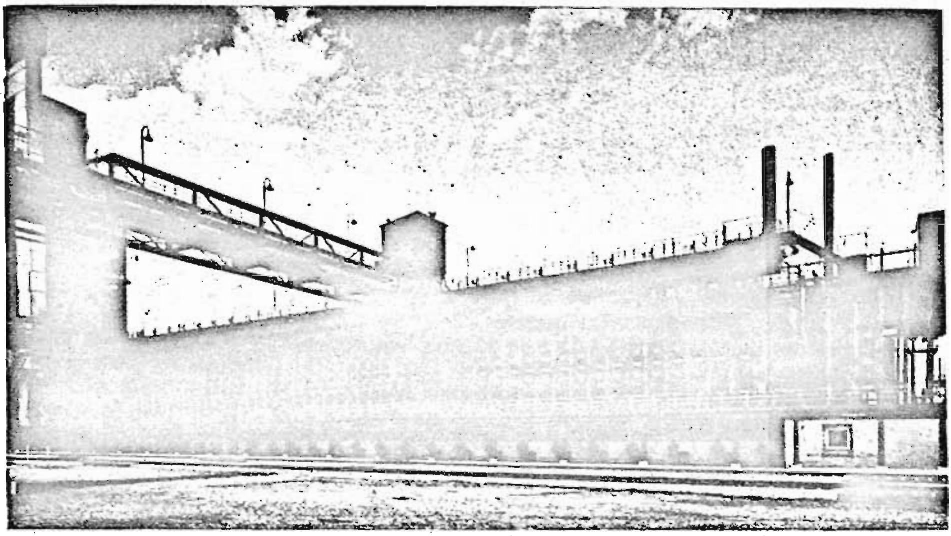


First Battery of Five Koppers-Becker Ovens Erected at the Chicago By-Product Coke Co. in 1922.

Although the horizontal flue was not eliminated in the Koppers-Becker oven, as it was named, it was possible to make it much smaller in cross-section than it had been in the Koppers cross-regenerative oven. In 1922, before making the new design generally available to industry, it was decided to build a small experimental battery of five Koppers-Becker ovens at a plant which the Koppers Co. operated for the Chicago By-Product Coke Co. of Chicago, Ill. The ovens were 37 ft long, 11 2/3 ft high, had a taper of 14¾ to 13¼ in. at the bottom and 13¾ to 12¼ in. at the top, and could be charged with 24 to 27 tons of coal. The battery was heated by producer gas. The success of this prototype installation brought rapid acceptance of the Koppers-Becker oven. In 1923 the Weirton Steel Co. put in 37 of the new ovens at Weirton, W. Va., and during the same year ovens were also under construction at Salt Lake City, Utah, at Alkali, Ohio, and at Warren, Ohio. A shorter version of the Koppers-Becker oven was also available to supply manufactured gas to small cities. Very similar in cross section, the short oven was about half the length of the full-size oven and accordingly was charged with approximately half the tonnage of coal.

An attempt to improve on the shortcomings of the old Koppers cross-regenerative oven was also made by Louis Wilputte, who at one time had worked for Heinrich Koppers in the United States. Wilputte was the son of a construction foreman from Flanders. As an employee of the firm of Evence Coppée, the elder Wilputte had been entrusted with the erection of the first Coppée ovens to be built in England—a battery of 30 ovens at Chapeltown near Sheffield. From Chapeltown he went to South Wales where the Coppée firm had a contract to build coke ovens at the well-known ironworks in Ebbw Vale. Remaining at the ironworks, Wilputte's father married a Welsh girl and became a naturalized British citizen. The son, Louis, was born in Ebbw Vale on December 21, 1876. At the age of 15, after finishing primary school, Louis Wilputte started work at the local ironworks, but four years later he went to Brussels where he obtained a job as a draftsman with Evence Coppée. In that capacity he had ample opportunity to learn the theoretical basis of coke oven construction. When 25 years old, Wilputte left Coppée for the firm of Dury and Piette, and his next three years were spent building coke ovens in the province of British Columbia. He happened to learn, however, of the possibility that Heinrich Koppers might build a large coke oven plant for the Illinois Steel Corp. and he therefore promptly left Canada for Essen where he persuaded Koppers to appoint him as his general manager in the US. Wilputte handled the negotiations with the United States Steel Corp. very capably, and quickly negotiated a contract for the erection of 280 ovens which were built under his direction during 1907-1908. Between 1913 and 1917 Wilputte cooperated with the various interests of Dr. C. Otto and Co. in America, but on July 1, 1917, he left the Otto Co. in order to work independently.

In July of 1917 Wilputte was granted US Patents 1,212,865 and 1,212,866 for an oven rather similar in design to the Koppers cross-regenerative oven. Separate regenerators were provided for each flue,



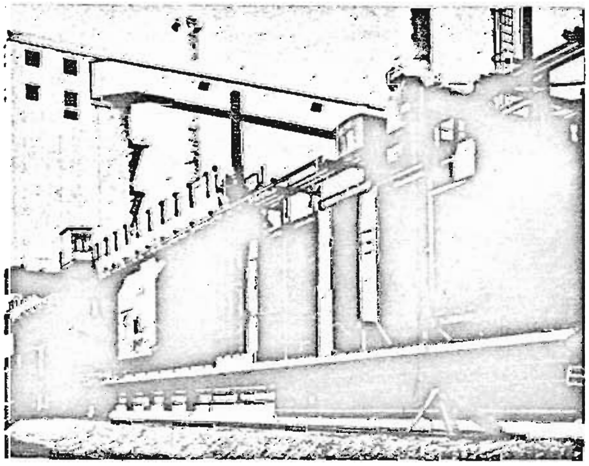
A Modern Installation of Koppers-Becker Coke Ovens.

and a controlled quantity of air was supplied to each regenerator by means of forced draft from a blower. By a decision of the US Circuit Court of Appeals on May 22, 1919, however, it was held that the Wilputte oven was an infringement of US Patent 818,033 granted to Heinrich Koppers in 1906. Above the oven floor the Wilputte design did not greatly differ from that of the Koppers cross-regenerative oven, and it therefore did little to solve the problems associated with the horizontal flue. Subsequently, however, the size of the horizontal flue in Wilputte ovens was limited by dividing it at the center of the oven, giving, in effect, an oven consisting of two short, cross-regenerative ovens placed end to end. Since 1940, when Louis Wilputte disposed of his interests in the Wilputte Coke Oven Corp. to the Allied Chemical and Dye Corp., Wilputte ovens have been erected by the latter organization.

The development of the by-product coking industry during the twentieth century was steady rather than spectacular up until the outbreak of World War I. The stimulus of wartime demand for coke and by-products, however, led to a sharp increase in the rate of oven building, so that by 1918 more than twice as much coke (26 million tons) was being produced than had been made in 1914 (11.2 million tons). In 1919 the quantity of coke from by-product ovens exceeded that turned out by the beehive section of the industry, and in the years following, the slot oven supplied an increasing share of the country's production at the expense of the beehive oven. During the depression years of the early 1930's, by-product coking suffered along with all other sectors of business and industry. From a peak of 53.4 million tons of coke in 1929, production fell to 45.2 million tons in 1930, 32.4 million tons in 1931, and a low of 21.1 million tons in 1932. The industry gradually recovered during the later 1930's and then entered a period of remarkable activity during World War II; in 1944, for instance, more than 67 million tons of by-product coke were produced. Under the influence of an expanding economy the demand for coke reached new heights after the second World War, and in 1953 an all-time record output of 78,836,857 tons was attained, of which 73,593,528 tons came from by-product ovens. Production of by-product coke reached a maximum in 1957 when 73,860,692 tons were made out of a total of 75,950,721 tons.

By-Product Coking During the 20th Century

Year	Ovens in Existence at End of Year	Ovens Built	Tons of Coke Produced
1900	1,081	65	1,075,727
1905	3,135	213	3,462,348
1910	4,082	89	7,138,734
1914	5,660	228	11,219,943
1915	6,238	670	14,072,895
1916	7,240	1,002	19,069,361
1917	7,819	579	22,439,280
1918	9,229	1,800	25,997,580
1920	10,771	1,044	30,833,951
1925	11,278	404	39,912,159
1930	12,771	533	45,195,705
1931	12,864	93	32,355,549
1932	12,809	87	21,136,842
1933	12,809	—	26,678,136
1934	12,857	138	30,792,811
1935	12,754	177	34,224,053
1940	12,623	3	54,014,309
1941	12,910	687	58,482,422
1942	13,303	423	62,294,909
1943	14,253	1,010	63,742,676
1944	14,580	568	67,064,795
1945	14,510	176	62,094,288
1950	14,982	552	66,890,618
1955	15,980	641	73,584,214
1956	15,923	361	71,992,242
1957	15,897	560	73,860,692
1958	16,244	808	53,005,730
1959	15,993	101	54,612,986



A Modern Battery of Wilputte Ovens.

HISTORY OF THE COKING INDUSTRY IN THE UNITED STATES

V—The Coke Industry Today

by C. S. Finney and John Mitchell

On December 31, 1959, there existed in the United States 15,993 slot-type coke ovens capable of producing 81,447,700 net tons of coke. These ovens were concentrated in 74 coke plants in 21 different states. As of the same date, there were 7448 beehive ovens in existence at 45 plants in the states of Pennsylvania, Virginia, West Virginia, and Kentucky. Total annual capacity of the existing beehive ovens was 4,368,800 net tons, but only 5148 ovens with a capacity of 3,131,600 tons were in operating condition.

It is interesting to compare the average dimensions of slot-type ovens built during recent years with the 30 ft x 5½ ft x 16½ in. ovens erected at Syracuse, N. Y. in 1892. A composite oven built according to the average dimensions of all those erected between 1954 and 1958, for instance, would be 39 ft long, 12 ft high, and 18 in. in width. The coal capacity would be 16 tons as against the 4.4 tons which could be charged to the Syracuse ovens. Of the 15,993 slot-type ovens in existence at the end of 1959, by far the greater number were built by the Koppers Co. whose total of 11,280 ovens included 7891 Koppers-Becker and 3389 Koppers ovens. Of the remainder, there were 3260 Wilputte, 1350 Semet-Solvay, 63 Otto, and 40 Simon Carves ovens.

By-product coke oven plants are usually classified either as *furnace* or *merchant* plants. According to the definitions used by the US Bureau of Mines, the former are "those that are owned by or financially affiliated with iron and steel companies whose main business is producing coke for use in their own blast furnaces. All other coke plants are classified as merchant. They include those that manufacture metallurgical, industrial, and residential heating grades of coke for sale on the open market; coke plants associated with chemical companies or gas utilities; and those affiliated with local iron works, where only a small part (less than 50 pct of their output) is used in affiliated blast furnaces." The annual coke capacity of the merchant plants during 1959 was 10,393,000 tons. However, the by-product oven of today is essentially an appurtenance of the iron and steel industry, rather more than 87 pct of total by-product coking capacity being concentrated at furnace plants.

This was not always so. There was a time when the merchant plants played a much greater part in meeting the US demand for coke and gas. High noon for the merchant plants was reached during the early 1930's. By 1932 there were as many by-product oven installations being operated by the merchant sector of the industry as by the coke divisions of the iron and steel industry (44 of each), and in the same year the merchant plants produced 46.5 pct of all by-product coke made in the country. Since that time their contribution has drastically declined. In 1940 merchant plants were responsible for only 23.2 pct of total US production, and by 1950 their number had decreased to 30 plants which turned out 18.5 pct of the total by-product coke made. At the end of 1959 only 20 of the 74 existing by-product oven installations were merchant plants. They accounted for 12.5 pct of the year's production, or 6,849,786 net tons. This percentage has remained fairly constant since 1954.

There are several reasons for the decline of the merchant coking industry. For example, on the grounds of economy, quality control, continuity of supply, and so on, the iron and steel industry usually prefers to control its own mines and carbonize its own coal at or near to the blast furnace rather than rely on independent operators for metallurgical coke. As the steel companies have enlarged their own coking facilities, so has the need for coke obtained from other sources declined. Furthermore, not only has the steel industry increased in self-sufficiency by building more coke ovens during recent years, but it has also progressively improved the fuel efficiency of its blast furnaces. During the years 1947-49 the average coke consumption per ton of pig iron was 1892.8 lb. During 1958 the corresponding figure was 1613.4 lb. There are many individual furnaces where still better results are being obtained, and further reductions in the average may be expected. Perhaps the greatest threat to the merchant coking plant has been the fantastic increase in the use of natural gas and petroleum products for purposes which manufactured gas once served. So deadly has the competition from natural gas and oil been that it has almost eliminated by-product oven installations owned by public utilities. In the peak years of the early 1930's there were 23 such public utility plants. In 1960 only two were left. One of these, owned by the Citizens Gas and Coke Utility, was at Indianapolis, Ind.; the other was the plant operated by the Philadelphia Electric Co. at Chester, Pa.

The non-utility merchant plants have also been sorely hit. With gas sales revenues reduced, domestic

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coke market almost gone, and sales of water-gas coke nearly eliminated by natural gas and oil, their difficult situation has been mitigated to a considerable extent by the foundry-coke market which in 1958 accounted for almost half of their total coke revenue, and by the elimination of competition from utility plants. The increasing availability of, and the widespread predilection for, natural gas, together with the consequent effects upon the production of manufactured gas are shown by the following data.

When on April 28, 1960, the very first of the coke oven plants built specifically to supply city gas ceased to operate at Everett, Mass. there must have been many who felt that the end of an era had been reached. The Otto coke which had competed with anthracite for grandmother's favor did not survive the more sophisticated demands of her daughters, and long since followed anthracite into the limbo. Today, the housewife of the greater Boston area may warm her home, cook her food, and heat her water with natural gas from fields far to the south.

At the end of 1959, of the 7448 beehive ovens in the United States, only 5148 were in operating condition. These could have produced 3,131,600 tons of coke, but actual production was only 1,074,296 tons. However, one mechanized beehive coke plant was placed in operation in 1959, and plans to build two other plants were reported.

1959 Production of Beehive Coke by States—net tons

Pennsylvania	713,150
Virginia W. Virginia and Kentucky	361,146
Total	1,074,296

The stronghold, if such it can be termed, of beehive coking is still the state of Pennsylvania, in which there remain 4125 of the 5148 ovens still capable of operating.

Beehive Ovens in the United States as of December 31, 1959

State	Plants in Existence	Ovens: In Existence	Ovens: In Operating Condition	Ovens: Not in Operating Condition	Ovens: Abandoned
Pennsylvania	35	6,080	4,125	1,955	1,425
Virginia	5	653	626	37	—
West Virginia	4	512	204	308	—
Kentucky	1	193	193	—	—
Total	45	7,448	5,148	2,300	1,425

For the Connellsville area, once famous for its burgeoning economy, the virtual elimination of the beehive oven as an effective coke producer has been especially disastrous, and the communities of Fayette and Westmoreland counties have for many years comprised one of the most economically distressed areas in the eastern United States. Dominated by the fortunes of a single industry, the Connellsville region had few attractions to bring new enterprises into the district when the beehive ovens were abandoned, and the extent to which the area suffered has not always been realized. Between 1865 and 1918 the Connellsville district produced practically all the coke used in western Pennsylvania and eastern Ohio, and supplied more than 80 pct of that needed by the iron and steel industry in the rest of the country. In 1916 more than 40,000 ovens carbonized 33,792,256 tons of coal to produce 22,489,056 tons of coke, which was being railed out at the rate of some 25,000 carloads daily. After 1880, rather more than three out of every four workers in the region were employed by the mines and coking establishments, and it was estimated that during the first 10 years of this century the coal and coke interests owned more than 80 pct of the capital investments in the area. The population of Fayette County rose from 58,000 in 1880 to 188,104 in 1920, while in Westmoreland County an increase from 78,036 to 273,568 was recorded for the same period. Between 1920 and 1940, however, Fayette County increased in population by only 12,895. In the latter year, of the 57,390 men in the county available for work, only 38,658 were actually employed. Of the remainder, 5834 were on public emergency work, and 12,898 were seeking jobs. Between 1938 and 1951 employment in the mines of Fayette County went down from 19,639 to 11,965, in Westmoreland County from 10,253 to 7046. A further mirror of the times is provided by the population figures given in the census reports of 1940 and 1950. In 1940 there were 200,699 people in Fayette County; by 1950 the number had dropped by 5.8 pct to 189,899. In the case of Westmoreland County a 3.2 pct reduction took place, the 1940 and 1950 populations being 303,411 and 293,859, respectively. In view of the unlikelihood that there can be more than temporary and minor resurgences of the demand for beehive coke, it seems likely that this is a trend which will continue.


Abandoned beehive ovens to the southwest of Latrobe, Pa.

Epilogue

In the 120 years which have passed since John Taylor built his two crude ovens by the banks of the Youghiogheny, the coke industry has made an immeasurable contribution to the comfort, convenience, and security of life in the United States. Like the smelting of iron and the making of steel, the carbonization of coal has been essential to our well-being in peace and vital to our very existence in war.

What of the future? There can be no doubt that in the years to come this great industry will continue to serve America well. Little publicized, unconcerned with the aura of glamor which has attended the growth of more recent industrial enterprises, the coking industry has yet accomplished much. The endeavors of an industry which in 1959 gave rise to products valued at $1.3 billion should not be underrated. Neither should its capacity for further achievement, and its promise for a bright future.

It has been possible in this article to do no more than remark the most notable features of the coke industry's development, to follow only the broad tide of its progress leaving many of the lesser rivulets and tributaries unexplored.

Slot-Type Coke Ovens in the US as of December 31, 1959

State	Plants in Existence	Ovens in Existence	Annual Coke Capacity, Net Tons
Alabama	7	1,488	7,249,900
California	1	315	1,450,000
Colorado	1	237	985,500
Connecticut	1	70	410,000
Illinois	6	507	2,714,000
Indiana	5	2,191	10,765,200
Kentucky	1	196	1,185,200
Maryland	1	758	4,174,000
Massachusetts	1	108	665,000
Michigan	4	769	4,416,500
Minnesota	3	241	1,083,600
Missouri	1	96	327,600
New Jersey	1	230	1,100,000
New York	3	830	4,529,100
Ohio	14	2,390	12,648,900
Pennsylvania	14	4,133	20,450,300
Tennessee	1	44	264,000
Texas	2	140	832,000
Utah	2	308	1,345,700
West Virginia	4	742	4,281,100
Wisconsin	1	200	570,100
Total	74	15,993	81,447,700
At merchant plants	20	2,249	10,393,800
At furnace plants	54	13,744	71,053,900

Types of By-Product Oven in the US as of December 31, 1959

State	Koppers	Koppers-Becker	Semet-Solvay	Wilputte	Others	Total
Alabama	338	842	180	65	63[a]	1,488
California	—	315	—	—	—	315
Colorado	100	137	—	—	—	237
Connecticut	—	70	—	—	—	70
Illinois	—	177	—	330	—	507
Indiana	340	1,079	120	652	—	2,191
Kentucky	—	—	120	76	—	196
Maryland	—	758	—	—	—	758
Massachusetts	—	108	—	—	—	108
Michigan	—	259	362	148	—	769
Minnesota	65	156	—	20	—	241
Missouri	56	—	—	—	40[b]	96
New Jersey	165	65	—	—	—	230
New York	186	236	180	228	0	830
Ohio	694	762	176	758	—	2,390
Pennsylvania	1,191	1,965	88	889	—	4,133
Tennessee	—	—	24	20	—	44
Texas	—	140	—	—	—	140
Utah	—	308	—	—	—	308
West Virginia	154	514	—	74	—	742
Wisconsin	100	—	100	—	—	200
Total	3,389	7,891	1,350	3,260	103	15,993

[a] Otto ovens.
[b] Simon-Carves ovens.

Furnace and Merchant By-Product Coking Plants for Selected Years from 1913 to 1959

Year	Number of Active Plants		Total Coke Production, Pct	
	Furnace	Merchant	Furnace	Merchant
1913	20	16	73.0	27.0
1918	36	24	73.9	26.1
1930	46	43	73.5	26.5
1931	46	42	64.3	35.7
1932	44	44	53.5	46.5
1933	42	43	60.5	39.5
1934	41	42	62.5	37.5
1935	40	41	67.3	32.7
1940	45	40	76.8	23.2
1945	53	34	78.4	21.6
1950	55	30	81.5	16.5
1951	56	28	81.7	18.3
1952	57	27	81.6	18.4
1953	58	25	85.1	14.9
1954	58	24	87.5	12.5
1955	58	23	87.6	12.4
1956	57	23	86.7	13.3
1957	57	22	88.2	11.8
1958	55	22	87.7	12.3
1959	54	20	87.5	12.5

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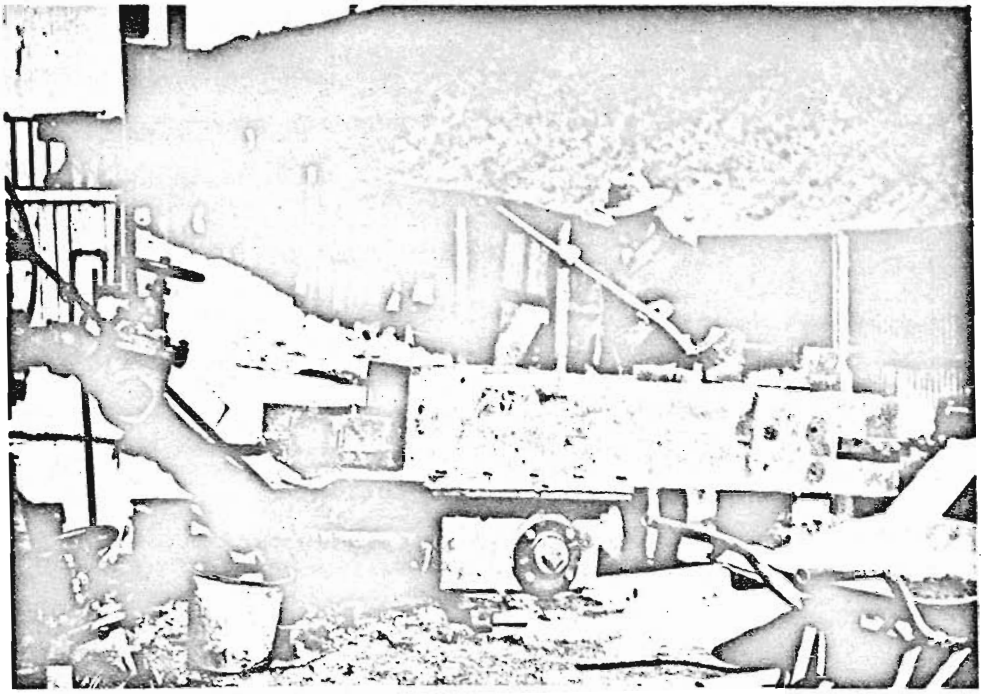

Fig. 1—R. L. Lloyd charging the first successful continuous sintering machine.

Development of the Dwight-Lloyd Sintering Process

by H. E. Rowen

As high grade iron ore deposits dwindle and costs rise, sintering becomes more and more important. The steel industry is now faced with beneficiation problems once peculiar to nonferrous work. Succeeding articles describe recent advances in this field. Here is presented the first chapter of a history still being written.

SINTERING, for the purpose of this discussion, is defined as *the art of burning a solid fuel with 90 to 95 pct ash content.* Considering problems of combustion involved in keeping a home furnace burning properly with 12 to 20 pct ash in the fuel, it is evident that combustion represented by the definition has to be right or nothing is going to happen.

Our forefathers discovered that many ores containing metals essential to the steadily rising standards of living were associated with elements such as sulfur and arsenic, which had to be removed before refining. This they did by utilizing the solid fuels they had available—the sulfur or other readily combustible components—to create roasting heat.

One of the early methods is demonstrated in an old woodcut of the *roast heap,* Fig. 2. Ore was broken into chunks, piled on an ignition layer of solid fuel—logs in this case—and then ignited. The sulfide ores roasted as the sulfur burned out. As shown in the background, the countryside was rapidly denuded of all vegetation by the great quantities of SO_2 and other liberated gases.

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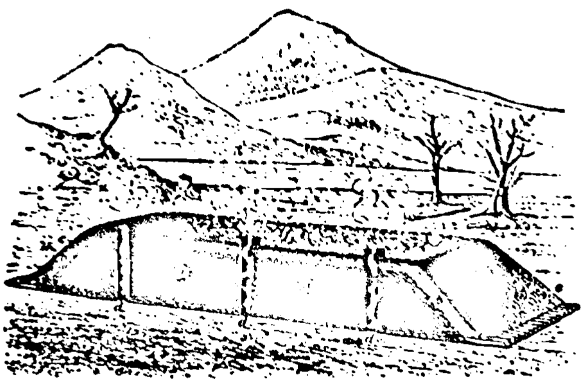

Fig. 2—The roast heap, from an early woodcut.

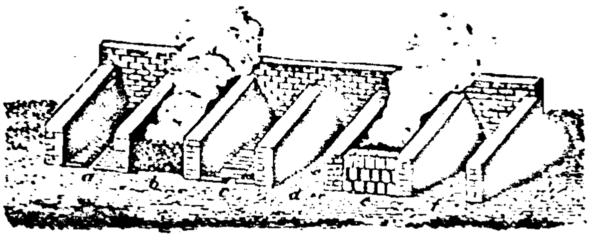

Fig. 3—The roasting stall, a decided improvement.

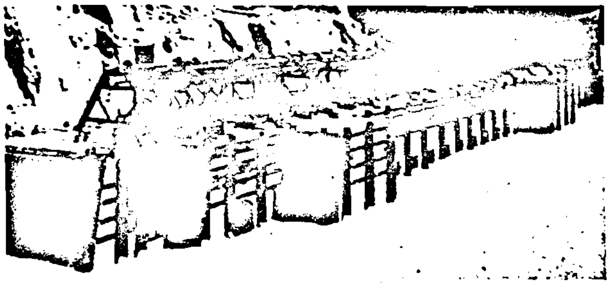

Fig. 4—Mechanically rabbled reverberatory furnace.

Because burning of heaps was erratic, time-consuming, and uncontrolled as to product, man's inventiveness soon created the *roasting stall*. At *A*, Fig. 3, the first layer of ignition logs is laid with spaces between them and a channel between the ends for passage of air. At *C* the second layer of logs is laid crosswise and endwise to support the bed of ore, and at one of the stalls, *B*, ignition has been accomplished. At *E* the draft control has been set up to prevent uncontrolled burning. Although this was a start toward continuous production, like the earlier method it destroyed the countryside. The famous Tennessee Copper Basin still shows results of these older operations.

Most of the ores treated were copper and lead ores, and not all the sulfur could be removed if they were to be left in condition for further smelting. With constant efforts to control the process and composition of the product and to make the roasting continuous, modern sintering practice gradually evolved.

Early vertical kilns for coarse ore were merely refractory columns with top feeds, controlled natural side drafts, and exit stacks. The hand-rabbled reverberatory furnaces later used for roasting required a large ventilation area for the men who were working.

The old revolving cylinder roasters need little description. Loaded from hoppers near the center, they were operated like peanut roasters and then dumped out.

Hand rabbling of the reverberatory soon gave way to a mechanical rabbling furnace, Fig. 4. Comparatively high shaft furnaces with deflector plates, as well as the oxidizing furnace, were used. These were followed by continuous roasting in round hearth rabbling furnaces, of which the six-hearth Herreshoff furnace is typical.

All these devices left something to be desired. The product was not in a proper physical state for furnace charging, great quantities of flue dust were produced, and considerable metal values were lost. It was obvious that the product had to be agglomerated in some manner.

An early answer was provided by the Huntingdon and Heberlein blast roasting pot, Fig. 5. The ore, bedded down in a pot with a perforated bottom plate, was bottom-fired, and a cover with offtake pipe was fitted on. After a long period of blowing, a large agglomerated cake was formed, and everything appeared to be solved. The trouble began when the roasting pot was dumped, Fig. 6. To make matters worse, dumping was followed by a heavy hand-breaking operation, Fig. 7.

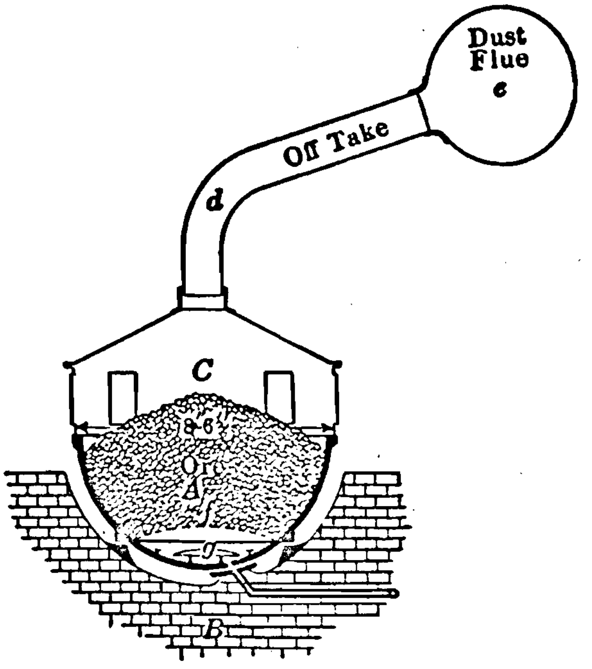

Fig. 5—Diagram of the Huntingdon and Heberlein blast roasting pot.

This was the type of equipment A. S. Dwight and R. L. Lloyd had to work with when they were superintendent and metallurgist, respectively, of the Greene Consolidated Smelter in Cananea, Mexico. An obvious solution was to develop some continuous method of production and to make the cake of agglomerated material thin enough to be broken.

A long series of experiments started, resulting in the general developments shown in Fig. 8. *A* is the Huntingdon-Heberlein principle of blowing upward through a deep bed of ore. At *B* there is a reversal of air flow. Neither method was suitable,

Fig. 7—Breaking up the cake was a back-breaking sledge hammer operation.

Operation of the Huntingdon and Heberlein blast roasting pot was not without difficulties:

Fig. 6—Left, Smoke and fume were serious problems when the Heberlein pot was dumped.

as the product was too large and dense to be handled and channeling of air produced many pipes of overburned and underburned material. *C* illustrates a pressure-operated downdraft thin-bed rectangular furnace, which began to show the desired results. *D* is the same bed with suction used.

The suction fan was of the type represented by the Roots blower. Wear on impeller and casing was excessive, and the experimenters returned to the principle of the blast pot, using a thin bed as shown at *E*. Upward air currents through the bed created a fluidizing condition that prevented the highly desirable agglomeration through incipient fusion of adjacent particles as they momentarily came up to a sintering temperature. An effort to maintain quiescence in the bed by using an overlay of heavy screen proved successful. This generic sintering process, however, was not the Dwight-Lloyd process employed today because it was not continuous. Continuity was the goal.

For many weary days the inventors tried to combat the thin fluidized condition of the bed caused by the upflowing air. At last they concluded that the process must be used with a downdraft. Pallets were put in the charging hole after the hand screw had been turned, and the material was carefully spread on a shovelful at a time. A blow torch flame was directed on the bed through an opening, and the sinter, pallet and all, fell off the end.

Three people comprised the operating crew. In Fig. 9 the charger stands on top, the operator stands with his hand on the screw crank watching the timing for each operation, and the man at the left holds a small board used to smooth off the bed before the blow torch flame is applied. A wheelbarrow holds material for a shift run, and at right a box contains sinter from the previous shift.

At Cananea, Mexico, the first commercially operated machine, Fig. 10, started production in June 1906. Sintering on the lower strand, it had a hearth layer hopper, a feed hopper, an igniter, a suction box below the bed, and a hood over the bed.

This pioneer machine did the job but could not be fitted into the rapidly evolving high production straight line processing so characteristic of American practice. Straight line link and pin arrangements were tried, but the nature of materials handled and general corrosive and abrasive conditions resulted in high maintenance costs. To meet these difficulties the machine known as the Dwight-Lloyd sintering machine was designed.

Basically the machine consisted of a drive end with a speed regulator, feed hopper, igniter, and driving sprockets to push the individual ore-carrying pallets across the machine. Directly ahead of the drive end an active section was located. It comprised the suction, or windbox area where air was drawn down through the ignited layer, or, in some cases, was blown upwards. This section could be of any length required to complete the reactions and by adding additional windboxes capacity could be increased. The final section was the end where the individual pallets discharged the sinter and were guided to the lower track where they returned to the main sprockets by gravity. A gap to allow pallets to move rapidly into the curve was usually provided to assure the complete discharge of sinter.

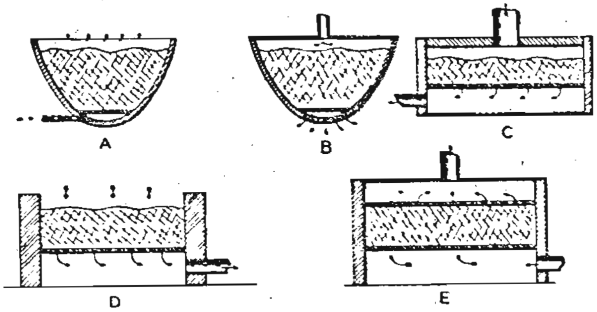

Fig. 8—Many experimental designs were tried by Dwight and Lloyd. Starting with the Huntingdon-Heberlein principle, the idea of a thin flat bed and a downdraft gradually evolved.

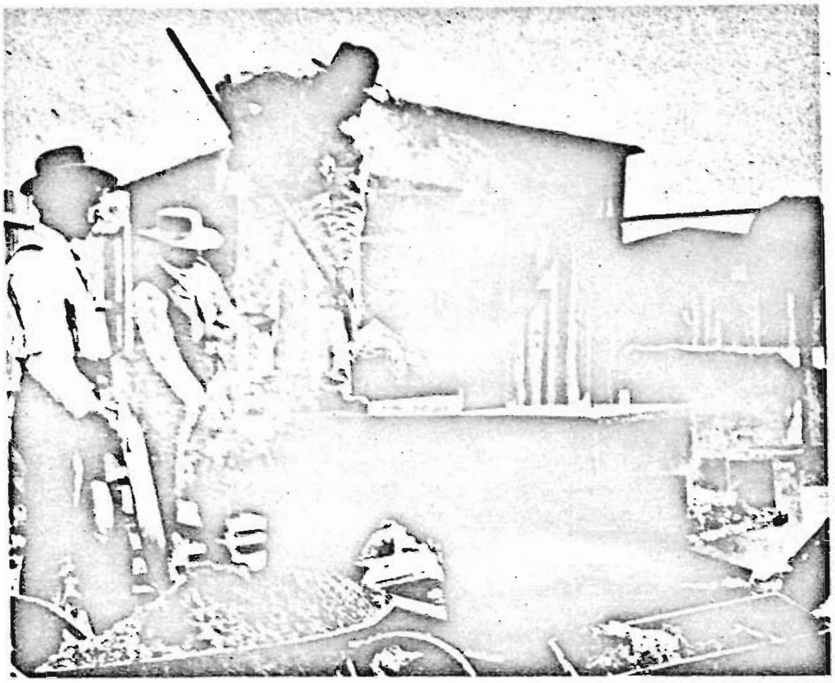

Fig. 9—The first continuous sintering machine in operation at Cananea. The operating crew consists of the charger, on top, the timer, with his hand on the crank, and the man at the left, who smooths the sinter mix with a board before a blow torch flame is applied.

This gap also allowed for expansion and contraction in use.

This design, with its individual pallets being pushed without any limiting connectors between moving members, provided an automatic take-up for wear and a means of removing any sections damaged in use.

Alleviation of dust, production of some sort of an agglomerate, and the controlled burning of volatiles such as sulfur was the total role of the old machines. But the impact of this system on metallurgical practices was important. Anything that a sintering machine would produce was so much better than what industry had been forced to use previously that design thinking became static. A long series of plants, each duplicating a former one, were built without much thought being given to the problems the individual plant had to face.

Little attention was given to controlled charge preparation and mixing. Rough volumetrically proportioned charges handled through such devices as a flat rotating plate with a few rabbling arms above it to turn the material over, gave way to the pugmill.

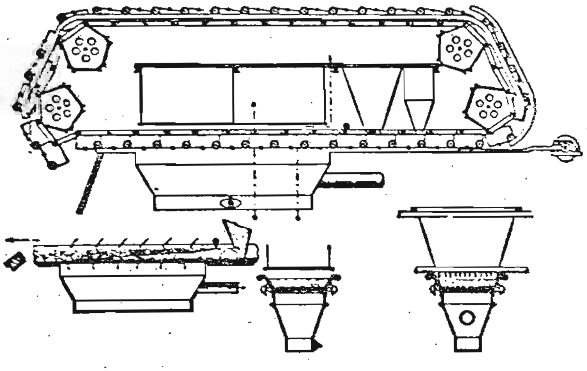

Fig. 10—The first commercially operated Dwight-Lloyd machine, June 1906.

Rotating drums with and without paddle shafts in them followed and began to show the value of controlled bed permeability produced by proper proportioning and mixing.

The value of preparing fine ores for iron blast furnaces and of agglomerating flue dusts was studied, and about four years after the introduction of the Dwight-Lloyd sintering system a ferrous plant was designed. A series of charge bins, each with its feeder, placed material on a collector belt. This discharged into a primary or dry mix pugmill followed by a secondary pugmill which had a roll crusher ahead of it to break up lumps coming from the primary pugmill. From here the mixed charge went to the sintering machine and then to a round cooling table which had rabbles on it so the sinter could be turned over for efficient contact with the water sprays.

The nonferrous industry quickly saw the value of controls and gradually incorporated various improvements. The ferrous industry continued sintering their flue dusts and eventually more of the fines which were contributing to the dusts. But extensive studies of the full problems were bypassed and the sinter plant served much as an incinerator handling waste materials.

Today, ferrous sintering is of such importance to efficient iron production that necessary studies have started. They are being undertaken in pilot-research laboratories such as those of the U. S. Steel Corp. in their new Monroeville, Pa., Research Center and the Dwight-Lloyd Research Laboratory of McDowell Co. in Cleveland. (See p. 843)

The original straight line Dwight-Lloyd sintering machine has proven so versatile that it has met the needs of calcining, firing discrete pellets by both up and down draft, and other heat treating processes of a similar nature. Today's sintering machines range from 12 in. to 12 ft in width and to over 200 ft in length, but the design principles remain the same.

One Hundred Years of Bessemer Steelmaking

by A. B. Wilder

We study the past
Because it is a guide to the present
and a promise for the future.
The struggle for a better world is strengthened
By the hopes, ambitions, and deeds
Of those who were before us.
As we look backward
Our attention is directed forward.

ONE hundred years ago, the manufacture of steel from molten pig iron without the use of fuel first began. In the earlier part of the nineteenth century the crucible process was the principal steelmaking method. It was a costly process, producing only a few pounds of steel at a time; so, most of the ferrous metal output was in the form of wrought or pig iron. With the perfection of the converter technique it became possible to produce low cost steel by the ton, thereby completely changing the structure, not only of the ferrous metal industry, but also of industrial production in general. This was the turning point from the *Iron Age* to the *Age of Steel.*

Fig. 1—Sir Henry Bessemer

William Kelly (Fig. 2), Sir Henry Bessemer (Fig. 1), and Joseph G. Martien experimented with the process before 1856. William Kelly began in Eddyville, Ky., in 1847 and has been given credit for first discovering the principle of the pneumatic converter process. Several years later in England Henry Bessemer independently conceived a steelmaking process similar to Kelly's. Bessemer made public his invention at the annual meeting of the British Association for the Advancement of Science held at Cheltenham, England, August 1856. As a result of his paper, "On the Manufacture of Malleable Iron and Steel Without Fuel," and his progressive leadership in the years to follow, the process became permanently identified with the name, Bessemer.

Credit for the commercial adaptation of the process must be given two additional persons. Robert Mushet (Fig. 3) in 1856 in England recognized the necessity of deoxidation and recarburization of the converter product and evolved the technique for adding high manganese iron following the blow. In Sweden, in July 1858, G. F. Göranson produced steel under license from Bessemer, but the success of the process was dependent upon Göranson's redesign of the converter, increasing the tuyere area and decreasing the air volume.

Competition With Other Steelmaking Processes

After the acid bessemer process had been successfully developed, the open hearth and electric furnace processes were introduced. The first acid open hearth furnace in the U. S. was built in 1868. The basic steel making process in the U. S. began in 1884 in a basic-lined bessemer converter at Steelton, Pa., and the first basic open hearth steel was produced in the U. S. at Homestead, Pa., in 1888. The first electric arc furnace used for the production of steel was patented by Sir William Siemens in 1879.

Fig. 2—William Kelly

Before 1900 open hearth steel was little used for the production of rails, and the replacement of iron rails with steel rails, as well as the rapid expansion of the railway network, provided an opportunity for the development of the bessemer process.

In 1887 when 500 tons of bessemer steel welded pipe were first produced by the Riverside Iron Works, Wheeling, W. Va., a new era developed for the bessemer process. The decision by National Tube Works Co. to abandon the production of wrought iron pipe and build a bessemer steel plant in 1890 was the beginning of events which led to the production of large quantities of bessemer steel for welded pipe. At the same time, seamless pipe was being introduced. Seamless pipe, however, was made from open hearth steel, and contributed toward the development of the open hearth process. Only during the past 15 years has seamless pipe been commercially produced from deoxidized bessemer steel.

During the period 1900-1910 the production of open hearth steel surpassed bessemer steel (Fig. 4). Part of the reason for this development was due to the almost complete change over from the use of bessemer to open hearth rails.

The growth of the automobile industry and the use of flat steel products had a great influence on steel producing processes. Prior to 1920 the steel industry was principally a producer of heavy products, but in 1924 John Tytus developed the continuous hot strip mill, and this process provided an outlet for large quantities of open hearth steel, much of which was destined for the automobile.

During the past 25 years the production of open hearth steel in the U. S. (Fig. 4) has out distanced the production of bessemer steel for the following reasons:

1) The open hearth process provides a greater utilization of scrap.
2) The nitrogen and phosphorous content of open hearth steel is lower.
3) The high capacity of open hearth furnaces has been increased still further in recent years.
4) The open hearth process is relatively versatile with respect to raw materials and fuel.
5) Basic open hearth steel is economically produced from iron of intermediate phosphorous content.
6) Open hearth steel, because of relatively high uniform quality, is widely accepted in specifications and codes.
7) Carbon may be caught on the way down in the open hearth; thus, it is possible to melt many different grades of steel within narrow chemical limits.
8) The open hearth requires less iron and coke production facilities.

Fig. 3—Robert Mushet

In Western Europe the trend has been quite the opposite, for the basic bessemer process has retained its position as a major process for producing carbon steel (Fig. 5). The smelting of high phosphorous ores on the Continent results in high phosphorous pig iron ideally suited for processing in the basic converter. The resulting slag serves as a valuable fertilizer because of its phosphorous content. Further, the high cost of fuel and the relatively low avail-

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A. B. WILDER is Chief Metallurgist, National Tube Div., U. S. Steel Corp., Pittsburgh, Pa. This paper was presented at the New York meeting, February 1956.

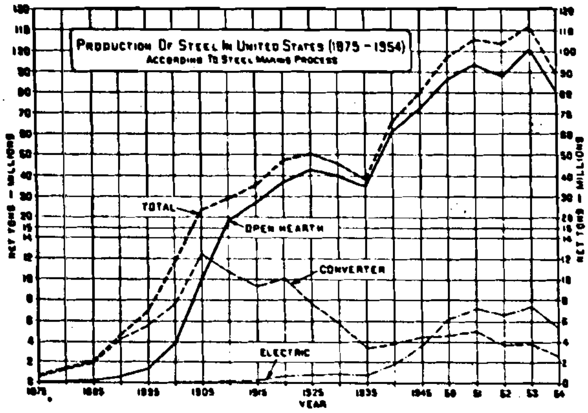

Fig. 4—Steel production according to process in the U. S.

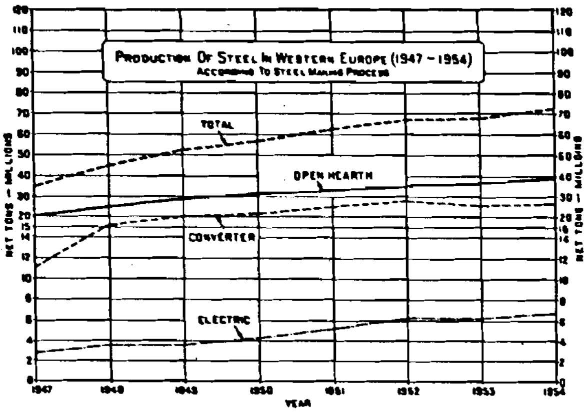

Fig. 5—Steel production according to process in Western Europe.

ability of scrap in Europe has favored the basic converter.

The open hearth and electric furnace process require a considerable time to produce a heat, although with expanded furnace capacity each heat consists of a considerable volume of steel. While the energy efficiency of the open hearth has been improved, the Btu requirements remain high and can not compete with the converter. It will, however, be necessary for converters to follow a pattern of increasing capacity. The production of tonnage oxygen at low cost is largely responsible for the present progress in the production of converter steel, for this has not only made it possible to control the nitrogen content, but also provided the possibility of melting increased quantities of scrap.

The control of industrial fumes has been a problem in many areas, and considerable progress has been made in this field during recent years. Today, it appears that fume control methods for most metallurgical processes are feasible; however, the problem of fume collection and control in present day bottom-blown converter plants is uncertain due to the design of plants and the nature of operation, particularly when oxygen is employed.

The nitrogen factor has had a fundamental relationship to the development of the pneumatic converter process; it was recognized by F. W. Harbord and T. Twynam[1] as early as 1896. Nitrogen is undesirable in many types of steel, particularly where toughness is a factor. It has taken years to evaluate the influence of nitrogen in steel, but its behavior is now well understood, and methods have been developed for controlling the amount and behavior of nitrogen in converter steel. The fixation of nitrogen with aluminum is well recognized. The control of nitrogen by surface blowing with oxygen enriched air and oxygen-steam mixtures is now used on a commercial basis.

It has been said that the pneumatic converter process lacks control due to the fact that it is possible to blow a heat of steel in 10 to 15 min. Also, in making converter steel it is quite difficult to catch carbon on the way down. These problems have long been recognized,[2] but it should be pointed out that many grades of steel can be made by the converter process with a high degree of control. This is particularly true with capped and rimmed low carbon steels, but to gain closer control for other grades a greater length of time for making the blow might be considered. This may be achieved in the surface blown vessel by not only controlling the volume of air or oxygen, but also by changing the depth of bath. With increased time the bath and slag may be adjusted to produce the desired result, and the temperature may be determined and controlled, but it may be necessary to utilize larger converter units approaching those of the conventional open hearth size. Thermal losses in the larger converters would control the length of blow.

Although duplexing (using bessemer blown metal in the open hearth) is widely used, the process has certain limitations. When the converter is blown very young and silicon is removed, a duplex open hearth product low in nitrogen is produced. Blast furnace iron may be desiliconized in a ladle with oxygen if a converter is not available. When fully blown converter metal is used, the duplex open hearth product will contain nitrogen which may be fixed by aluminum deoxidation. The bath boiling technique may also be used to reduce the nitrogen content of duplex open hearth steel. Duplex steel can always be used for applications in which nitrogen is not objectionable.

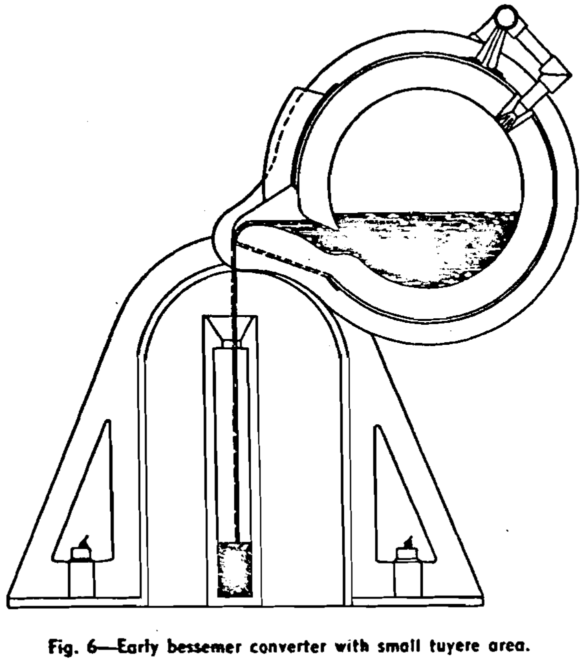

Fig. 6—Early bessemer converter with small tuyere area.

The Age of Steel

The steel industry as it exists today had its beginning in 1856 with the development of the bessemer process for the low cost conversion of iron into steel. The early history of the process is recorded in the patent literature, and a brief summary of the more significant claims is presented:

Henry Bessemer, London, England; English Patent 356, February 12, 1856, and U. S. Patent 16082, November 11, 1856.

The conversion of molten iron or of remelted pig iron into steel or into malleable iron (Fig. 6) without the use of fuel for reheating or continuing to heat the crude molten metal, such conversion being effected by forcing into and among the particles of a mass of molten iron a current of air, oxygen, or gaseous matter containing or capable of evolving sufficient oxygen to keep up the combustion of the carbon contained in the iron until the conversion is accomplished.

Joseph G. Martien, Newark, New Jersey; U. S. Patent 16690, February 24, 1857.

The purification or conversion of fluid or molten iron, subjecting the molten iron to the action of atmospheric air, steam, or other gaseous body or chemical agents, in any form capable of evolving oxygen or other purifying gas, in such a manner as to cause the air, steam, or other solid, liquid, or gaseous body to impinge upon, penetrate through, or search among the metal while it is flowing.

Robert Mushet, Coeford, England; English Patent 2220, September 22, 1856, and U. S. Patent 17389, May 26, 1857.

The addition of a triple compound or material of, or containing, iron, carbon, and manganese to cast iron which has been purified and decarburized by the action of air in a molten or fluid state, or in any convenient manner, so as to become mixed and combined in the process of manufacture in order, by the union of the substances, to obtain malleable iron and steel.

William Kelly, Eddyville, Kentucky; U. S. Patent 17628, June 23, 1857.

Blowing the blasts of air, either hot or cold, up and through a mass of liquid iron, the oxygen in the air combining with the carbon in the iron causing a greatly increased heat and boiling commotion in the fluid mass and decarburizing and refining the iron.

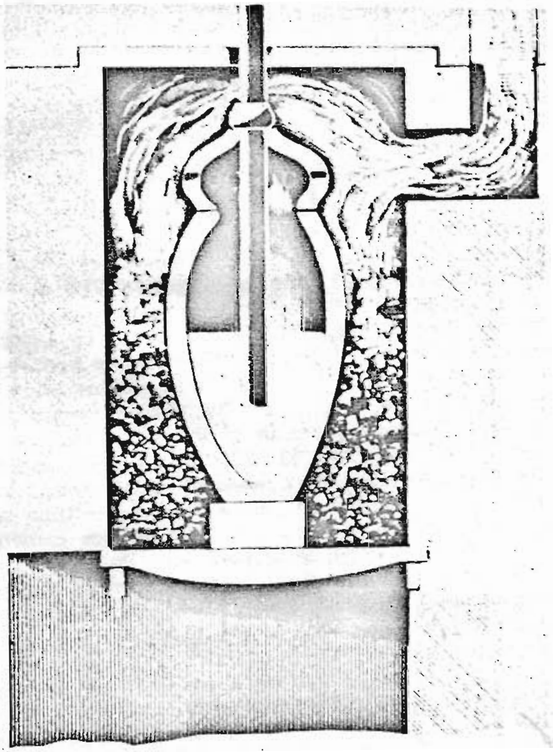

Fig. 7—The first bessemer converter.

Sir Henry Bessemer performed his first experiments in the vessel shown in Fig. 7, produced steel in this vessel in 1855 and made his first public announcement of the process on Aug. 11, 1856. In 1858 Bessemer erected a converter at Sheffield, England (Fig. 8), which was an improvement over previous vessels. The use of spiegeleisen as proposed by Robert Mushet made it practical to produce steel on a commercial basis by the converter process. In 1863 Bessemer patented the first detachable bottom (Fig. 9). Other early bessemer converters are shown in Figs. 10 and 11.

During the period in England when Sir Henry Bessemer was developing his process for steelmaking, developments were taking place in the U. S. and on the Continent. Sweden in 1864 produced 3178 tons of bessemer steel and 4500 tons of crucible steel; the French in 1866 were manufacturing bessemer steel in six plants and produced 10,791 tons.

The Kelly steel converter shown in Fig. 12 was experimentally used by the Cambria Iron Works in 1861 and 1862, but Kelly had previously constructed other converters in Ky. The Kelly Pneumatic Process Co. began building a plant in 1862 at Wyandotte, Mich. W. F. Durfee, manager of the plant, made steel by use of the Kelly and Mushet patents in a 2½-ton converter in Sept. 1864. This was the first steel made on a commercial basis by the pneumatic converter process in U. S.

In 1864 Alexander L. Holley organized the Albany and Rensselaer Iron and Steel Co., and under the Bessemer and Mushet patents made steel in a 2½-ton converter at Troy, N. Y., in February 1865. Later two 10-ton converters were constructed at this plant. In 1866 the two companies at Troy, N. Y., and Wyandotte, Mich., were consolidated into the Pneumatic Steel Ass'n. Licenses were then obtained by other producers and plants of a larger capacity were rapidly erected throughout the U. S. in the years to follow. This consolidation of Bessemer, Kelly, and Mushet interests eliminated the controversy in America regarding the process.

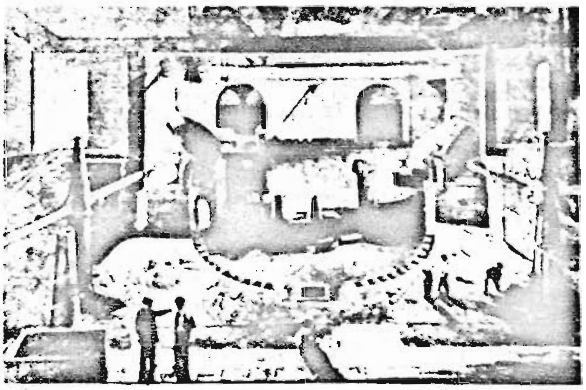

Fig. 8—Bessemer converter plant in 1858.

The Basic Bessemer Process

On the Continent steel makers faced with the problem of treating many high phosphorous iron ores did not find the bessemer process entirely satisfactory and set about trying to modify the process to treat these raw materials. In 1860 Turner in Germany recommended a basic converter lining consisting of burned magnesite. Wedding in 1865 proposed removal of phosphorus in an acid converter by removing the slag after oxidation of silicon, and then oxidizing the phosphorus and removing the slag. Dephosphorization, however, was prevented by the presence of a silica lining, and the second slag contained no phosphorus. In 1877 Krupp in Germany and Bell in England initiated the first step toward a solution of the problem. They charged pig iron into a special revolving furnace and removed phosphorus by use of iron and manganese oxides as a lining and flux.

The next step was taken in 1878 by an Englishman, Sidney Gilchrist Thomas, when he manufactured basic dolomite bricks and reported at a meeting of the Iron and Steel Institute that he was able to remove phosphorus from bessemer steel. Later Thomas observed that limestone could be satisfactorily used as a flux. In 1879, with a basic lining consisting of bricks and a rammed bottom and the use of a basic flux, Thomas observed the necessity of an after-blow at the completion of decarburization. The success of the basic process utilizing the iron from high phosphorous ores in Germany was thus assured with 1) a basic lining, 2) basic flux, and 3) an after-blow. There was no essential difference between the design of a basic and an acid converter.

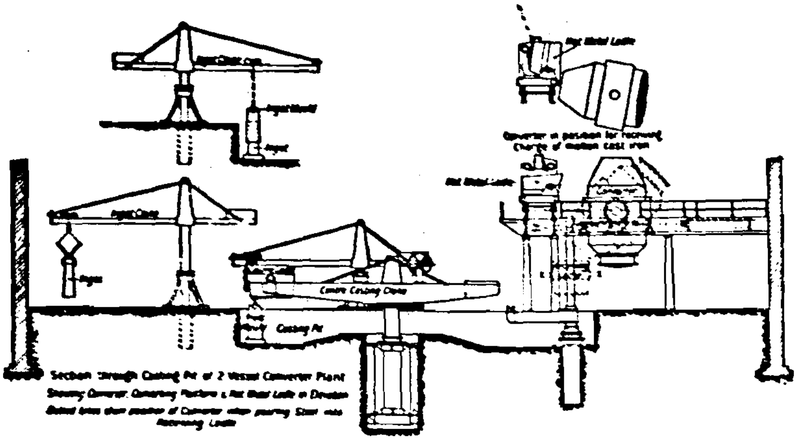

Fig. 17—A two-vessel bessemer steel converter plant in 1900 looked like this.

Steel made in a basic converter was later called *Thomas* steel, while the product of the acid converter was called *Bessemer* steel. In addition to Thomas, there were Percy C. Gilchrist (his cousin) and George J. Snelus of England, and Jacob Reese of Pittsburgh, Pa., who were interested in the development of the basic process. Reese obtained a patent in U. S. in 1866, and in 1872 Snelus discussed the process at a meeting of the Iron and Steel Institute in London. The basic converter process developed rapidly in Germany due to the availability of suitable ores and the use of slag for agricultural purposes. In 1884, there were 32 steel works with 88 basic converters throughout the world with a combined vessel capacity of 795 tons; in Germany alone there were 41 of these converters.

Surface Blown Foundry Converter

In 1862 Bessemer patented a side blown tiltable converter shown in Fig. 13. The tuyeres were placed through the side all around the bottom of the vessel. In Sweden there were a number of fixed converters operated with tuyeres on the side near the bottom. Later the tuyeres were gradually raised from the bottom but maintained below the surface of the molten metal.

In the Waldren converter (Fig. 14), designed in 1884, there was a distinct departure from the other converters with tuyeres all around the circumference. Waldren placed four tuyeres on one side close together but slightly inclined from the center to provide for rotation of the liquid metal.

In later designs the tuyeres on the sides of the converters were gradually raised toward the surface. Finally, F. A. Tropenas designed a converter (Fig. 15) with the blast directed upon the surface from the side of the converter. In the Tropenas patent of 1891 two rows of tuyeres are shown. In later years the top row of tuyeres was found to be unnecessary.

Developments from 1890 to 1940

Following the development of the surface side blown converters there were only a limited number of fundamental changes in bessemer steelmaking during the next 50 years. The improvements which occurred were essentially of a mechanical nature largely directed toward material handling, although many new plants were constructed with a trend toward larger converters.

There were a number of small side blown converters of 2-ton capacity in 1900, but these were used primarily in the production of steel castings and were not practical where facilities existed for open hearth or bessemer steel production. Production facilities for bottom blown bessemer converters did not exceed 20 tons in capacity. The eccentric and concentric types of converters employed at the time of Sir Henry Bessemer's death in 1898 are shown in Fig. 16. Detachable bottoms and equipment for rotation were used, and the air blast was provided by horizontal double cylinder engines. A typical bessemer plant in 1900 is shown in Fig. 17. The U. S. Steel Corp. in 1901, for example, operated 35 bessemer converters ranging in size from 5 to 17 tons with a combined capacity of 7.5 million tons. Several 10-ton bessemer converters are shown in Fig. 18 in operation at McKeesport, Pa.

During the period 1910-1930 a number of bessemer plants were built in conjunction with tilting open hearth furnaces. The blown bessemer steel when added to the open hearth permitted more open hearth steel to be melted and, as a result, increased open hearth capacity. The converters were also used for the production of bessemer ingots. Larger vessels were installed, and the air blast was supplied by centrifugal blowers. Adequate mixers were provided, and metallurgical practices were improved. Converters of 30-ton capacity were operated with production rates of 40,000 tons per month. The number of tuyeres was increased with the use of larger volumes of air. With the larger production rates, mass handling of material was improved.

During the 1890-1940 period considerable attention was directed toward the control of temperature during the bessemer blow and the state of oxidation at the end of the blow. High temperatures at the end of the blow not only increased the oxygen con-

Varying Converter Shapes Over the Century

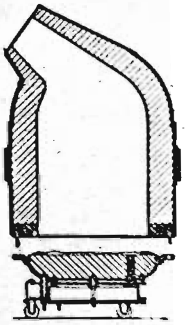

Fig. 9—Detachable bottom, 1863.

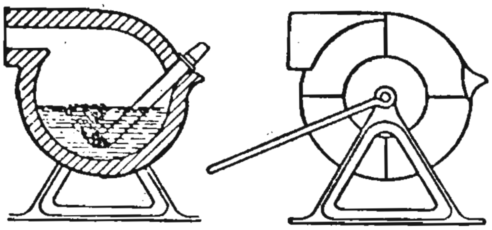

Fig. 10—Early bessemer converter.

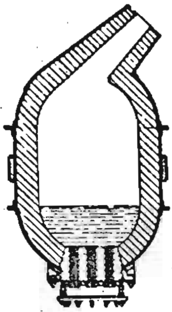

Fig. 11—Early bessemer converter with large tuyere area.

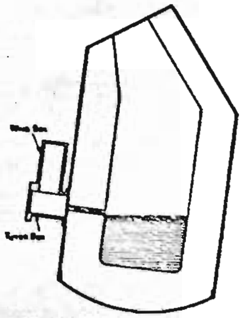

Fig. 32—Side blown foundry converter of present day.

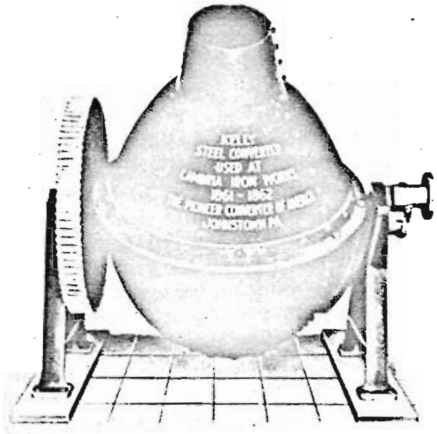

Fig. 12—Kelly converter, 1861 (R. Earl Penrod).

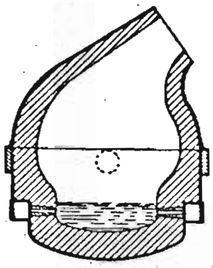

Fig. 13—Bessemer side blown converter, 1862.

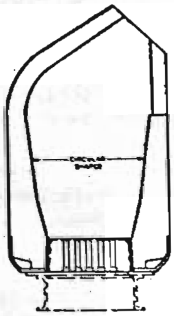

Fig. 20—Modern European basic converter with monolithic lining.

Since the earliest designs of Bessemer and Kelly, the size and shapes of the pneumatic converter has changed to meet the varying ideas of steelmakers. The detachable bottom was a significant innovation . . . large tuyere areas were found necessary . . . side blowing techniques have been tried repeatedly since the earliest days . . . and today opinion still varies on what is the best size and shape of converter profile and the best location and design of tuyeres.

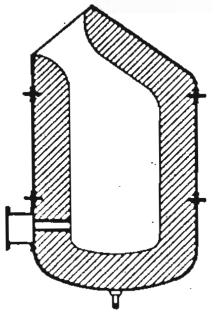

Fig. 14—Waldren side blown converter, 1884.

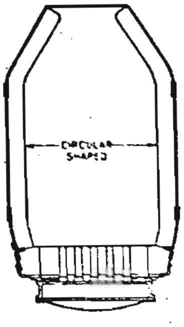

Fig. 19—European 25-ton acid converter of present day.

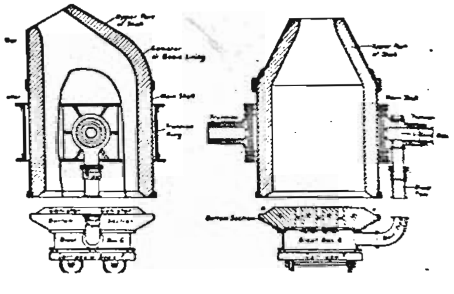

Fig. 16—Eccentric and concentric converters, 1898.

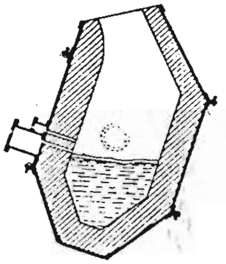

Fig. 15—Tropenas side blown converter, 1891.

tent of the blow, but also its nitrogen content. Composition of the molten iron and steel, the use of coolants, and the mixing of additions were other factors which received attention.

Special Bessemer Practices

Iron quality, temperature, handling, separation of blast furnace slag, slopping, lining life, and temperature of the blow are important factors in modern converter practice.[3] Titanium in iron and variations in blowing pressures are reportedly undesirable. Attention has been directed over the years to kidney (lining build-up) formation. All of these factors are related to converter design and methods of operation.

Among the many modifications in bessemer steelmaking, a process for producing seamless steel pipe was developed in 1940 by Wright. In this process molten pig iron is used for deoxidation of the bessemer blow. In 1940, R. Perrin[5] developed a method for dephosphorizing steel by pouring it from a height into a ladle with a basic oxidizing slag. After additions of silicon and manganese the steel is poured into an acid converter and blown. In the Yocom[6] process, completely blown metal is poured into a dephosphorizing ladle, with lime, iron oxide, and flux introduced during pouring. In the manufacture of wrought iron by the Aston process, the blown acid converter steel is required to be low in sulfur, and White and Storey[7] developed a process in which molten iron is poured into molten caustic soda to remove sulfur. The iron is then blown in an acid converter to remove metalloids. There have been many other methods developed for desulfurization of iron which may be used for production of converter steel.

In the Ugine-Perrin[8] process, developed in 1939, basic bessemer steel is poured into a ladle of lime-alumina slag. This synthetic slag is melted in an electric furnace. During pouring of the blown metal, additions of aluminum, ferrosilicon, etc. are made to the stream of metal. In order to provide sufficient heat at the end of the bessemer blow it may be necessary to add ferrosilicon and blow before pouring into the ladle of lime-alumina slag.

Fume

The nature of converter fume has been reported by several investigators.[9-12] One theory is the formation of iron carbonyl (FeCO) which burns in air to form FeO and CO_2, but brown fumes have also been explained by vaporization of iron which oxidizes in the air. It has also been observed that in order to reduce fume when oxygen blowing, a certain amount of steam is effective. The large volume of gas in the converter process, with dilution and variations in volume, influences efficient removal of brown fumes.

P. J. Leroy and L. Septier have shown that dust concentration with oxygen may be 0.0045 lb per cu ft and with steam-oxygen 0.0027 lb per cu ft. They indicate that particles vary from a spheroidal shape of about 0.05 μ to various proportions of 0.1 to 5.0 μ, with average dimensions of 1 μ.

In the oxygen lance process at Linz, Austria, the fume consisted of 93 pct Fe_2O_3 and MnO, CaO, and SiO_2. The particle size was 5 pct over 1.0 μ, 45 pct 0.5 to 1.0 μ, and 50 pct under 0.5 μ, and about 25 lb of dust were produced per ton of steel. In the basic bessemer process with oxygen enriched air, 50 lb of dust per ton of steel were produced, and the density of the dust is such that 15 cu ft may be discharged from a 30-ton heat.

H. Kosmider and coworkers determined the composition of dust during a basic blow. In the first period with air blowing, the dust contained 25 pct Fe and 5 pct Mn. The second period dust, with oxygen enriched blast, contained 50 pct Fe and 2.5 pct Mn. During dephosphorization with air blowing the dust contained about 50 pct Fe and 10 pct Mn, and the fumes were brown due to the oxides. Maximum temperature calculations at the interface of the gas and metal in a gas bubble indicated a temperature of 4175°F, but when the oxygen content was increased to 100 pct, the temperature was 5525°F. Temperatures of 3550°F were obtained with steam-oxygen mixtures (1:1.2). Particle size was difficult to determine due to coagulation, but particles 0.5 to 2.0 μ were observed. The dust content of the waste gases at the beginning of the blow were 0.35 g per cu m, and at the end of the blow 0.90 g per cu m.

The wet washing method is usually employed for fume control in top blown oxygen converter plants. Gases leaving the converter exceed 3000°F and are collected in a water cooled hood about the mouth of the converter. Dilution with air lowers the temperature of the gases, and they pass from the hood into a spark arrester at a temperature of about 1500°F. The gases then go through water sprays and finally through a disintegrator for final cleaning. At the Linz plant in Austria a waste heat boiler is used above the mouth of the converter, and the gases then pass into a wet washer.

Converter Blow Control

For more than 75 years attention has been directed toward control of the bessemer blow.[2] The

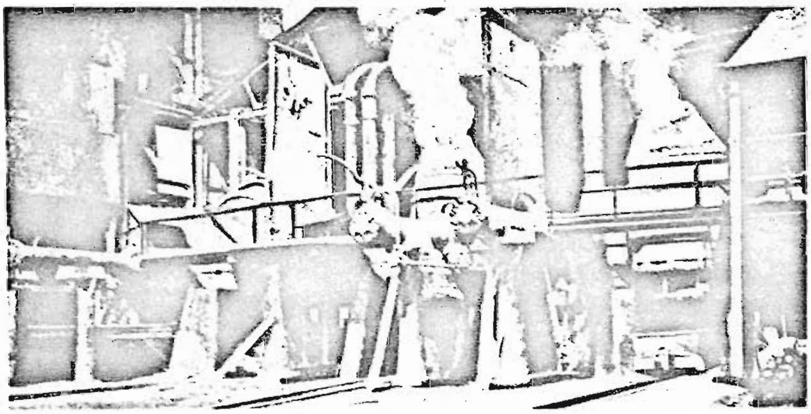

Fig. 18—During the fifty year period from 1890 to 1940 there were only a limited number of fundamental changes in bessemer steelmaking, although there was a trend toward larger converters. The figure shows 10-ton acid bessemer converters in operation at McKeesport, Pa. in 1890.

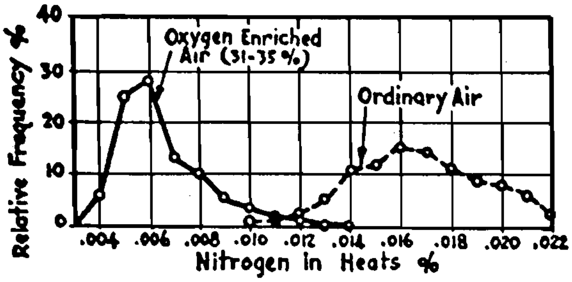

Fig. 21—Influence of oxygen enriched air on nitrogen content of thomas steel—Graef.

spectroscope is being used with success, but the most common method of turning down the vessel is by visual observation of the flame with colored glasses. H. K. Work[13] in 1940 developed a photocell end point control which is also being used for turning down the vessel.

The radiation pyrometer has been experimentally employed by many investigators. Insertion of the instrument in the tuyeres or the mouth[14] of the converter has been used. Temperature measurements may be checked with a thermocouple in the molten steel.

minimum contact of the blast and metal, and 3) low finishing temperature. Application of these principles includes a shallow bath or surface blowing, wide nose vessels to reduce back pressure, ore or scale instead of scrap for cooling, close control of the finishing temperature, and use of oxygen enriched air.

Oxygen enriched air has been used for the commercial production of converter steel since 1931, and Bessemer in 1856 recognized its possibilities. Oxygen reduces the nitrogen content of the steel by reducing partial pressure of nitrogen in the blast (Fig. 21) and also melts additional scrap. A process developed by Morrison,[16] consisting of blowing initially with air and finishing with oxygen enriched air, is of particular interest. Oxygen enriched air has also been used following the start of the carbon flame to melt additional scrap.[17]

The use of ore in the HPN process in Germany at Duisburg-Hamborn or the use of scale in the LNP process at Corby, England, (Figs. 22, 23) and close control of the finishing temperature have made it possible to reduce nitrogen by 50 pct to a level of 0.008 pct. This reduction is due to the low partial pressure of nitrogen in the gas bubbles resulting from action of carbon in the iron with ore or scale.

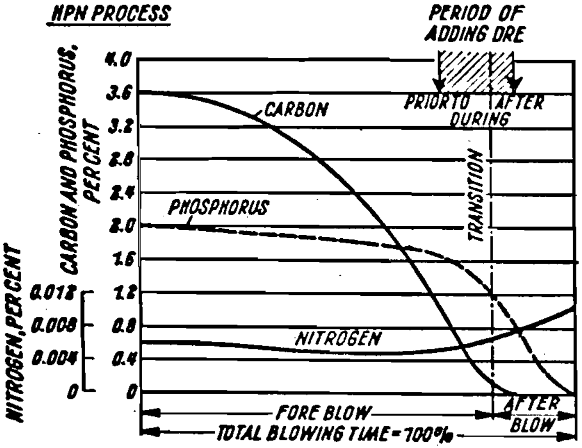

Fig. 22—Variation of nitrogen with time when ore additions are made during the blow (HPN process) in Germany—Weyel & Kosmider.

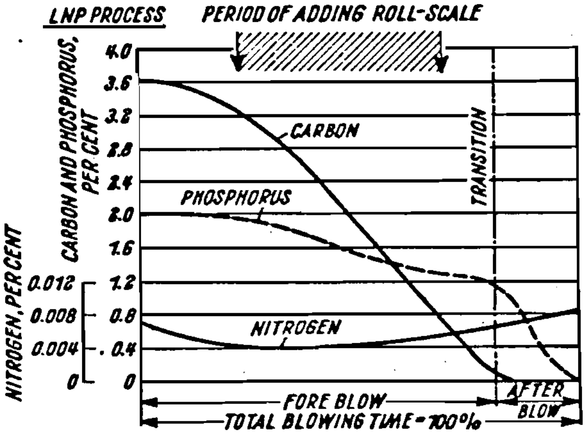

Fig. 23—Variation of nitrogen with time when scale additions are made during the blow (LNP process) in England—Weyel & Kosmider.

P. J. Leroy and coworkers[15] have recently made an extensive study of converter instrumentation (see p. 764). Slopping in a basic vessel has been controlled by a new type of flowmeter for regulation of wind. A pyrometer in the tuyere box and a flame pyrometer have been used for temperature measurement. For determining the end point, the transmission rather than emission characteristics of the flame were studied, and the opacity of the flame was also measured. These developments have been applied to the production of thomas steel on the Continent.

Low Nitrogen Steels

With the increased production of hot and cold rolled strip on continuous wide strip mills in Europe, it has become necessary to improve the deep-drawing qualities of thomas steel by reducing the nitrogen content. Much attention has been drawn toward modification of existing equipment, as shown in Figs. 19 and 20.

The production of converter steel with a low nitrogen content depends upon a number of factors including: 1) low partial pressure of nitrogen, 2)

Mannesmann Röhrenwerke in Germany produced low nitrogen steel in an MA converter. This converter was side blown beneath the surface of the metal and provided a contact of short duration between the blast and metal. An oblique blown converter with a regular converter bottom and with all tuyeres blanked except those near the surface of the metal provided similar results. There have been many modifications of tuyere arrangement to provide lower nitrogen steel. The influence of blast pressure on nitrogen, shown in Fig. 24, is related to the time of contact between blast and metal. Many methods have also been developed to reduce the nitrogen content of bottom blown converter steel. These modifications of the bessemer process permit it to approach, but not equal, the open hearth in respect to nitrogen content of the product.

The Bayer process[18] is of particular interest. Blown iron with 1.00 to 2.50 pct C is charged into the open hearth to produce steel of deep drawing quality with 0.005 pct N. This process, first desiliconizing iron in the converter, is based upon the fact that the solubility of nitrogen in iron or steel depends upon carbon content and temperature of the bath. Another well established method for desiliconizing molten iron which does not involve a converter is ladle treatment with an oxygen lance.

Rotating Converter

Sweden has had an important part in the development of converter steel. Although thomas steel is currently being produced, the principal method for producing quality steel in Sweden is by the electric furnace process. In 1948 experimental work began in Sweden on a 3-ton rotating converter[19] blown with oxygen (Fig. 25). Rotation increased the rate of slag-metal reaction and proved so fruitful that it was continued with a 15-ton rotating converter. The influence of slag on phosphorus removal is shown in Fig. 26. With rotation, less oxygen pressure is required and the fume under certain circumstances almost completely disappeared. The bath temperature was controlled with scrap or iron ore additions and lime was used as a flux.

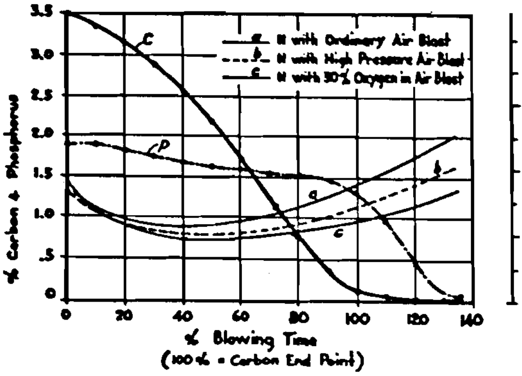

Fig. 24—Bath analysis of thomas steel with high pressure blast—Mayer & Knuppel.

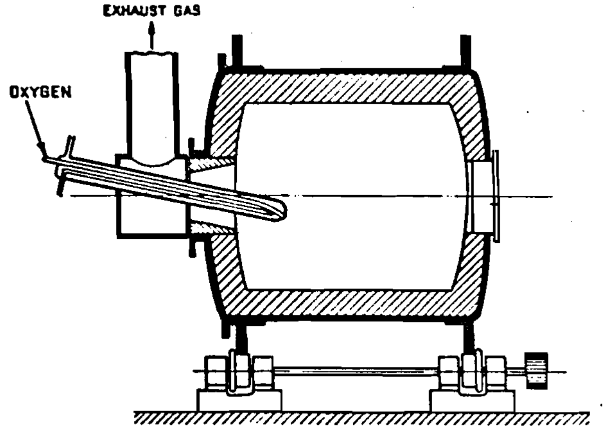

Fig. 25—The rotating converter opens the way to increased rate of slag-metal reaction.

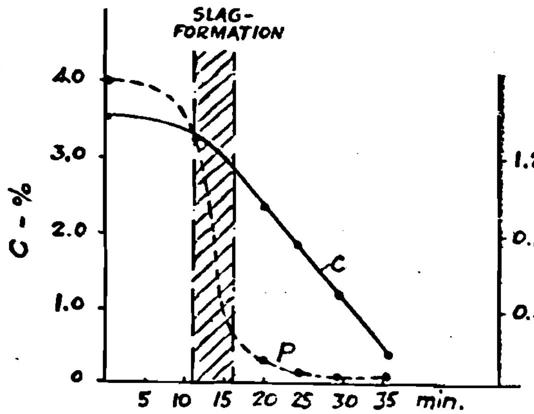

Fig. 26—Influence of slag formation on carbon and phosphorus when using pure oxygen in the rotating converter.

The nitrogen content was 0.001 to 0.003 pct with marked reduction in sulfur. The combustion of CO to CO_2 may be controlled by varying the amount of oxygen, but no attempt was made to recover the heat content of the exhaust gases. The possibility of producing a slag lining and maintaining this lining by water cooling the rotating drum was not explored. A properly controlled slag lining would reduce the refractory problem.

Oxygen-Steam and Carbon Dioxide Converter Blowing

The nitrogen content of steel may be reduced without modifying the principle of bottom blowing by enriching the blast with oxygen, adding ore, and controlling the temperature with scrap. Other methods involve the use of oxygen-steam or oxygen-carbon dioxide mixtures.

When blowing with steam or carbon dioxide, endothermic reactions occur, and the additional heat requirements are provided by using oxygen instead of air. Because of low nitrogen partial pressure low nitrogen steel is obtained. The various mixtures of gas which have been used do not appear to decrease lining life appreciably.

The use of oxygen and steam in bottom blowing has been described by J. Daubersy,[20] P. Coheur,[21,22] and others.[23] The use of oxygen with superheated steam has received particular attention. Copper lining of tuyeres has been successfully used with basic bottoms, but it is not necessary with acid bottoms in which a refractory tuyere is employed.

The relationship between the iron content of the slag and the phosphorus content of the steel, shown in Fig. 27 indicates that lower phosphorus is associated with increased oxidizing conditions of the slag. The nitrogen content of steel blown with oxygen-steam and a lime slag, Fig. 28, shows a lower nitrogen content is the result of increased concentrations of steam.

A small amount of steel has been produced with oxygen-carbon dioxide blowing. One of the blowing mixtures employed is shown in Fig. 29, and analysis of the bath throughout the blow is shown in Fig. 30. The relationship of oxygen in the metal to the iron oxide content of slag, Fig. 31, is similar for air and oxygen enriched blows. The decomposition of car-

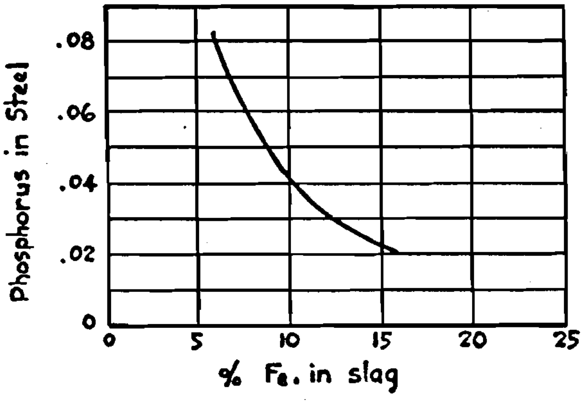

Fig. 27—Relationship of iron in slag to phosphorus in thomas steel with oxygen-steam blowing—Kosmider.

bon dioxide provides additional oxygen for removal of carbon from the melt.

Side Blown Steel Converters

At the beginning of the twentieth century the side blown converter was used principally in the foundry for the production of cast steel. Ten years ago in the U. S. there were 66 foundry converters of the type shown in Fig. 32 with a capacity of 1 to 6 tons.

It has been only within the last 15 years that the low nitrogen content of side blown converter steel has been properly recognized. In side blowing, CO is oxidized to CO_2 inside the vessel with the evolution of heat, and this increased heat is generated with less danger of over-blowing the bath. A blast pressure of 5 psi is used compared with 25 psi for bottom blow vessels.

Side blown converter experiments have been conducted with plastic converters to determine the behavior of liquids and flow of gases so that converters may be properly designed.[34] Recent experimental work with the acid side blown converter process in the U. S. has been described by Webster and Clark.[35] An experimental converter of 22-ton capacity, was designed after work with a 3-ton vessel. The results indicate that steel equivalent to duplex open hearth practice could be obtained with the practice employed. Work and Webster[36] were concerned with blowing air into the bath at the beginning of the blow and on the surface of the bath near the end of the blow. During the past ten years a considerable amount of side blowing was also conducted with basic converters in Europe.

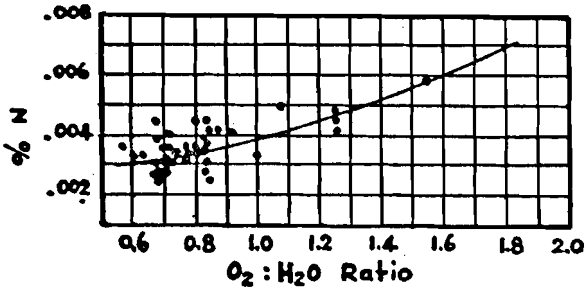

Fig. 28—Nitrogen content of oxygen-steam blown thomas steel—Kosmider.

An advance in converter practice may be associated with the side blown basic converter proposed by C. E. Sims.[37] Results obtained with a ½-ton basic vessel are shown in Fig. 33. The removal of phosphorus with the carbon is of particular interest, as basic open hearth pig iron was used for the experiments and no after blow was required. There was also a decrease in sulfur. The CO_2 content of the waste gases indicates an important source of heat which was utilized to some degree in the vessel.

As a result of Sims' work a large basic lined converter was constructed and placed in operation.[38] This converter, shown in Fig. 34, is of 10-ton capacity. The steel produced contained 0.002 to 0.003 pct N, and the properties were similar to those of open hearth steel.

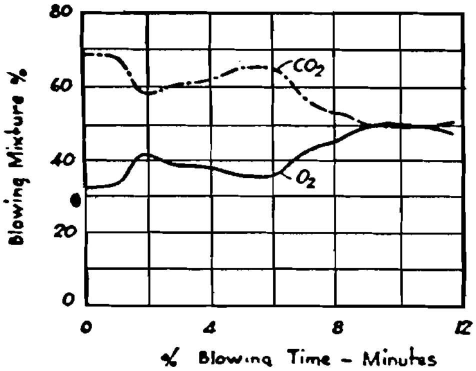

Fig. 29—Oxygen-carbon dioxide blowing mixture for thomas steel—Mayer & Knuppel.

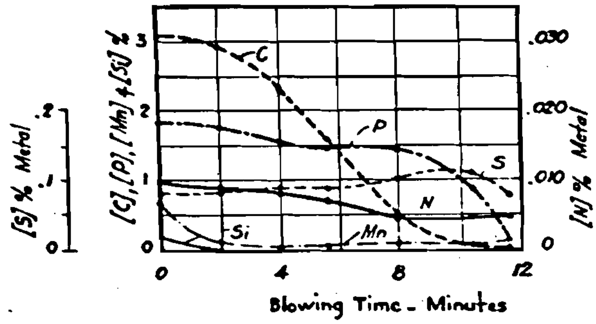

Fig. 30—Bath analysis of thomas steel with oxygen-carbon dioxide blowing—Mayer & Knuppel.

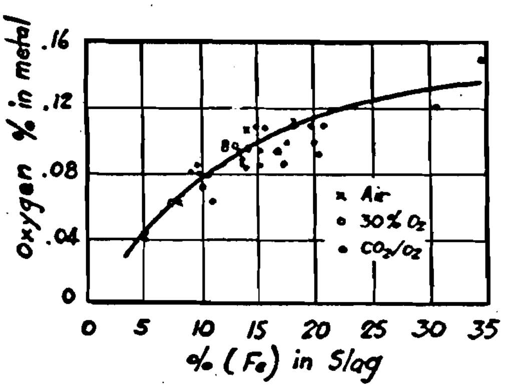

Fig. 31—Relationship of oxygen in steel to iron oxide in slag is similar for air, oxygen enriched air, and O_2-CO_2 blows—Mayer & Knuppel.

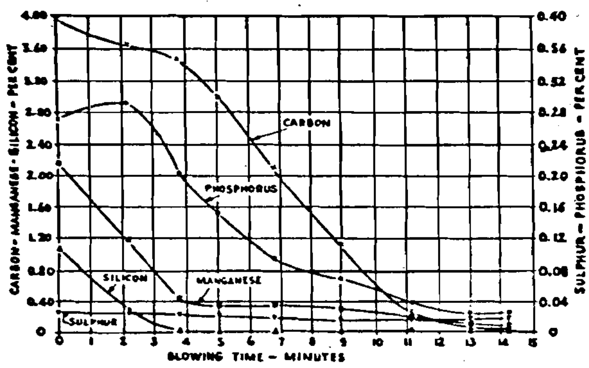

Fig. 33—Chemical analysis during a Sims basic converter blow.

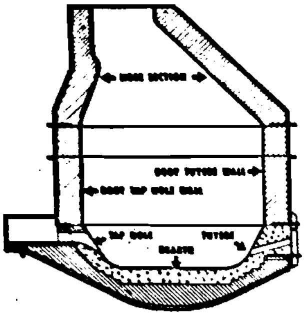

Fig. 34—Side blown 10-ton basic converter, the turbo hearth.

Oxygen Lance Surface Blown Converter

Sir Henry Bessemer in 1856 recognized the possibility of using oxygen in the converter process, but the cost was prohibitive. In recent years, however, the tonnage production of low cost oxygen has made possible its widespread use in the steel industry. The purity of oxygen used for surface blowing steel is usually 98 pct, but for low nitrogen steels it may be as high as 99.5 pct, with argon as the principal impurity. The influence of oxygen purity on the nitrogen content of steel is shown in Fig. 37.

At Linz, Austria,[11] the installation of a hot wide-strip mill and cold reducing mill created the need for low nitrogen deep-drawing steel. Open hearth scrap was in short supply, and pig iron produced at this plant was not of converter quality. In 1949, upon the suggestion of R. Durrer, an attempt was made by E. Suess, H. Trenkler, H. Hauttmann, and others to blow oxygen downward on the bath of a 2-ton converter. Later a 15-ton vessel was used. The process was successful, and in November 1952 a plant with 250,000 tons annual capacity was in operation. Compared with an open hearth, the investment and labor in Austria were 50 pct less. The refractory and flux costs were also less. A number of patents[illegible] have been issued in England and other countries, and the process has been called the L-D process.

During the past several years the Linz plant has produced over one million tons of steel with two 30-ton oxygen lance converters of the type shown in Fig. 35. A third converter is being installed. The Donawitz plant in Austria, placed in operation in May 1953, has a similar capacity. At the Dominion Foundries & Steel plant in Hamilton, Ontario, Canada, two 45-ton oxygen lance converters are in operation with an annual capacity of 320,000 tons of ingots. The McLouth Steel Corp., Trenton, Mich., has in operation three 50-ton oxygen lance converters. The iron analysis of typical blows is shown in Table I. It should be noted that the phosphorus content of the iron is low, for with higher levels of phosphorus a greater slag volume would be required with a reduced scrap charge. The steel produced from the iron in Table I is similar to open hearth steel.

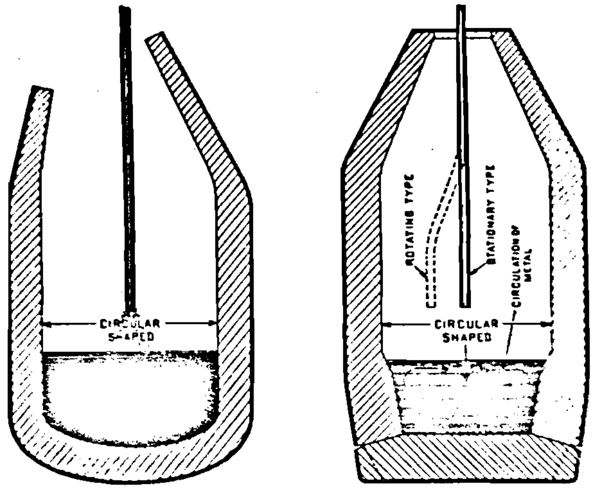

Fig. 35—Oxygen lance converter, L-D process.

Stages in the oxygen lance converter process[11] are shown in Fig. 36. The beginning, middle, and end of a blow are illustrated from left to right. A temperature of 4500°F may be obtained under the lance, and refining is concentrated in this area—the reaction area. However, the rotating motion of the bath caused by thermal diffusion, and the higher specific gravity of the refined metal, Fig. 35, causes the reaction of oxygen with the metalloids throughout the bath. The CO gas developed at the reaction area also promotes a rotating motion in the bath. As the metal is refined, the rotating action of the bath decreases, for the hottest part of the refined melt, which is under the oxygen jet, has the lowest specific gravity.

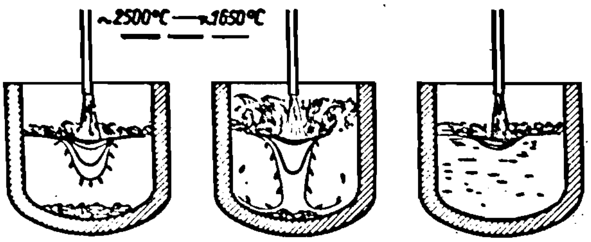

Fig. 36—Beginning, middle, and end of blow in oxygen lance converter (left to right).

The oxygen lance converter charge consists of molten pig iron, 125 lb of lime or small size limestone per ton of ingot, a small amount of spar and scale, and 15 to 20 pct scrap. The converter lining, consists of tar-dolomite brick with 250 to 300 heats obtained per lining. Dolomite consumption is 25 lb per ton of ingots.[illegible] About 2000 cu ft of oxygen per ton of ingot is consumed during the 20-minute blowing time. The slag shown in Table II contains only a small amount of phosphorus and, therefore, has no value as a fertilizer; about 300 lb of slag are produced per ton of ingot.

The oxygen lance converter process is used primarily for the production of low carbon steels, although medium and high carbon steels have been produced with the addition of molten iron or carbon in various forms to the blown metal. It is reported that the cost of low carbon steel produced with an oxygen lance is less than open hearth steel with similar yields, and the quality of oxygen steel is equivalent to open hearth steel. However, some factors which control the most effective use of the oxygen lance remain to be determined. Production of steel with 0.5 pct residual Mn, as shown in Fig. 38, desulfurization of the bath, and production of low phosphorus steel, as depicted in Fig. 39, are results which have been achieved and should be considered in future efforts directed toward the more effective use of the oxygen lance. Increasing the size of the oxygen lance converter and catching carbon on the way down for the higher carbon grades are considerations which remain to be developed.

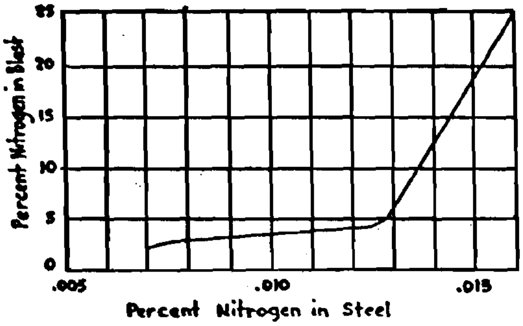

Fig. 37—Influence of nitrogen in oxygen lance blast on nitrogen content of steel—Trenkler.

Refining action may also be obtained in an open hearth[30] with an oxygen lance as determined by A. J. Kesterton in Wales. A saving in heat time was achieved with satisfactory roof life and reduction in fettling time, using a water cooled oxygen lance through the roof. In Russia[31] an open hearth is being experimentally blown with oxygen through the roof.

Summary

During the one hundred years since development of the pneumatic process, steel has provided a low cost material for the continuing industrial revolution. The first part of the present century provided few fundamental changes in steelmaking, but recent development of low cost tonnage oxygen made possible the use of the oxygen lance. Surface blowing with air and other gases and bottom blowing with oxygen-steam have also been new approaches.

The present large capacity for open hearth steel in the U. S. and the U. K. will provide a basis for the widely continued use of this process, particularly with variation of raw materials and in conjunction with oxygen lance techniques. In continental Europe production of low nitrogen steel requires different methods, and the new blowing techniques for the basic converter have been a commercial success with high phosphorus iron.

Table I. Analysis of Hot Metal For Oxygen Lance Converter

	Linz	Donawitz	Dofasco	McLouth*
C	4.0	4.0	4.4	4.2
Mn	1.8	2.75	1.3	1.5
P	0.18	0.18	0.125	0.15
S	0.04	0.04	0.025	0.025
Si	1.0	0.65	1.2	1.1

* Estimated.

Table II. Analysis* of Oxygen Lance Converter Slags

	Linz	Donawitz	Dofasco	McLouth
CaO	41	42	50	45
SiO_2	14	11	17	15
FeO	20	19	16	23
MnO	15	20	8	5
MgO	7	5	3	4.5
P_2O_5	1.5	2	1.2	—

* Al_2O_3 not shown may be 3 pct.

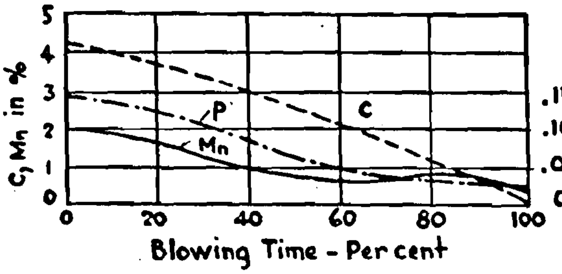

Fig. 38—C-Mn-P removal in oxygen lance converter—Trenkler.

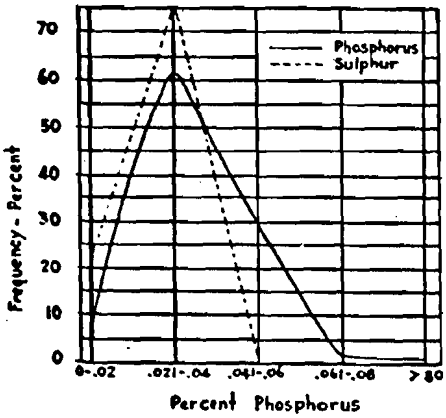

Fig. 39—P and S distribution in the oxygen lance converter process—Trenkler.

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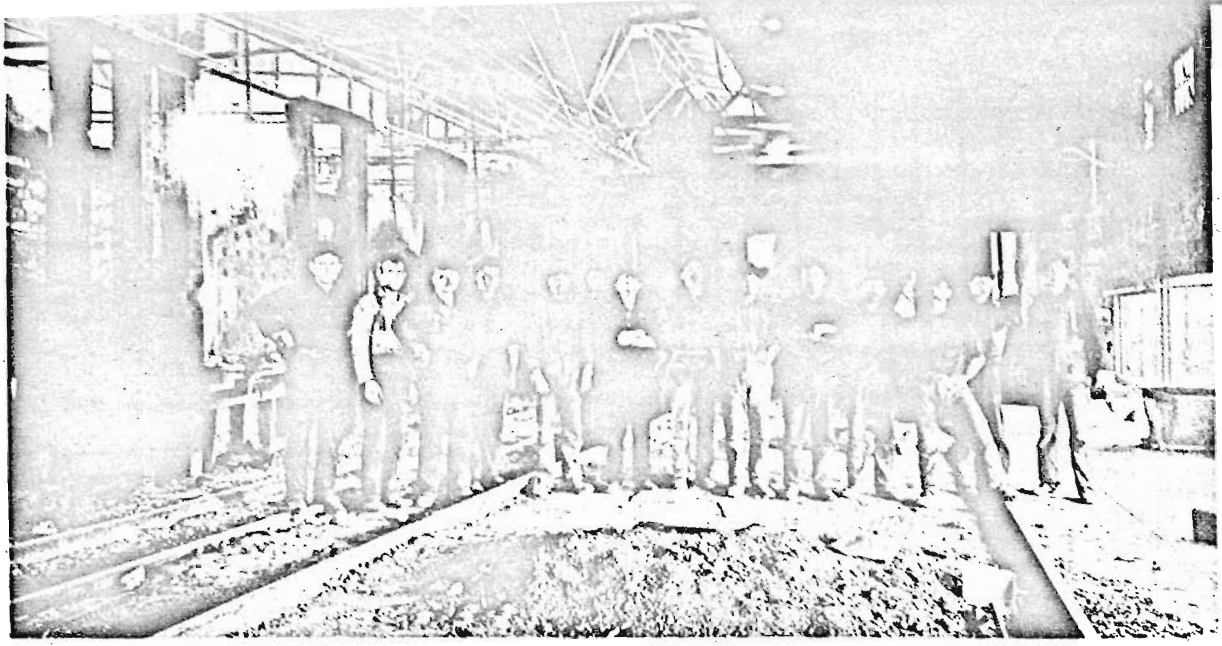

STEELMAKING / U.S.A.

Part I

The history of steelmaking in the United States is a fascinating story of determination, sudden tragedy, exploitation, and inventive genius rolled into one gigantic plot. Mr. Reinartz' flowing interpretation of the progress made in the last one hundred years is being presented in a series of four articles.

by Leo F. Reinartz

THIS is the Age of Steel. We live in a mechanized era. Our everyday lives—everything we see or do—are organized and influenced by this versatile metal. Our industries, our farms, our homes, and our transportation—yes, our vocations and avocations, or luxuries and necessities—all are dependent upon smelting iron and making steel. Take away iron and steel and soon our vaunted civilization would revert to a primitive existence.

These metals, often in crude forms, have been known for thousands of years. Down through the ages, until about one hundred years ago, steel was made laboriously, and at high cost, in small batches. During those years, methods of manufacture did not change very much. Over long periods of time only warriors, royalty, and wealthy people could afford to use articles made of iron or steel.

History has recorded that the nations which were expert in iron and steel manufacture, and had access to rich iron-ore deposits, were the leaders in war or in peaceful pursuits.

At the end of the 18th century, thirteen struggling American colonies had broken not only the political shackles that bound them to Great Britain, but also many of the economic bonds. They had showed their skill, Yankee ingenuity, and energy by making iron and steel articles for their own use.

After the Revolutionary War, more and more hardy American pioneers pushed westward through the Allegheny Mountain passes and down the rivers into the fertile Ohio River and Kentucky country. Demands for articles made of iron increased. The iron industry on the east coast grew and prospered.

As this trend continued, iron industrialists moved their plants westward to be near the large deposits of high-grade coal in western Pennsylvania, eastern Ohio, and nothern West Virginia. They also desired to use the local iron ores and water resources of those areas. Blast furnaces and ironworks were built in the Pittsburgh, Youngstown, southern Ohio, and northern West Virginia districts.

In 1810, the United States produced 53,908 gross tons of cast iron and 917 tons of steel.

Iron ore discovery

A white man first discovered large deposits of iron ore in the northern Michigan and Lake Superior country in 1844. One year later, the Sault Ste. Marie

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ship canal was completed, making these easily mined ores accessible to the iron and steel-producing centers south of the Great Lakes.

In 1853, Jones & Laughlin Ltd., a pioneer in steel manufacture, began its operations at Pittsburgh.

It is worthy of note that in 1857, the first of the one hundred years of modern iron and steel industry, a severe commercial depression hit the United States. Its effects were felt by the growing iron and steel industry.

Nevertheless, that year saw the coming of the industry to Chicago. Also during that first year, 26,375 gross tons of iron ore were shipped from Lake Superior iron-ore mines to steel plants. Hard ore could be delivered on Cleveland docks from the Marquette Range in Michigan at a cost of $7 per gross ton. At that time, a sample of Lake Superior iron ore showed the following contents: iron oxide, 98.02 pct; manganese oxide, 1.22 pct; silica, 0.44 pct; calcium oxide, 0.32 pct.

It was only natural that as early as 1857, attempts were made to produce steel directly from such rich ores, but because of deficiencies in process and equipment, the experiments were unsuccessful.

In those days, puddled iron was made in small batches by refining pig iron. The puddled iron blooms could be cut up, piled, reheated, and rolled into rails, shapes, and bars. The latter could then be reheated and rolled into sheets.

High-grade tool and spring steels were made in crucibles in even smaller batches. However, strange to relate, it was the cheapest and best steel made in that period.

Many foundries made cast-iron commodities. In 1857, iron and steel products consisted mostly of boiler plates, bar and sheet iron, nails, rivets, spikes, rails, plow and spring steels, crowbars, sledges, as well as steel and iron castings of many shapes and for many uses.

There were 16 foundries in Pittsburgh. Rolling mills were erected at Niles, Ohio in 1857. The equipment consisted of puddling furnaces and forges, heating furnaces, a train of rolls, and cut nail machines. In this plant, as a rule, workmen's wages were paid in *scrip* which could be exchanged for goods at company stores. The workmen were given one dollar in cash for the Christmas and July 4th holidays.

In the same year, Scioto Rolling Mill Co. was organized at Portsmouth, Ohio. It was a forerunner of the present day Detroit Steel Corp. of that city.

Early plants

It is interesting to note that the Wheeling Steel Corp., of Wheeling, W. Va., traces its early history back to the Principio Co. of Maryland, one of the first iron-producing companies in the US, where a crude furnace was built in 1715.

The St. Louis Stamping Co. was incorporated by William F. and Frederick G. Niedringhaus in 1866. The brothers were thrifty, independent businessmen, who had immigrated from Westphalia in the 1850's. In 1878, they erected the Granite Iron Rolling Mills at St. Louis, Mo. These mills were the forerunners of the Granite City Steel Co., now at Granite City, Ill.

On July 5, 1875, the Joseph H. Brown Iron & Steel Co. was founded on the site of the present Wisconsin Steel Works of the International Harvester Co. It is now the oldest plant in the Calumet steelmaking district of Chicago.

In 1858, labor made the first of many attempts to organize the iron and steel industry in the Pittsburgh area. Workers lost this contest. During the year 1860, the Sons of Vulcan, an organization of puddlers, heaters, roughers, and rollers—the cream of steelworkers—was formed. It played a prominent and, at times, violent part during the next few decades in the strenuous, though unsuccessful, effort to organize the steel industry.

In 1860, James M. Swank reported a production of 821,225 gross tons of pig iron (but only 11,838 tons of steel) in the United States. In the same year, 200 Catalan forges were operating in the southern Ohio and Potomac River districts, and 30,626 miles of railroad rails were laid in the US.

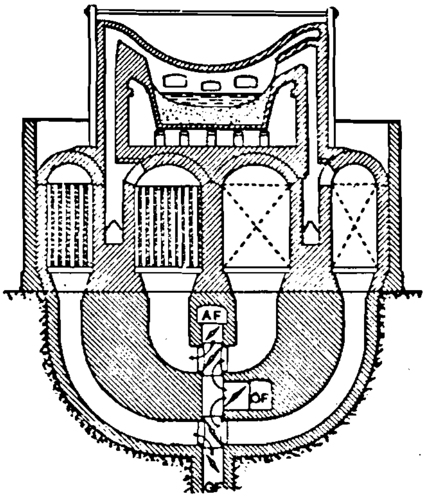
The trek westward

Prior to the Civil War, most Americans lived on small farms or in villages. Many young people became dissatisfied and craved change and excitement. Thus, in the early 1860's and in the years following the War, the great trek west, which had started before the 1849 California gold rush, began to assume tremendous proportions.

In the human avalanche were pioneers who liked "the wide open spaces," adventurers, prospectors, criminals, discouraged persons, and discharged soldiers from the Gray and Blue armies. By the thousands—on horseback, by stagecoach, and by covered wagon—they traveled from the great Mississippi and Missouri Rivers across the central plains. Some stayed in this vast area to farm or to raise cattle; almost overnight, villages and towns sprang up.

Other restless, adventurous spirits relentlessly pushed on to the Rocky Mountains seeking fortunes through prospecting and mining. Many hardy souls continued, despite terrible hardships, until they reached the fertile valleys of the Pacific Coast. Here they joined with those who, years before, had come to this wonderful country by ocean travel from the eastern states, or from Mexico and other foreign countries.

Demands for equipment and supplies to outfit these modern *nomads* were enormous. Even when they had settled down to farm, raise cattle, mine, or engage in commercial pursuits, the itinerant ped-



Section of Siemens steel melting furnace showing arrangement of regenerators, flues, and valves. AF is air flue, CF is chimney flue, and GF is gas flue.

dlers, pony express, and stagecoaches were often too slow and uncertain to bring their necessities—many of them iron and steel articles—from the industrial east. In addition, the population of the industrial middle west was rising, increasing the demand for steel products.

The resulting clamor acted as an incentive for industrialists and manufacturers to move their plants westward. This move, in turn, necessitated prompt delivery of raw materials.

The bessemer process

The stage was now set for the exploitation of a more dependable, faster, and cheaper method of transportation. The railroads were looking for a process to make rails rapidly and cheaply.

William Kelly decarburized molten iron by the use of an air blast, at Eddyville, Ky., in 1850. At that time he was merely trying to burn out carbon and silicon. In 1856, when Kelly heard that Henry Bessemer had filed a patent in England on a similar idea, he filed an American patent. During the next ten or more years, considerable litigation took place before the two men merged their interests.

To this day, possibly because of the prominence of the English inventor (he was knighted by Queen Victoria) this method for making steel pneumatically is known world-wide as the bessemer process.

Sir Henry Bessemer was successful in making commercial steel because the ores used in his experiments happened to contain a considerable amount of manganese and a low sulfur content. However, if Robert Mushet, another Englishman, had not developed spiegeleisen, an alloy of iron and manganese, and used it for deoxidizing and recarburizing the blown bessemer metal, that process would have had only limited commercial value.

The invention of the bessemer process was one of the outstanding milestones in the steel industry and in human history. It marked the breaking away from age-old, slow, tedious, costly processes of making steel. Whereas puddled iron could be made in lots of less than 500 lb in 3 to 5 hr by dint of hot, heavy work, the new process could make steel in 5-ton lots with much less labor in less than ½ hr. It was more uniform and of better quality than its predecessor.

From 1867 on, the adoption and improvement of the bessemer process was rapid. It made possible the "winning of the West." Structural shapes could now furnish strength and economy to build steel skyscrapers; streams—large and small—could be be bridged; steel ships replaced wooden windjammers; steel could be used to build machinery and equipment for modern factories.

Because steel could be produced cheaply and rapidly by the bessemer process, this method of making steel was in its heyday. As more and more plants installed new converters, the sky glowed with their sparks, flames, and dense brown fumes day and night. *Kish* from blast furnaces, brown deposits from bessemers, and black smoke from the combustion of coal were signs of prosperity and wealth. When the air was clear in steel communities, it was the sign of a strike or a business recession, and no pay checks. Since most steelworkers lived from hand to mouth, such occurrences were calamitous.

The years from 1870 to 1900 witnessed the greatest expansion of steel manufacturing and railroad building in the United States the world has ever seen. More than 500,000 miles of rails were laid between 1865 and 1885. By 1890 this country had become the leading steel-producing nation in the world. The bessemer process accounted for 6,685,000 gross tons of ingots in 1900, while its younger rival, the Siemens-Martin process (see below), could muster only 3,404,000 gross tons.

The narrowing down of the bessemer process preeminence was due to its "Achilles' heel." It could make steel for pipe, rails, wire, and common varieties of sheet steel, but because of the high nitrogen, sulfur, and phosphorus contents, steel made by this process could not be used to produce high-quality, deep-drawing sheet and other specialty steels. Furthermore, manufacturing depended on hot metal made from iron ores, not readily available and decreasing in quantity. In the bessemer process only limited amounts of scrap iron could be melted.

The Siemens-Martin process

During the early days of the industrial era, large tonnages of scrap iron began to accumulate. It came from steel plant operations, fabricating shops, and wornout, damaged, or obsolete steel products from the railroads, farms, homes, and elsewhere. Scrap iron, therefore, became a drug on the market. Huge piles of cheap scrap iron, as well as the success of the bessemer process, attracted and stimulated the minds of many inventors.

In the early 1860's, Sir William Siemens, a German-born English citizen, had invented the regenerative principle for heating materials to high temperatures. In 1862, he had built his first regenerative furnace in England. By 1868, he had developed a pig-iron and iron-ore method for making steel on a sand bottom, using this regenerative idea for heating.

The practice of charging scrap iron to dilute the pig-iron impurities—in place of Siemen's pig and ore process—was developed by Emile and Pierre Martin in France. This process now could make use of the large scrap-iron inventories. The duration of heats could be decreased because less time was required to decarburize the molten bath.

This method for making steel soon began to be known as the Siemens-Martin open-hearth process. Its development was painfully slow. In 1868, a small furnace was built at Trenton, N. J., but after a short period of experimentation, it was abandoned.

The first successful regenerative steel-melting furnace was built in South Boston, Mass., in 1870. It was a tiny, 5-ton furnace, very crude when compared with present day, modern, open-hearth giants. Since silica brick were as yet not available, fireclay brick were used to build this furnace on ground level.

The furnace had multiple uptakes and downtakes, no slag pockets, and an acid-lined hearth. Direction of the flame was helped by a roof depressed at the center. Regenerative chambers, located directly under each end of the furnace, were rapidly clogged with slag, a condition that did not change until Siemens, in 1877, patented his idea for placing the chambers under the charging floor. Slag pockets were then put under each end of the furnace. Since those early days, furnace design has not changed a great deal.

Generally, producer gas was used as an open-hearth fuel. The manufacture of artificial gas was in its infancy in the US and left much to be desired for such a purpose.

Early furnaces were charged manually through a charging door by means of long handled peels. The charge consisted of a mixture of puddle bars, scrap iron, and English hematite pig iron. The day when hot metal would be poured into a furnace was still distant. Approximately eight hours were required to make a heat. The metal was then removed from the furnace through a tapping hole and spout located opposite the charging side, and run off into a brick-lined container equipped with a nozzle and stopper rod. It was then teemed into molds situated below the container.

In October 1874, two 7-ton acid open-hearth furnaces were started at the Otis Steel Co. in Cleveland. Two 15-ton furnaces were added in 1878, and two more of the same size went into operation in 1881 and also in 1887. This was the first company in the US to depend exclusively on open-hearth steel.

The furnaces were built 10 ft above ground level. The charge was raised to the charging floor by a hydraulic lift. Each heat was tapped into a ladle hung on a hydraulic jib crane. To teem the metal, the ladle was swung around over a short drag of molds. This operation, preceding the day of electric cranes, was a great advance in steel production.

The general use of acid open-hearth steel in the United States was short-lived. This process, though it could use large quantities of scrap iron, was similar to the bessemer process in that sulfur and phosphorous could not be eliminated from the molten metal.

Basic open-hearth shops

The first basic steel was made experimentally on May 24, 1884, in a bessemer converter at the Pennsylvania Steel Co., Steelton, Pa.

In 1886, the bottom of one 15-ton furnace at Otis was lined with basic magnesite imported from Austria. It was fritted in with heat, and slag was melted on the bottom to fill up the voids. After a 4-month trial, the bottom was changed back to acid construction.

The idea of using a basic hearth bottom by means of which the sulfur and phosphorus content of the metal could be controlled was sound. Thus, the basic open-hearth process, as we know it today, was given its greatest impetus when Carnegie, Phipps & Co. Ltd. built fifteen 35-ton furnaces with basic hearth bottoms at the Homestead Works, Munhall, Pa. The first heat was tapped on March 28, 1888.

These furnaces were built on the ground. Checker chambers were below ground level, under the charging floor, between the furnace and the stack. Natural gas, found in abundance nearby, was used as a fuel. Only the air for combustion was preheated. The furnace was reversed by means of cast-iron butterfly valves. The hearth was cylindrical, having an area of 176 sq ft. Tar-impregnated dolomite was used to frit in the first bottoms.

In a few years, the company changed most of its hearths to a rectangular design. A few round furnaces with removable roofs were kept for many years to melt large chunks of scrap iron, spills, and other irregular pieces from all the corporation plants.

The No. 2 shop was built in 1890. It contained eight 47-ton basic open-hearth furnaces. The last eight furnaces were installed in 1901.

No. 3 shop was started in 1898 and finished in 1899. It contained 24 furnaces under one roof, all of which were built on ground level. Checker chambers, valves, and open-hearth pits were below ground level.

The first two-level shop at Homestead was started in 1906, when 10 furnaces were built. It was completed in 1910 with the erection of four more furnaces.

Hot metal was first used in the open-hearth furnaces at the Homestead Works about 1900.

During its first 50-year history, the open-hearth process seemed to have more than its share of difficulties. The work was hard, hot, and dangerous. Furnace operators and maintenance men labored long hours on two shifts: 11 hr in the day and 13 hr in the night, with a grueling 24-hr shift at the end of every second week, when crews changed over from day to night work.

In those days, American boys were not interested in working in the scrap yard, the open-hearth pit, or on the labor gang. A few asked for jobs on the open-hearth charging floor because they were attracted by the relatively high wages of first helpers and melters.

Melters were jealous of their jobs and prerogatives. Novices often had to pay them for the privilege of learning a furnace job. It was rumored that sometimes new furnace men paid as much as $250 for this privilege.

The melter usually drew the pay for his entire crew. He then distributed the money as he saw fit. Naturally, irregularities and favoritism crept in. Later, this practice came to haunt management, when workers began to rebel against unfair practices. Those were the days when cocky steel-mill melters and rollers came to work carrying large rolls of bills or cash in special money belts, which they loved to exhibit to their underlings.

Foreign workmen

The hot, dirty jobs of the open-hearth shop were done by foreigners—men with strong backs from the undeveloped countries of southeastern Europe. Most of them, in the early years, did not speak English. They had to be given orders in sign language or by means of fluent, though vulgar, Anglo-Saxon words from none-too-gentle American straw bosses, as labor foremen were known in those days.

In the late 1890's and in the early years of the 20th century, thousands of foreigners came to America and worked in steel plants. Usually they were brought to this country by sponsors, sometimes referred to as "padrones." At the steel plants, foreigners were housed and fed in cheap, none-too-sanitary boarding or bunk houses. A heavy price in the form of kickbacks from their low wages was exacted from these foreigners for repayment of their passage fare and for their keep.

As time went on, progressive steel plant managements eliminated many of these abuses. More livable quarters were provided. Classes in Americanization and English were started.

Foreigners, as a class, were thrifty. Many saved enough to bring their wives and families from the old country. In some steel towns, foreigners bought homes away from the sections where former language, customs, and prejudices were still in vogue. Their children went to school with Americans. These people became substantial citizens of the communities in which they lived.

The steel industry owes much to these unsung, humble, hard-working pioneers. Their sons, grandsons, and even granddaughters are often the backbone of present day steel organizations. Some descendants manage the plants where their elders toiled as laborers.

American Iron Works of Jones & Laughlins (Pittsburgh), in the 1880's: from an old etching.

STEELMAKING / U.S.A.

Part II of a four-part series on the history of steelmaking in the US, points out the inadequate safety and living conditions that existed in steel mills at the turn of the Century. Also defined are furnace and process developments.

by Leo F. Reinartz

OPERATIONS in steel plants today are highly mechanized. Men work in light, clean, orderly melting shops, making it difficult for oldtimers to convince young men that primitive, hazardous conditions existed in steel plants at the turn of the century. Working conditions then were very poor as compared to present day standards. In small plants especially, sanitary, locker, and washroom facilities, first-aid practices and stations were unknown. Accidents were frequent and severe.

Workers had a fatalistic attitude toward getting hurt. He who had an accident was looked upon as a hero. A dirty bandanna often served as a bandage. Infections were frequent.

Electric cranes were in their infancy and broke down often. Cables had not as yet replaced chains. Pig iron and scrap iron were loaded by hand in the stockyard, and stockyard locomotives were unknown; mules served as the usual motive power. It was not unusual to see recorded a delay of ½ hr in charging a furnace because of a balky mule.

Furnace operations

A few plants had primitive charging machines, but most furnaces were charged by placing scrap or pig iron on the paddle of a long peel, which rested on a bar across the furnace door opening. Laborers at the handle end of the peel, using the bar as a fulcrum, would heave the material into the furnace by a down and sideward motion of the peel handle. In time they became expert in placing these materials in the furnace, but it was hard, hot work, and a long time was required for charging. Cold charges of 25 tons required more than 12 hr for melting and refining the steel.

Ports, doors, and frames were not water cooled. The charging and working area in front of the furnace was covered with steel plates. They were hot and often warped by the intense heat of the uninsulated checker chambers directly below. In the summer, working conditions on the charging floor were almost unbearable.

Silica refractories were of poor quality. Because of this, and the inadequate training of furnace men in fuel control and furnace operations, roofs, front and back walls, and ends burned out rapidly. **Dolomite machines** were unknown; consequently, furnace banks and hearths were fettled with dolomite by the use of hand shovels.

The **round system** required six or more men. Each man took a shovelful of dolomite and, in his turn, deposited it on the back wall and bank by a dexterous forward swing and twist of the shovel. The upward swing of the shovel partially protected his face from the searing heat of the furnace coming out through the wide-open door. Considerable skill and stamina were required to do this job properly.

Reverse valves, usually of the cast-iron butterfly type, were located below the charging floor. They were operated by long levers on the charging floor level. When they became warped, because of heat and abuse, great strength and skill were required to reverse them.

Furnace operations were difficult. The quality and quantity of producer gas coming from irregularly stoked, hand-operated gas producers was uncertain and unreliable. Furnace linings and ports were quickly burned out.

Poor bottom and side-wall refractories, indifferent and inexperienced crews, as well as irregular re-

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versals, caused many breakouts. Molten metal ran out through the brickwork onto the floor, through the back wall into the pit, or through the end chill boxes of the furnace into the slag pockets. These happenings were often accompanied by explosions and fire. Because of the lack of floor cranes, breakouts on the floor were responsible for numerous delays and long hours of backbreaking work to clean up the mess.

Topping: Early furnaces were built on ground level to reduce construction costs. As a result, tapping pits were below floor level. Ladle stands under the furnace tapping spouts were unknown. When a heat was ready (which was indicated by beating on a large steel plate, blowing a whistle or ringing a bell), the ladle was brought by the ladle crane to the furnace and lowered into the pit under the spout.

At times, owing to faulty refractory materials or to inefficient closing of the taphole after a heat had been tapped, the next heat might tap itself before a ladle could be placed under the spout. It was an awsome and nerve-racking sight for the superintendent to see an entire heat of steel go down into a deep ladle pit. Usually such an event meant a furnace delay of several days, together with grueling, dangerous work cooling and removing the chunk of steel.

No oxygen was available in those days to cut up such scrap. Often the chunks could not be salvaged because of their size and shape. In these cases, a hole was dug in the ground and the piece was jacked off the car into the hole to rest there until skull crackers or the oxygen torch (at a later date) made salvage economical. During such periods, open-hearth furnaces could be operated almost entirely on skull and breakout scrap.

Hazards did not stop there. Stopper rod and nozzle assemblies were tricky. If they were not properly made up, handled, and dried carefully, or if the heat was on the cold side, a *running stopper* might be caused by rod or nozzle failure. This would mess up molds, stools, cars, and tracks. It was dangerous to go near the ladle. The craneman, at considerable discomfort and danger to himself, moved the ladle from mold to mold, accompanied by a geyser of sparks and flame, as best he could. The quality of a heat produced by long hours of careful melting and refining could be ruined in minutes by a running stopper or other pit mishap.

Because of the lack of dynamite, jack-hammers, conveyors, bulldozers, and other modern mechanical facilities, and because of the location of slag pockets and checker chambers below ground level, furnace repairs were long, tedious, and relatively costly. Furnace availability, therefore, was very low.

Only a portion of the trials and tribulations faced by workers, supervisors, and management from 1888 (when basic furnaces began to operate at Homestead, Pa.) until about 1910, have been enumerated. It will now be desirable to relate how Mother Necessity, over a period of many years, has increased production in the open-hearth shops, improved quality, decreased costs, and immeasurably improved the lot of the steelworker in the melt shops.

Improvement through invention

Samuel T. Wellman invented the **electric charging machine** in 1887. However, records indicate that the first electric charging machine was installed in the Lakeside plant of the Otis Steel Co. in 1894. This invention decreased the number of laborers in the shop, greatly speeded charging, increased production, and decreased costs. A number of years elapsed before all open-hearth shops adopted this labor and time-saving machine.

In 1895 Wellman invented another great boon to steel management, the **electric magnet**, which could load pig and scrap iron into charging pans rapidly and cheaply. Again, this invention eliminated much hard labor.

During the 1890 decade, **silica brick** manufacture for open-hearth roofs, side walls, and end walls was started. About this time it became a regular practice to import Austrian and Grecian magnesites for making basic furnace bottoms and tapholes, respectively.

Prior to 1900, open-hearth doors and frames were steel castings. The doors were lined with firebrick. During the 1900 to 1910 decade, crude **water-cooled doors** and, later on, **water-cooled frames** came into use in some of the large steel shops. The water-cooled doors and frames as they exist today came into use prior to 1915. By 1920 they had become standard in most open-hearth shops.

Reversing valves on open-hearth furnaces caused much trouble for many years. They warped, leaked, maintenance was high, and because of many turns in gas or air direction, they restricted draft and thus furnace production. Prior to 1920, reversing valves were of many sizes, makes, and shapes. In the fall of 1915, the first **straight-line gas and air valves** were installed on an open-hearth furnace by Maryland Steel Co., Sparrows Point, Md., followed early in 1916 by a similar installation at the South works of Illinois Steel Co., South Chicago.

This invention marked a great advance in furnace design and performance because an improved straight-line flue system was made possible, cutting out tortuous routes for air, fuel and waste gases. As time went on, the design was improved and this type of valve became standard in practically all open-hearth shops.

The only exception appears to be the Isley control system. The first of which was installed in 1924 on a small open-hearth furnace in Worcester, Mass. The initial installation on a large open-hearth furnace was made in a middle eastern plant in 1925. The setup required no valves in any of the flues to the stack, and the design assured adequate draft at all stages of the heat. Waste-heat boilers cannot easily be applied to such a design. Air pollution hazards are somewhat accentuated by the low stack or stacks.

These innovations, as they appeared on the scene many years ago, helped to lift the burden of hard, hot, manual work from furnace crews.

Hot metal

It is not clear just when hot metal was first used in basic open-hearth furnaces.

The hot metal mixer, invented by William R. Jones (AIME member, 1875), was first used in bessemer steel manufacture at the Edgar Thomson works of the Carnegie Company, Braddock, Pa., in 1889. It is known that such large steel companies as Carnegie, Phipps & Co. Ltd., Pennsylvania Steel, and Jones & Laughlin used hot metal from mixers prior to 1900.

Mixers increased in size until at some shops today they can hold 1500 tons of hot metal. However, they have their weaknesses. Various casts of molten iron are not truly mixed. The vessels are difficult and costly to maintain. Hot metal is transferred from the blast furnace to the open-hearth department in small, open-top ladle cars. The metal cools considerably before it is dumped into the mixer, where it is difficult to maintain the temperature. Modern vessels, therefore, are heated with gas.

The first mixer-type hot-metal car was put into service by Jones & Laughlin at Eliza furnace, Pittsburgh, early in 1916. Its rated capacity was 90 tons. Everyone concerned was afraid that the metal might freeze in the ladle. The first ladle, therefore, was made of three steel castings bolted together for swift dismantling if a freeze did occur.

This submarine-shaped ladle with a small opening on top holds heat very well without the use of a mixer. It can be revolved on its horizontal axis to pour hot metal into an open-hearth transfer ladle which rests on a scale. Present day mixer cars hold up to 200 tons. Improvement in the uniformity of analysis and temperature of hot metal cast from blast furnaces has increased the trend in recent years toward mixer cars only.

Furnace developments

Tilting Furnace: Harry H. Campbell built six 50-ton tilting open-hearth furnaces at Steelton, Pa., in 1889. A mixer was used in connection with these furnaces. The furnaces were hydraulically tilted. Fuel could be kept in the furnace when the latter was in a tilted position. A high percentage of molten iron was charged.

This process was advantageous because the first slag could be removed easily and a new slag formed. Tons per hour was high. The taphole was simple, and back wall and bottom maintenance easy.

In 1899, Talbot tilting furnaces were installed at the Penncoyd Iron Works, Philadelphia. The Talbot method left some metal and slag from a preceding heat in the furnace. Burnt lime, scale, or iron ore was then charged. Next, hot metal was then added. Reactions were rapid and violent, and tons per hour was high. There were several serious disadvantages: large quantities of scrap iron (which often was very cheap) could not be used; furnace maintenance and fuel costs were high; metal losses were excessive; and quality of steel was questionable. Also investment costs were high.

A number of tilting furnaces were built during the next 20 years; 10 Talbot furnaces were operating in the U. S. in 1906.

Duplex process: The duplex process—acid bessemer and basic open-hearth furnaces—was started at Tennessee Coal & Iron Co., Birmingham, in 1904. A number of plants, especially those with high capacities for hot metal, followed this example.

Stationary furnaces: During the past 20 years or more, many of the remaining tilting furnaces have been converted to the stationary type, except in the southeast, where high-phosphorus pig iron is still being refined.

From 1870 to 1900, the size of furnaces increased slowly. Originally, furnaces held 5 to 15 tons. By 1900, open-hearth furnaces were tapping 35-ton to 65-ton heats. In that year, 75-ton furnaces were designed.

Between 1907 and 1908, the open-hearth tonnage exceeded bessemer steel production for the first time. Open-hearth production increased rapidly, especially during World War I (233 new furnaces were built between 1915 and 1918, more than doubling the 1909 tonnage).

For a number of years after the War ended, the demands of a peacetime economy were less than required to utilize this excess steel capacity. But in time the economy caught up and new capacity figures were set.

By 1925, new stationary furnaces were tapping 150-ton heats, and some prominent steel men were questioning the quality of steel made from such large furnaces.

Almost from the beginning, tilting furnaces had greater capacities than stationary ones. By 1928, these capacities had risen to 300 tons. In October 1925, Ben Talbot, developer of a continuous process for making open-hearth steel, predicted that furnaces of 400 to 500-ton capacity would be built some day.

Despite the depression years in the 1930's, a steady advance was made in improvements in steel manufacture. Progressive managements took this opportunity to enlarge capacities of existing older furnaces to 150 or 200 tons and to install new auxiliary equipment.

During this period the use of increased tonnages of steel for sheet manufacture was accelerated by the installation in many steel plants of continuous strip-rolling mills, first operated by Armco Steel Corp., at Ashland, Ky., in the early 1920's. This process greatly increased tons-per-hour rolled, radically decreased costs, and improved surface quality. As a result, it now became possible for American workmen to own high-quality automobiles, household appliances, radios, and other articles made of steel.

World War II upset this trend for a number of years. During that period the demand for steel for war purposes was tremendous, especially for plates, sheets, and strip. In addition, thousands of tons had to be sent to America's allies.

Thus, more and larger furnaces—up to 250 tons in capacity—were built. Fuel efficiencies and the skill of workers increased. Alloy steels, formerly made only in small electric-melting furnaces, were produced satisfactorily in large open-hearth furnaces. Low-alloy, high-strength steels conserved strategic materials and helped win the war.

By the end of 1945, the last year of World War II, steel capacity in the United States had risen to 91,000,000 net tons. Despite greatly increased capital installation costs, the capacity of new furnaces continued to increase during and after World War II until, in 1958, a number of open-hearth furnaces were tapping heats of 300 to 350 tons. Republic Steel Corp. tapped up to 425 tons into a single ladle in its Cleveland plant. National Steel Corp., at Weirton, W. Va., tapped 500-ton heats into two ladles through a bifurcated spout. The latest furnace has a capacity of more than 600 tons.

Because of pit, crane, and runway limitations, some companies, notably Bethlehem Steel and U. S.

Steel Corp., have enlarged hearths of existing furnaces to capacities of 300 to 350 tons and are tapping these heats through bifurcated spouts into two ladles. Tons per hour of such converted furnaces is reported to be 25 to 40 pct higher than it was before the change was made.

Waste-heat boilers

In 1910, the first waste-heat boilers were installed on a 65-ton open-hearth furnace in the South Chicago works of the Illinois Steel Co. These were Heine water-tube boilers. As time went on and plant steam requirements increased, especially after fuel oil began to be used for combustion, waste-heat boilers were installed on many new open-hearth furnaces. In the early years, probably owing to draft fan limitations, steam at times was made at the expense of furnace production. In modern shops, oversized draft fans prevent this waste.

Oxygen in steelmaking

Oxygen is reported to have been first used to open tapholes in 1906. Because of its high cost, the adoption of this labor-saving commodity was slow. Today, however, an open-hearth shop, with management's accent on minimizing delay and increasing efficiency, could not function properly without the use of oxygen. It is used for preparation of scrap, maintenance work in the shop and on the open-hearth floor, as well as for tapping and teeming heats of steel. It is now customary to pipe gaseous oxygen to all parts of an open-hearth shop.

Oxygen may be injected through wicket holes in charging doors at a rate of 15,000 cu ft per hr or more to melt down scrap iron or, later in the heat, to reduce the carbon content of the molten metal quickly. Such a procedure increases tons per hour, reduces the use of expensive feed ore, and improves quality.

During recent years in some shops, oxygen has been successfully injected with the fuel into the hearth through specially designed end burners. This practice shortens the flame and increases its temperature, thus speeding up the melting rate.

In a few plants, oxygen has been injected into the furnace through permanently located auxiliary lances in each of the four corners of the furnace hearth. Such an installation is helpful in increasing production, especially in furnaces using low-pressure natural gas as a fuel. An overall improvement of 10 to 15 pct in tons per hour is possible when oxygen is injected in this way.

Prior to the 1957-58 recession, several operators had experimentally installed an oxygen lance extending down into an open-hearth furnace near the center of the roof. Such a lance helps to speed up melting of the charge without floor delays and to reduce the carbon in the metal bath. Fantastic increases in production, ranging up to 40 pct at some plants, accompanied by an increase in refractory cost of about 10 pct, have been reported.

Experiments have been made whereby hot metal, as it comes from the blast furnace, is blown with oxygen coming from lances located in the bottom of the furnace trough. The object is to reduce the silicon content of the metal. The hazards are: uncertain analysis, high temperatures, and difficulty in handling the resultant siliceous slag.

In other shops, attempts are being made to remove all the silicon and at least part of the carbon from hot metal. High-pressure oxygen is blown onto the metal in the open-hearth transfer ladle before the metal is poured into the open-hearth furnace. This practice increases metal temperature and eliminates considerable silica from the charge. Furnace additions of limestone can be reduced. Flushing operation is unnecessary, and tons per hour may be considerably increased.

Electric cranes

The first crane driven by electric motor appears to have been built in 1881. It had a single motor supplying power to various motions through a square shaft. From that time, electric motors have been used in steel plant work and for crane services to an increasing extent. It is believed that the first crane having a separate motor for each motion was built in 1889. Thereafter, a number of electric cranes were built for iron and steel companies.

Prior to 1891, electric cranes had been installed at the plants of Wellman Iron & Steel Co., Thurlow, Pa.; Jones & Laughlin Steel Corp., Pittsburgh; Carnegie, Phipps & Company's Homestead works, Munhall, Pa.; the Johnson Co. Rolling Mills, Johnstown, Pa.; Central Iron Works, Harrisburg, Pa.; and Penn Steel Castings & Machine Co., Chester, Pa.

Some of these cranes may have been used in open-hearth pits as ladle cranes. However, the first reference to a crane actually being designated as a ladle crane for open-hearth pit work was a 60/15-ton 58-ft 8-in. span ladle crane built for the Homestead works in 1897.

The first double-drum ladle crane similar to the basic design of today was built in 1903 for the Alan Wood Steel Co., Conshohocken, Pa. It was an 80/25-ton, 55-ft 2-in. span crane. Today, 4-girder, 500/125-ton ladle cranes have been installed in some of the most recently built shops.

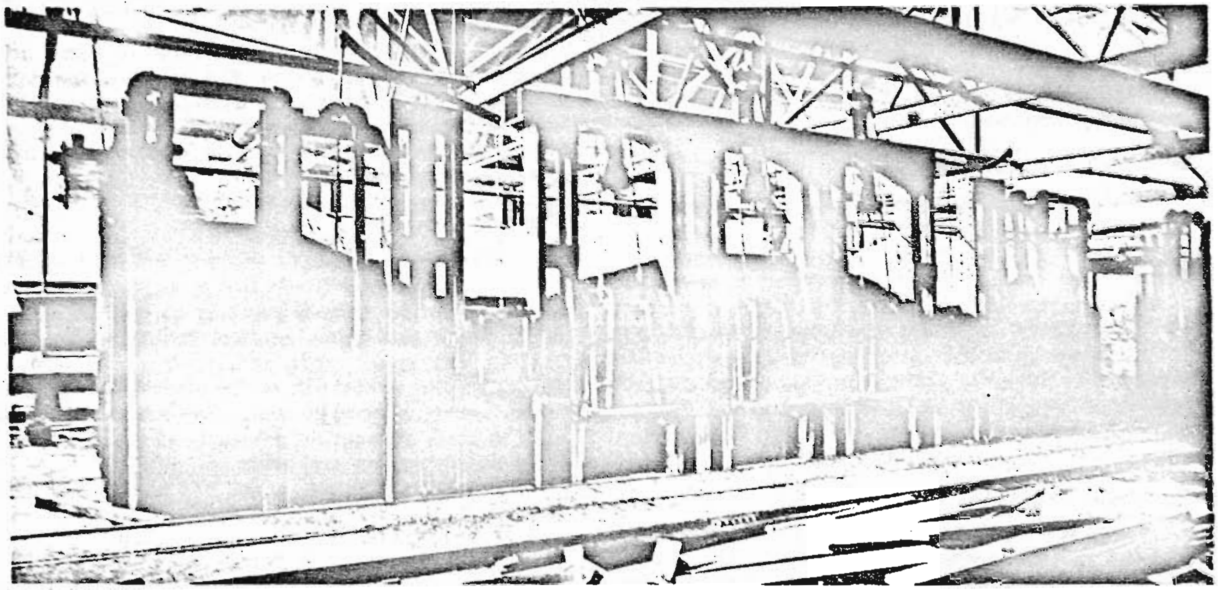
Electric charging

Manpower began to give way to electric charging machines in the early 1890's. It is known that a 5-ton, 3-motor charging machine was built for the Edgar Thomson Steel Works, Braddock, Pa., in 1893. A 7-ton floor-type charger was installed at the Sharon Steel Co., Farrell, Pa., in 1900.

In the next few years, electric charging machines were installed in all open-hearth shops. Charging time was greatly decreased, delays reduced, and tons per hour greatly increased.

It must not be thought that these machines solved all the steel operator's delay problems. The early electric motors, cranes, and chargers were crude, slow, and often inefficient. Breakdowns were frequent and usually came at inopportune times. Electrical and mechanical crews were poorly trained, or not trained at all. Repairs by trial and error were the order of the day.

Breakdowns of ladle cranes were particularly serious. Large skulls often were formed in the ladle. Running stoppers were common occurrences. At times, entire heats of steel froze completely in the ladle as a result of a long delay, making it necessary to dig out the ladle brick laboriously before the chunk could be dumped from the ladle. It was customary to jack such masses of steel from railroad flatcars and bury them in the plant yard.



No. 1 furnace at the Cambria Open Hearth Shop, Cambria, Pa., about 1910.

STEELMAKING / U.S.A.

Part III of a four-part series on the history of steelmaking in the US, describes furnace developments, improvements during the last few decades, and the contribution of the AIME.

by Leo F. Reinartz

THE invention of the dolomite machine was a great boon to the open-hearth furnaceman. By speeding up bottom making, it helped to increase tons per hour and decrease cost. The first homemade unit was built and operated before 1925 at the South Side works of Jones & Laughlin Steel Corp., Pittsburgh. The first commercial machine, similar to those known today, was built for the Donner Steel Co., Buffalo, N. Y., in 1925.

Heavy slab buckstays, 6 in. by 15 in., supplanted lighter I-beam buckstays as furnace framework in the middle 1920's. They greatly improved the rigidity of the furnace binding.

Although the first sloping back wall had been installed prior to 1920 on a small basic open-hearth foundry furnace at Columbus, Ohio, the impetus to install such back walls universally in ingots shops came after S. Naismith installed the first one on an open-hearth furnace at Illinois Steel Company's South works in June 1924. Before that event, back-wall life had already been improved somewhat by the use of chrome rock or metal-encased basic brick.

Here again, these changes heralded major forward steps in furnace design, decreased costs, increased production, and improved safety and working conditions on the back standing of the furnace.

Fuels

Up to 1930, a number of different kinds of fuel were used to melt and refine steel in American open hearth furnaces. During World War I, powdered coal was used in a few plants as an open-hearth fuel, but because of the high sulfur and ash content in the coals, many operational difficulties arose. There were also dust, explosion, and accident hazards, so that after the War its use was discontinued.

In some steel-manufacturing centers, natural gas was available as a fuel and gave good performance.

In most steel-manufacturing centers, operators had to rely on producer gas made from bituminous coals in producer gas houses. Low-sulfur, low-ash, high-fusion coals required for the manufacture of such gas were not readily available. The quality of producer gas was uncertain. The gas had to be preheated. Maintenance problems connected with the use of this fuel were serious. Tons per hour per month was unsatisfactory.

Although petroleum had been first discovered by Edwin L. Drake at Titusville, Pa., in 1859, it was not until the early 1930's that heavy fuel oil residues for open-hearth use began to appear on the market. They were cheap; the calorific value was high, and it was not necessary to pass this fuel through the checkers to preheat it. Various plants began to use such oil as an open-hearth fuel. Others used it in combinations with tar, coke-oven, and/or blast-furnace gases. Because of its low calorific value, blast-furnace gas had to be preheated in the checkers.

These fuels were cleaner and more dependable than producer gas. The dirty gas house adjacent to the open-hearth shop was no longer needed, and

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with it went many serious personnel and maintenance problems.

Long, water-cooled ports, which were difficult to maintain, could be reduced in length or entirely eliminated. The hazard of an interchange of gas and air through uptake walls was gone. Hearths could be lengthened to increase their capacities 20 to 30 pct. Air and gas checkers could be used to preheat the incoming air for combustion. Larger heats and more tons per hour with lower fuel costs and less furnace maintenance were made possible by such changes. The morale of furnace personnel was improved.

While producer gas was used, furnace operations depended on the skill of the first helper. Earlier than 1915, fuel control was erratic. Roof life was low. End walls, downtakes, and checkers were overheated. Day-by-day quality, based on modern standards was not uniform. Furnace sealing and insulation were almost unknown. Tons per hour were low because of excessive brick repairs and other delays.

Furnace and ladle brick

Silica brick first appear to have been made out of quartz pebbles and Sharon conglomerate, with lime as a bond, at Akron, Ohio, in 1866.

Since 1926, many improvements in the manufacture of silica brick have been made. Brick have been powder dry-ground instead of in a wet pan; powder-pressed dry; grains pre-sized; tunnel-kiln fired. All these operations are now under close chemical, physical, and temperature control. In 1940, low-alumina, superduty silica brick were put on the market. They contain less than 0.5 pct alumina, titania, and alkalies.

Present day silica roof brick have enough strength to withstand arch stresses and, at the same time, can withstand the corrosive action of basic dust and iron oxide fumes as well as high temperatures. The rib-type construction has been adopted almost universally. Roofs are thicker near the skewback channels than in the center of the furnace.

The first magnesite brick were made in 1895 by the Fayette Mfg. Co., Layton, Pa., using Austrian and Grecian magnesites.

The first chrome brick were made by the same company in 1896. At first, they were used as a neutral zone between silica walls and the basic banks in furnace hearths. In 1913, at the Phoenix Iron Works, Pheonixville, Pa., N. E. McCallum first installed magnesite brick in a back wall. Steel plates were used between the rows to help hold the brick in place when heated to furnace temperatures. Later on, magnesite was rammed into short boiler tubes. These were then used in back-wall and end-wall construction.

The first unfired basic brick were manufactured in 1923. Such brick contained about 65 pct magnesite and 35 pct chrome ore bonded with a little silicate of soda. Later, improvements in brick manufacture were made by better selection of raw materials, better grain sizing, use of metal containers, and so forth. These were the forerunners of the modern Metal-kase basic brick, which are often used whereever extreme heat and corrosion occur in the furnace.

Main basic roofs, arched or flat, have not advance as far as basic-end, back-wall, and front-wall construction. Basic roofs must be suspended from special hangers. Brick must be held together by tie rods and powerful tangential springs at front and rear skewbacks in order to equalize stresses in all parts of the roof. To prevent spalling, basic roof brick must be kept at as high a temperature as possible, preferably up to 2900°F. This is especially essential during bottom making.

The all-basic furnace allows improved combustion. Oxygen can be used with fuel for combustion. High fuel input throughout the complete melting cycle may be maintained. Preheat temperatures are high. Monthly ingot tonnage is high because of increased furnace availability and tons per hour.

Checker chamber roofs on new furnaces and on many modernized furnaces are flat and brick are suspended. High heat-withstanding, fireclay, superduty brick are used in such construction.

High-quality fireclay brick continue to be used for most checker chamber installations because they are highly refractory, have volume stability and resist spalling. Where firing rates have been stepped up in modern furnaces, high-alumina fireclay brick or basic brick have been installed in the top 8 to 12 courses of checker chambers, to resist temperature and dust slagging action. To date, their economy has not been universally acknowledged.

Ladle brick usually are not as refractory as furnace brick. They must resist spalling when sudden heat is applied and swell enough to close cracks between the bricks. In recent years, much has been accomplished by the manufacturers to improve the quality of ladle, sleeve, and nozzle brick. Stoppers continue to be made out of graphitized fireclay. More refractory materials are used only when extreme cleanliness is required, for example, in the manufacture of high-grade alloy steels.

Instrument control

Instrument control prior to World War I was limited to a few steam gages and other gages. In those days, fuel consumption in hot-metal shops was often more than 6 million Btu per ton. In cold-metal shops, this figure went up almost to 10 million Btu.

As time went on, instrument control increased and gradually improved. Furnace crews received better training in combustion and furnace control. Fuel systems were more flexible and adaptable. Furnaces were sealed and insulated. Year by year, the fuel consumption in open-hearth furnaces has come down. Today in modern shops using 50 pct or more hot-metal in the charge, it is a common occurrence to record the use of less than 3 million Btu to melt and refine steel. Progressive cold-metal shops can boast of less than 4.5 million Btu per ton.

National Open Hearth Committee

During the year 1925, an unheralded event took place in Pittsburgh. The American Institute of Mining Engineers, known as AIME, had been organized as a mining society in 1871. In 1919, the metallurgists joined this society and the name became American Institute of Mining and Metallurgical Engineers (but still AIME). An important part of the latter's activities was connected with the technical phases of iron and steel manufacture.

Organization

J. V. W. Reynders, a prominent consulting engineer, bridge builder, and a former vice president of Bethlehem Steel Co., was the President of AIME in 1925. He had an idea that open-hearth operators and metallurgists of smaller, independent steel companies would profit by meeting and discussing operating, maintenance, and quality problems in the same manner as had been done for many years by the Bethlehem and U. S. Steel Corporations.

He invited the presidents of independent steel companies to send representatives to Pittsburgh to determine whether a similar group could be formed. Twenty-six operators and metallurgists met in the William Penn Hotel in May 1925, to discuss this subject. They endorsed Mr. Reynders' proposal enthusiastically and immediately organized a practice committee which, in short time, became the National Open Hearth Committee of the AIME. Since then, national conferences have been held each year.

Growth

Some time after this committee began to function the Blast Furnace and Raw Materials Committee of the AIME accepted an invitation to join forces with the National Open Hearth Committee in the annual Conference, to the mutual benefit of the two groups.

Over a period of years begining in 1936, ten regional sections of NOHC have been organized. All are active. Each holds one or more technical and social meetings each year. The attendance at annual conferences has topped 1800. (attendance in 1959 was 1560) Regional meetings draw an additional 4000.

Effect of Conferences

The papers and discussions presented at the national meetings, as well as the informal discussions between sessions in the hallways and in the hotel rooms, have been valuable to individuals as well as to the companies they represent.

Through the years these conferences have mirrored, spark-plugged, and recorded the advances in the art of steelmaking. In fact, during the restricted travel days of World War II, the national committees were permitted to hold meetings because government officials believed their discussions were important for the war effort.

The yearly Proceedings of the national conferences have chronicled the improvements made in the steel industry, and also have recorded the results of experiments that did not turn out so well. They have become the repository of most of the accumulated knowledge and practices of basic steelmaking in the United States since 1925. Scientists, metallurgists, suppliers, and operators, young, and old, meet on an equal footing in these conferences to discuss their mutual problems. Throughout these years many lasting friendships have been formed.

Perhaps the passage of years mellows our memory so that we look back with nostalgic remembrance on the events of long ago. It is true, nevertheless, that many colorful and interesting men took part in the early deliberations of the National Open Hearth Conferences. Most of them had come up through the school of hard knocks as furnace helpers, melters, and superintendents. The names of only a few can be cited, as the list is long. The majority have either retired or gone to their reward but they have left behind the imprint of their forceful personalities:

Operators: "Major" T. W. Mills, Granite City Steel Co., T. T. Scott, Sr., Sheffield Steel Co., L. E. Yost, Corrigan-McKinney Steel Co., John Gething, Laclede Steel Co., E. L. (Buck) Ramsay, Wisconsin Steel Co., William Kitto, Pittsburgh Steel Co., F. A. King, Weirton Steel Co., R. L. Levantry, Republic Steel Corp., S. B. Muir, Donner Steel Co., Clem Collinswood, Stanley Works, W. A. Maxwell, Inland Steel Co., A. W. Smith, Youngstown Sheet & Tube Co., Jerry Walters, Lukens Steel Co., J. M. Hughes, Sharon Steel Hoop Co., H. B. Hubbard, Inland Steel Co., A. R Maxwell, Pittsburgh Steel Co., E. A. Whitworth, Boure-Fuller Co., F. B. McKune, Steel Company of Canada, J. R. Mountain, Trumbull Steel Co., H. A. Young, Allegheny Steel Co., J. H. McElhinney, Lukens Steel Co., K. C. McCutcheon, Armco Steel Corp., G. D. Cain, Republic Iron & Steel Co., Marion Crabtree, American Steel Foundries, G. D. Tranter, American Rolling Mill Co., K. V. McCausland, Wickwire Spencer Steel Corp., T. J. Costello Follansbee Company.

Metallurgists, combustion men, and others: Dr. C. H. Herty, Jr., US Bureau of Mines, Prof. W. J. McCaughey, Ohio State University, H. V. Flagg, American Rolling Mill Co., F. E. Leahy, Youngstown Sheet & Tube Co., J. N. Nead, American Rolling Mill Co., W. J. Fleming, Andrews Steel Co., L. B. Lindemuth, Lindemuth & Carney Co.

No attempt has been made to cite the names of all those who are still active in the steel industry. It is interesting to note how many company names in this list have disappeared or have been swallowed up by mergers and other combinations.

Suffice to say that the National Open Hearth Steel Committee of AIME owes a great debt of gratitude to those, living and dead, who helped to lay the foundation of this great movement.

(Mr. Reinartz is too modest to mention his own contributions. He was foremost in the work of forming the Committee and served as its Chairman for 18 years (from 1927 to 1945).—Ed.)

Advances in industry recorded

Improvements made in open-hearth design and practice prior to 1925 have already been cited. The records of the Open Hearth Committee between 1925 and 1945 show the installation of chrome-ore subhearths; rammed basic bottoms, sealing and insulation of furnaces below floor level, the introduction of rigid binding with large slab buckstays, improved instrumentation and furnace controls, better mold design, improved ladle refractories, vertical stopper-rod ovens and better pit practices, oval all-welded ladles, improved refractories (silica, fireclay, and basic brick), the use of powerful diesel locomotives, improved auxiliaries, and many other items.

In the control and improvement of quality, discussions have been held with reference to residual nonferrous metals in scrap iron; effect of hot-metal temperatures and analyses; effect of iron oxide in slag and metal; methods of preventing segregation, inclusions, and excess gases; use of mechanical aids such as viscosimeters, slag cakes, pyrometers to improve slag and metal control, and other control methods; manufacture of hot-topped and deep-drawing steels.

Discussions with reference to quality were usually led by Dr. Charles H. Herty, Jr. Because of his brilliant, practical efforts and those of a number of other young metallurgists, open-hearth superintendents and furnacemen gained a nontechnical insight into the quality requirements of modern steel users and a greater appreciation of their needs. Tney learned how to improve quality by slag and metal temperature as well as combustion and analysis control, together with careful furnace manipulations.

This knowledge was put to excellent use during World War II, when demand for specialty open-hearth steels increased by leaps and bounds, which necessarily led to an unprecedented increase in open-hearth production during war days.

Upward spiral in steel industry

After a slight pause in building new capacity following the end of the war, by 1950 this upward spiral began again at a rapid pace. The consumption of steel per capita increased from about 300 lb in 1900 to almost 1400 lb in 1957. Ingot capacity figures released by the American Iron and Steel Institute record a total US steelmaking capacity of 147,633,670 net tons as of Jan. 1, 1959, of which more than 87 pct is basic open-hearth steel.

The unprecedented postwar demand for steel had many causes. Some of them were: 1) the need to catch up on restricted civilian requirements caused by the war, 2) the urgent need for rehabilitation of devastated Europe, 3) the public's increased demand for the products of industry: automobiles and trucks, airplanes, steel pipelines, transportation, home and office appliances, highways, air conditioning, steel buildings, and many others—the marvel and envy of all the other peoples of the world, 4) the new technology: radios, television, electronics, nuclear fission, jet planes, rockets, and guided missiles, plus the breathtaking predictions for space conquest, 5) the Korean War interlude with the public's demand for "butter and bullets", 6) the phenomenal increase in chemical, petroleum, and related industries, 7) the increased crop of new citizens, 8) fewer hours of work, leaving more time for leisure, do-it-yourself jobs, moon-lighting, and recreation.

Notable advances

During the past 10 years, notable advances have been made in open-hearth furnace design and operation which have increased production, improved quality, and reduced costs. Only a few can be listed here.

1. Furnace hearths are being widened and lengthened. Roofs have been raised. Basic front and back walls are universally installed. Extensive experiments are going on in many plants using all-basic ends, baic roofs, and checkers capped with basic or high-alumina brick, permitting more heat units per hour from the fuel burned, especially during charging and melting periods.

2. Charging pans have been enlarged, some up to 75 cu ft capacity. Open-hearth doors have been necessarily enlarged. Scrap iron is prepared so that in many intergrated hot-metal shops charging time does not exceed 1 to 1½ hr. In one plant, scrap is being brought to the charging floor by means of elevators, one buggy at a time. Each furnace is a unit by itself. Floor delays have been greatly reduced and tons per hour of furnace increased.

Another plant is testing a new device that does away with many charging cars and pans on the charging floor. Scrap iron is charged by means of a magnet directly from 50-ton cars into a chute in front of the furnace. The scrap iron drops through the chute into a charging pan on one car and is quickly charged into the furnace.

3. Combustion control has received much attention; flame velocities have been increased, thus more Btu are burned per hour. Large furnaces using some oxygen have approached a production of 50 tons per hour. A number of shops use high-pressure natural gas to atomize fuel oil in open-hearth furnaces.

4. A new phenomenon is the increasing use of low-cost oxygen tonnage in open-hearth shops for maintenance, combustion, and carbon reduction.

5. Over a period of years, heat sizes in some plants have increased beyond ladle crane, runway, and ladle capacities. These larger heats, therefore, are being tapped through bifurcated spouts into two ladles. Increases of 20 to 40 pct in tons per hour, depending on furnace size, use of oxygen, and local conditions, have been reported.

6. Use of jet tappers and autopour devices has increased reliability and safety in handling molten metal in open-hearth pit operations.

In addition, a number of other outstanding developments in recent years might be cited:

1. Improved methods of repairing and rebuilding open-hearth furnaces in record time by the use of bulldozers and traxcavators, elevators, machines to remove roof brick from furnaces, air washers and fans to cool open-hearth floor and furnaces, during repair times, gravity and power conveyors, metal centers for roof installations, powerful explosives, and others.

2. The incorporation in new furnace designs of large single-uptake slag pockets, suspended chill walls, fantail roofs and noses: suspended flat checker chamber roofs; two-pass and three-pass checkers, and soot blowers.

3. Redesigned fuel burners for higher heat input per hour and use of oxygen for combustion.

4. Improved furnace refractories and the development of an efficient gun with which to patch furnace interiors.

5. Automatic reversal of valves, large fans for sufficient combustion air, and adequate draft.

6. Increased use of instrumentation: air:fuel ratio control, roof and checker temperature control; indicating and recording meters for steam, fuel, air; immersion couples, telautographs, high-temperature optical pyrometers.

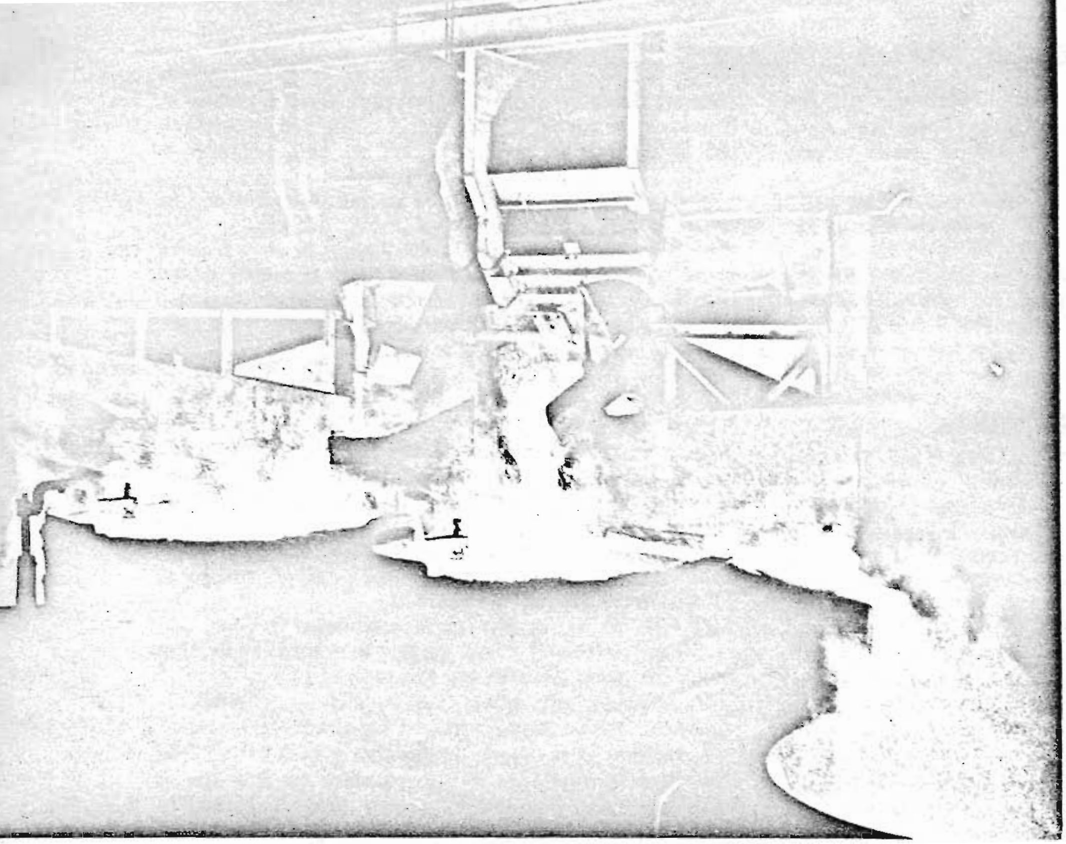
7. Improvement in hot-topping big-end-up ingots for quality improvement in forging and alloy steels.

8. Improvement in the manufacture of deep-drawing, non-aging steels for automobile manufacture, and oriented silicon steel for transformer and other electrical uses.

9. Standardization of all phases of operations and metallurgical control.

10. A greater appreciation of the value of good maintenance, training, and safety in open-hearth operations.

These are only some of the methods and equipment used in modern open-hearth shops to bring this process to its high state of perfection. Improvements will continue to be made in the future as in the past because of the intelligent work of all those who have anything to do with steel manufacture.



Tapping a 600-ton heat from the world's largest open hearth, at Weirton Steel Co., div. of National Steel Corp., Weirton, W. Va.

STEELMAKING / U.S.A.

This is the fourth and final installment of Leo Reinartz' summation of the steelmaking industry over the first one hundred years.

by Leo F. Reinartz

Although basic open-hearth steel has been in the limelight for many years, it has had to share some of its glory with two lesser but nevertheless important rivals, one 50 years old and one a rejuvenated process.

Electric steel

Electric-steel manufacture began in a humble way in the United States in 1906, when the first heat was tapped from a 3-ton Heroult electric furnace at the Halcomb Steel Co., Syracuse, N. Y.

During the intervening years, it has completely eliminated the crucible process. For many years electric melting furnaces were located predominantly in relatively small, nonintegrated plants, making all kinds of high-grade alloy steels. Most of these furnaces, with capacities ranging from 5 to 20 tons, had basic bottoms. During and after World War II, many large basic electric furnaces, some up to 200 tons in capacity, were installed in integrated plants to make commodity steels.

There were several reasons for building electric furnaces. Capital investment per annual ton of capacity was low and furnaces could be installed quickly. Since these furnaces used mostly scrap iron in the charge, no extra expensive coke- and blast-furnace capacity had to be added. The perfection of the top-charging design, and the development of large transformers and furnaces, made possible tons per hour as high as from modern 350-ton open-hearth furnaces.

Electric furnaces have high availability and repair costs are low. The process is flexible. Alloy and plain carbon steels of high quality can be made. Where power costs are low, the operating cost can

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approach that of the open-hearth, especially if all-cold-metal shops are being compared.

The process has several serious handicaps. Because of the high scrap charge, the total ingot cost is subject to the vagaries of the scrap market. Electric furnace ingots contain most of the tramp nonferrous metals that come into the charge with the scrap iron. Recently a new process for scrap iron preparation, developed in the southwest United States, indicates it can materially reduce the percentage of tramp nonferrous materials. Costs of electric power are high in many parts of the US.

The rated capacity of the electric furnace melting units on Jan. 1, 1959, was 13,495,130 net tons, or a little less than 10 pct of the annual US steelmaking capacity.

It is interesting to note that during the past 25 years, the bessemer steel capacity of the country has declined, until, on Jan. 1, 1959, its rated capacity, excluding oxygen converters, was only 3,577,000 net tons, or 2.4 pct of the total US steelmaking capacity. The greater part of this production is used as blown metal in open-hearth furnaces as part of the duplex process. The steel resulting from this practice is apt to be high in nitrogen and, therefore, not suitable for certain uses of high-grade steel.

The LD process

Not until 1950 did another process for making steel come into the picture. In that year a pneumatic process using pure oxygen as a fuel was started in Linz and Donawitz, Austria, soon known in the United States as the LD process. High-purity oxygen at high pressure (150 psi) was blown from above onto hot metal and scrap iron, which had been charged previously into a basic-lined, solid-bottom bessemer-like vessel. The charge could be melted and refined in about 40 minutes.

Capital expenditures to build such a plant were relatively low; steel of good quality, low in sulfur, phosphorus and nitrogen, could be made very rapidly at lower operating costs than in open-hearth furnaces. Depending on the silicon content and temperature of the hot metal, scrap iron up to 35 pct of the total charge could be added.

Since then, in North America, Dominion Foundries & Steel Co., Hamilton, Ontario, Canada, and McLouth Steel Co., Detroit, have installed, and are successfully operating larger LD units. Late in 1957, Jones & Laughlin Steel Corp., began operating the largest LD converter in the US, at Aliquippa Pa. Algoma Steel Co., and Kaiser Steel Corp., began to operate units having capacities of from 90 to 100 tons, during the latter part of 1958.

These converters are expected to produce 80 to 100 tons per hour, thus becoming the highest tonnage producers in the steel industry. Acme Steel Co. has recently built a combination hot-blast cupola and 40 ton oxygen converter system of new design.

Jones & Laughlin Steel Corp. has announced plans to build a new LD plant at their Cleveland works. Converters will have a capacity of at least 160 tons.

Other pneumatic oxygen-furnace units have been developed in recent years in Europe, particularly to melt and refine high-phosphorous hot metal; namely, the *Kaldo* process in Sweden (see JOURNAL OF METALS, July 1957, p. 972) and the *Rotor* process in Germany (see JOURNAL OF METALS, November 1957, p. 1435). Since these processes do not seem to be adaptable to American practice at this time, they will not be discussed here. It may be that some day in our country one or the other of these processes may be adapted to desiliconize and decarburize hot metal for speeding up open-hearth and/or electric-furnace production.

Notable steel companies

During the second half of the 19th century, numerous small, independent steel companies, some of which have been mentioned herein, were organized and began to operate in a number of cities east of the Mississippi River. Some of them operated for a while quite successfully, but adversities in the form of recessions, prolonged strikes, changes in steelmaking processes or practices, constantly cropped up. Those were days of ruinous, cut-throat competition. Many companies fell by the wayside or, with bewildering swiftness, were swallowed up by changes in ownership. There was no stability in steel markets. One wonders how any of them ever prospered.

It is not within the scope or the province of this paper to chronicle in detail the developments of basic steelmaking in each of those companies. However, it is desirable to mention the beginning dates of some major steel companies in our country, together with the names of the stalwart, courageous, and forward-looking men who had the most to do with bringing them into existence.

During the nineties

During the decade of the 1890's many discussions on how to bring order into the chaotic steel situation took place. Joseph E. Block and associates decided to organize the Inland Steel Co., Chicago, in 1893. The Indiana Harbor Works was built under the leadership of L. E. Block in 1901.

The Colorado Fuel & Iron Co., founded in 1872, was reorganized in 1892. Its main plant is at Pueblo, Colo. Its predecessor, the Central Colorado Improvement Co., in Denver, was incorporated by a man of vision, General William J. Palmer.

Armco Steel Corp. was incorporated in 1899. Under the benevolent leadership of George M. Verity, it started in a very small way in 1901 as the American Rolling Mill Co., at Middletown, Ohio. In 1930 it took over Sheffield Steel Corp. The name was changed to Armco Steel Corp. in 1948.

Republic Iron & Steel Co. started operations in 1899 at Youngstown, Ohio. In 1930, with the dynamic leader Thomas Girdler at the helm, Republic Steel Corp. was organized. Central Alloy, Donner, Bourne-Fuller, and Witherow steel companies, and the Interstate Iron & Steel Co. were merged with the Republic Iron & Steel Co. to form this corporation.

Late in the 1890s, a number of bankers, lawyers, and steel men decided that the times were propitious for the formation of a large steel corporation. Their object was to produce steel more efficiently and economically by what has since become known as integrated operations. They hoped to help bring greater stability to the steel markets.

Turn of the century

A few years prior to 1900, Judge Elbert Gary had been responsible for the formation of the Federal

Steel Co., in Chicago. J. Pierpont Morgan and John W. Gates, noted New York bankers, also were interested in the formation of a large steel corporation that would have under its control all the operations from mine to markets. This combine, they hoped, would operate iron-ore and coal mines, limestone quarries, iron-ore shipping facilities, steelmaking, and fabricating plants.

Charles M. Schwab was a rising young steel magnate, who had become president of the Carnegie Steel Co. in 1897. He interceded with Andrew Carnegie, the colorful steelmaker of Scotch descent and principal owner of the company, to sell his interest in the Carnegie Steel Co. to the proposed combine headed by Judge Gary.

Thus in 1901, the giant US Steel Corp. was organized, joining the Carnegie companies with the Federal Steel Co. and others to form the first billion dollar corporation in the world. Mr. Schwab was elected as the first president, and Judge Gary became the first chairman of the board.

Among the original members of this combine were American Sheet & Tin Plate Co., American Bridge Co., American Steel Hoop Co., American Tin Plate Co., Lake Superior Consolidated Iron Mines, National Steel Co., and National Tube Co.

In 1902 Schwab severed his connections with US Steel Corp. when he bought controlling interest in the Bethlehem Steel Co. which, in its present form as Bethlehem Steel Corp., began its principal operation at Bethlehem, Pa., in 1905 with Schwab as president.

Crucible Steel Co., under the guidance of W. P. Snyder, consolidated a large number of small plants (many in the Pittsburgh area) in 1900 to form the Crucible Steel Co. of America. In the same year James A. Campbell was the dominant spirit in organizing the Youngstown Sheet & Tube Co. in Ohio. Sharon Steel Hoop Co. began operations at Sharon, Pa., in 1900.

Pittsburgh Steel Co. started its plant at Monessen, Pa., in 1901. Four years later, the Allegheny Steel Co., later to become the Allegheny Ludlum Steel Corp., began operations at Brackenridge, Pa.

Weirton Steel Co. was organized by Ernest T. Weir and associates in 1905, when it began operations at Clarksburg, W. Va. In 1929, Weir incorporated this company into the National Steel Corp., with its principal plants at Weirton, W. Va., and Detroit.

In 1912, the Laclede Steel Co. was started by T. R. Akin at Alton, Ill.

The latest of the dynamic steel leaders to start a major steel company is Henry Kaiser. His Kaiser Steel Corp. began operations at Fontana, Calif., in 1942.

Men of vision

The rapid strides made by the steel industry in the past 50 years have been due to the leadership and optimism of men of vision, energy, skill, and great courage. They were willing to explore the unknown at the risk of capital and ruin itself. They knew how to exploit the almost inexhaustible natural resources of our country. They were enterprising men who were willing to risk and spend large sums of money to find cheaper and better methods of steel production and manufacture. Last, but not least, they had a true love for their fellowmen—the workers in their plants.

Because of this interest in human beings, they encouraged plant managements and supervisors to improve the lot of the steel worker with better lighting, sanitation, and protection against heat and cold. Because of their zeal for accident prevention, the improvement in the safety record of American steel plants during the past 10 years has been truly remarkable.

In all the technical advances of recent years, the producers of steel ingots have played the star role; without quality steels in great tonnages, this marvelous progress could not have been made. Results became possible only because of the conscientious, patient, and efficient work of countless thousands of steel managers, supervisors, engineers, metallurgists, mechanics, furnace operating and repair crews, as well as the expenditure of hundreds of millions—yes, billions—of dollars invested by the boards of directors of the steel industry for the improvement of old furnaces and accessories, and for building new ones—bigger and better than ever—as well as developing new processing and finishing equipment to fabricate these ingots into commercial steels.

It has been estimated that 30 pct of the gain in ingots has come from modernization programs and 70 pct from newly installed units. Each year the horizon is pushed back as larger furnaces go into production.

Predictions

The end of this race in size may be in sight. I predict this time will come sooner than some expect, not because of the lack of efficiency or because of increased operating costs of these monsters, but simply because of economics. Like the increased capital cost of building coke ovens and blast furnaces, the capital cost per annual ton of capacity for building new, big, open-hearth furnaces is now higher than the cost of building other newer types of furnaces and processes to produce ingots, such as the pneumatic oxygen converters or large electric furnaces.

During recent years, predictions have been made freely that by 1975 the increasing requirements of American citizens will demand a capacity of steel ingots of close to 180 million tons. Every prospect pleased the steelmakers.

Then in the fall of 1957 and the early part of 1958 came an awakening. Steel production, owing to decreased demand and inventory reductions in customer's shops and other causes, dipped down to less than 60 pct of capacity. It appeared that the US, after a tremendous economic sprint, had slowed down and was taking a breathing spell. For the first time in many years, the steel industry had a considerable excess steel capacity.

However, there was little reason to believe that this recession would be of long duration. The longtime trend, because of increasing population and wants in the US, seemed to indicate that an upward surge of ingot capacity could again be expected in the next few years.

In the future, competition in the US and from abroad will continue to be keen. Progress must continue to be made in open-hearth shops to increase production from its furaces, old and new.

Future open hearth plants

Suffice to say, the great bulk of steel requirements in the US within the next 10 or more years will be made in the basic open-hearth furnaces.

Open-hearth shops will be redesigned to decrease the effects of weak spots or bottlenecks in the system. Furnace refractories and quality of brick will be improved. This will be true also of bottom and bank construction and furnace maintenance.

As long as ambitious, imaginative open-hearth supervisors exist, they will continue to lengthen, widen, and deepen present furnace hearths. Thus they can tap larger heats, if conditions permit, into one ladle, or into two ladles through a bifurcated spout. It is well known that a 1 pct increase in heat size can give an increase of 0.5 pct in tons per hour.

With driven fuel, and by increasing the Btu consumption per hour for faster melting, it is possible to raise open-hearth roofs considerably without an increase in fuel consumption.

The all-basic furnace, I predict, will become a standard design in a few years Basic roofs may be flat or arched. I believe that high, flat, suspended basic roofs will replace silica brick roofs.

By the use of elevators, large scrap cars (as in the Calderon system) or by the improvement of present equipment and practices, prepared scrap iron will be charged from large pans into the furnace to bring the average charging time down to an average of one hour in hot-metal shops and to less than three hours in cold-metal shops.

Oxygen will be used with liquid or gaseous fuels through corner, end, or roof lances to speed up melting and refining steel. Thus, firing rates will continue to increase with more tons per hour and lower Btu per ton. In the not-too-distant future, average figures for hot-metal shops should be down to 3 million Btu per ton. Some modern shops will go considerably below 2.5 million Btu per ton.

This practice can be reached by paying more attention to proper combustion control. Higher preheat of the incoming air will be assured by better checker chamber gas flow, better checker refractories, improved sealing, and insulation of the entire furnace system below the charging floor level.

Two-pass checker construction will become more popular. The first pass of such checkers will be capped with 12 to 18 courses of highly-refractive brick. Fantails will be of basic design. Soot-blowing installations and methods for the rapid removal of deposits from the *blind* pass and from between the rider walls under the checkers will be standard practice. First-pass checker temperatures will be kept in close control by radiation pyrometers.

The furnace and its auxiliaries will be completely regulated by the use of automatic combustion and furnace reversal controls, tied in with continuous sampling and analysis of waste gases leaving the furnace hearth.

It must be realized that trained staff combustion engineers will be a great help to operators in meeting these objectives.

In furnace operations, flushing practice, where it continues to exist in hot-metal shops, will be carefully controlled, regulated, and speeded up. I visualize, however, the elimination of this messy time and labor-consuming practice. The hot metal will be top blown with high-pressure oxygen in a transfer ladle, or in some other kind of intermediate vessel. All the silicon and most of the carbon and siliceous slag will be removed quickly before the hot metal is poured into the open-hearth furnace. Such practice will assure higher hot-metal temperature and a considerable decrease in the amounts of limestone and expensive iron ore charged into the furnace.

Open-hearth production will be greatly increased and conversion costs lowered. In addition, in order to help increase monthly shop production, furnace repairs must be carefully planned, scheduled, and speeded up. This can be done by the use of many labor-saving devices, by increased skill and interest in bricklaying, and by faster tear-down and heat-up times.

Trained staff metallurgists will be required to assist furnace operators in devising better methods and practices to control metal and slag temperatures and reactions throughout the refining period. Final slags will be brought into closer equilibrium with the metal. Average sulfur content in the finished metal will be lowered by the use of better raw materials and improved furnace practices. Instruments will give better control of final carbon analysis.

Pit practice will be improved. Mud in runners and ladles will be entirely replaced by better refractories. Teeming practice can and must be improved. When more information is gained relative to the flow of molten metal through nozzles, I am sure a mechanism can be developed to lower the ferrostatic pressure of the metal without loss of stream regularity as the metal enters the mold. Such an improvement will help to decrease the quality hazzards of metal splash on mold walls. Nozzles up to 18 in. long will help solve this problem.

With improved metal-temperature controls, mold life will be longer, steel stools with cast-iron inserts will be developed to decrease costs of stools.

The importance of people

The open-hearth superintendent must depend mostly on people for the successful operation of a shop in the economical production of quality steels.

Brick, mortar, and steel are important to provide buildings, furnaces, and equipment, but they are lifeless and useless until actuated by the hands, minds, and I might add, hearts, of enlightened managements, and intelligent, cooperative workers.

Management will pay more attention in the future to the proper training of supervision, techical staff, and furnace crews. They will be taught how to produce quality products at low costs in a friendly atmosphere of cooperative effort. They will be shown how to obtain maximum tonnage from existing facilities. All will be encouraged and will become interested in making suggestions for improvements in equipment and practices.

Plants will have proper lighting, sanitation, and other working conditions. Wages will continue to be paid that will be adequate to enlist the best efforts of open-hearth personnel.

Future changes

There are a number of ways in which steelmaking may be changed in future years:

1) Oxygen LD converters, because of their low capital cost per annual ton of capacity, their flexibility, low operating costs, and acceptable qual-

ity, will probably be installed in integrated plants. Steel ingots that can be delivered hot, at frequent intervals, to the soaking pits, will increase the efficency of such pits, and help increase tons per hour through rolling mills.

2) Electric melting furnaces will continue to increase in size. Furnaces of 300 tons capacity, having six electrodes and transformers with large capacity are possible. Here again, the capital cost per annual ton of capacity is considerably less than for similar output from open-hearth furnaces.

In addition, coke plant and blast furnaces, under certain conditions, may not be required for the economical operation of electric furnaces. In non-integrated, cold-metal shops, present day modern electric furnaces can hold their own with open-hearth furnaces in ingot cost per ton and in quality.

In comparison with hot-metal open-hearth practice, electric furnaces have two serious handicaps:

a) As stated before, electric furnaces in most shops are charged almost entirely with scrap iron. As a result, contamination from nonferrous metals in such scrap is a serious quality hazzard. Prolerized scrap process may help to solve this problem.

b) Ordinarily no hot metal is used in electric furnaces. The ingot cost, therefore, is subject to the violent fluctuations of the scrap market prices.

If hot metal is available in an integrated shop, in the future it may be externally desiliconized and partially decarburized by the use of oxygen. Such *wash* hot metal can then be safely charged at least up to one half the total charge into modern top-charged electric furnaces. By the use of such a practice, the already high tons per hour can further be increased. By including capital charges in cost comparisons, ingot costs usually can be brought into line with average prevailing open-hearth costs.

3) Within the next 10 years, processes will be developed to produce high-grade sponge iron, especially in favored areas, to compete favorably in limited percentages—up to 50 pct—with scrap iron charges in open-hearth furnaces.

In shops where capital funds are not available for building additional, expensive coke ovens and blast furnaces, sponge iron, up to 60 pct of the total charge, may be charged into modern, top-charged electric furnaces. The sponge iron should be compressed immediately after manufacture into briquettes having a density of over 200 lb per cu ft. This practice will assure better furnace operation and normal tons per hour compared to average scrap iron charges. If the sponge iron contains 90 pct iron and less than 3 pct gangue, ingot costs should be comparable to those of average scrap practice. The absence of nonferrous contamination in sponge iron will improve the quality of the resultant steel.

4) It is entirely possible that some enterprising individual in the future may substitute a number of oxygen lances in the roof of a large electric furnace to melt the charge and then refine the steel with electric power. Such furnaces might be 25 ft or more in diameter, having a high basic roof, equipped with large vents for fume removal.

5) With improved methods for keeping checkers clean, as well as the modern technique of sealing and insulating, together with adequate forced-draft control, we might change the design of existing open-hearth furnaces. The present slag pockets and checker chambers could be used as enlarged dust and fume-settling chambers. They would be connected on the outside to three vertical stoves, similar to those on blast furnaces. Two stoves would be in operation and one in reserve or on repair. Furnace availability and repair costs might be improved, which means more tons per campaign.

6) Future requirements for rolling and improved quality may make it desirable for steel men to vacumn-melt or cast high-grade forging-quality, high-carbon steels as well as certain alloy and stainless grades.

7) Multiple casting machines will be perfected within the next 10 years, to cast billets and slabs at a rate high enough to justify their use in some plants for special steel manufacturing.

8) If nuclear power can be harnessed some day to provide heat for use in steel melting furnaces, we may see a radically different type of furnace. It may usher in a new era in steel manufacture, undreamed of today, in which steel of uniform quality may be produced at fantastic rates.

Conclusion

The best thoughts on the design and efficient operation of present and new basic-steel melting and refining furnaces will be required by American steel producers. In the next few decades, they will be called upon to meet and prevail over the ruthless challenge of the active and inventive minds behind the Iron Curtain. It must be realized that they are pioneers, who do not let past mistakes or precedents deter their advances or use of new ideas and practices.

As we enter the second hundred years of modern steelmaking, open-hearth operators and metallurgists can be counted on to continue the forward looking, excellent work they have done in years gone by and are doing today.

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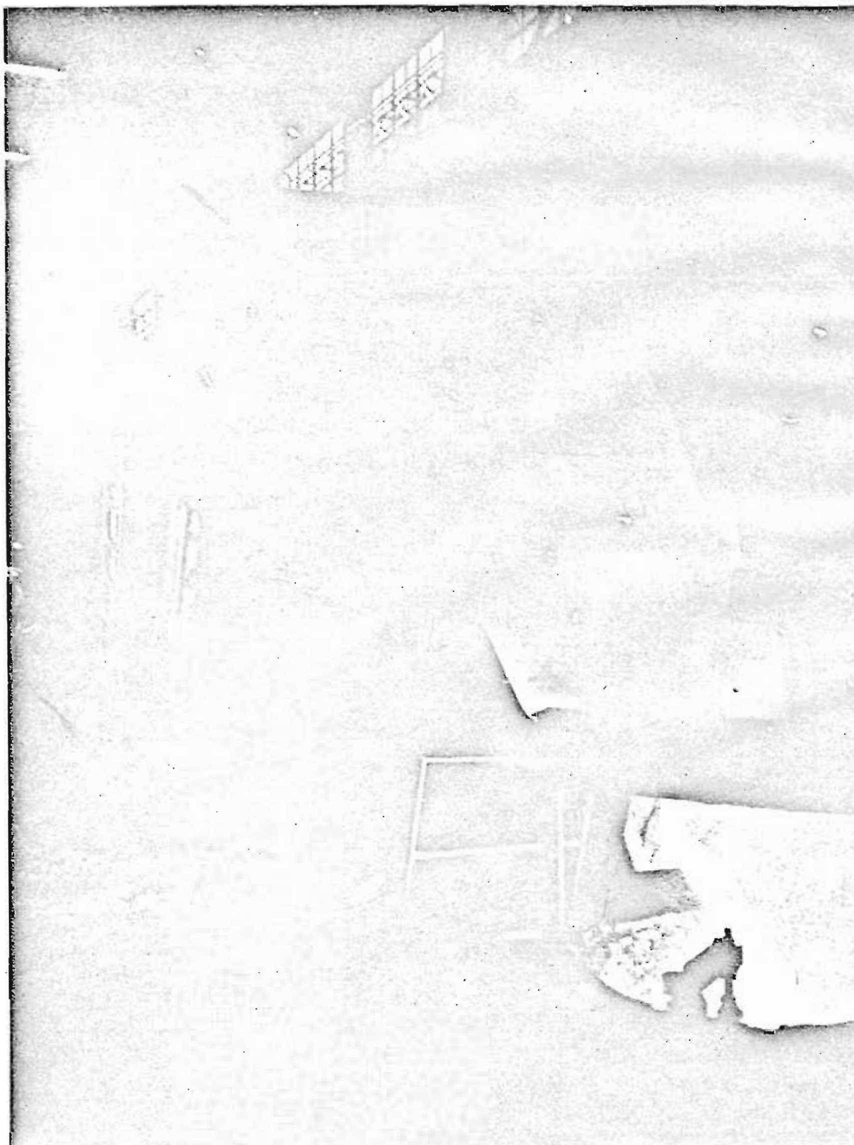
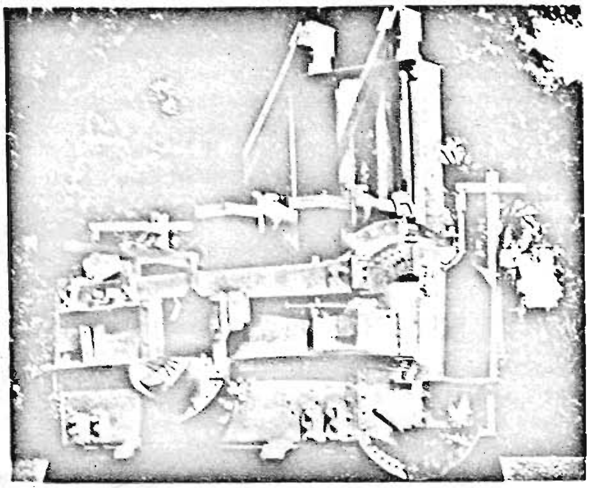
Dr. Paul Heroult, 1864-1914

The First Half-Century of Electric Furnace Steel Making

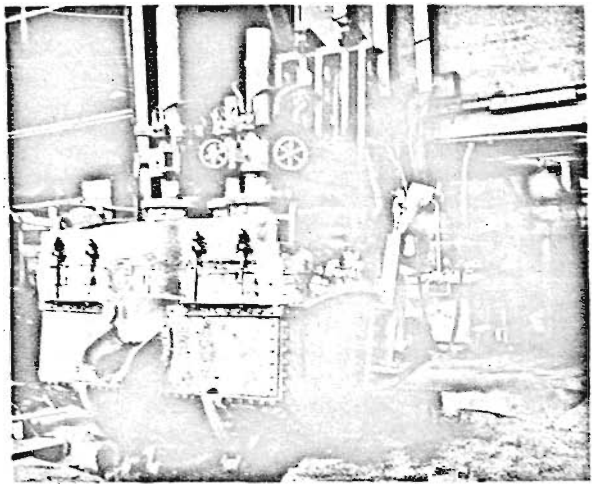
by S. B. Casey, Jr.

FIFTY YEARS OF ELECTRIC FURNACE STEELMAKING
1906
50TH
ANNIVERSARY
1956





This furnace poured the first heat of electric furnace steel in America on April 5, 1906. It now stands enshrined on its original site at the Sanderson-Holcomb Works of Crucible Steel Co. of America at Syracuse, N. Y.



The Treadwell Engineering Co. made the first electric steel castings in America with the above furnace. Initial heat was poured on November 11, 1911.

IN 1880, an electric arc was struck over metal for the first time to experiment with controllable melting. The glare of this arc has reflected on the stacks of the steel industry and continued to light the path of steelmakers in their never ending quest for faster, more economical, and better ways of producing steel.

William Siemens is credited with first employing the electric arc to melt metal in a closed hearth and produce basic metallurgical reactions. By the turn of the century, an Italian, named Stassano, was experimenting with ore reduction by the electric arc. In 1899, Dr. Paul Heroult, in France, used the direct arc principle for producing ferro-chromium. His experiments quickly led him to develop a closed-top arc furnace for the production of steel, and his first commercial shipment was recorded in December, 1900.

American steelmakers, quick to sense the possibilities of this method of melting, invited Heroult to our shores, where, in 1905, he was responsible for installing the first arc furnace on the North American continent. This furnace, at Sault Ste. Marie, was built for ore reduction. But Charles Holcomb, founder of Holcomb Steel Co. of Syracuse, N. Y. contacted Heroult in 1905 and contracted for the first American direct-arc electric furnace for steelmaking. On April 5, 1906, the first heat was tapped from this 3-ton unit. The furnace was basic lined and powered by a single-phase, 500 kw generator, producing high amperage at low voltage.

It is interesting to note that, although the first few heats were made with cold charges, subsequent heats were duplexed. R. H. Bully, first superintendent of Holcomb Steel, persuaded the directors to purchase the unit to effect a more economical and efficient means of making toolsteel by duplexing—prime melting in a combustion fired furnace, and transfer of hot metal to the arc furnace for temperature adjusting, refining, and adding carbon and alloying elements. Today, duplexing is foreseen by some as *the* steelmaking process of the future.

The promise shown by America's first arc furnace for ingot production quickly led to the purchase of a similar unit by The Firth Sterling Steel Co., in 1909, and to the purchase of the first arc furnace for production of steel castings, by the Treadwell Engineering Co., in 1911. From its humble start in 1906, production of arc furnace steel has never ceased to increase its yearly percentage of total steel production in the U. S., although certain other methods have declined or almost disappeared.

By its ability to be used intermittently, the arc furnace gained favor and enhanced its reputation during depression days. When the attack on Pearl Harbor plunged us headlong into the long days of World War II, the arc furnace stood ready, flexible enough to be overburdened hearthwise 30 pct and powerwise 25 pct, pouring its endless flood of alloy for the guns, tanks, ships, and planes which ultimately brought victory.

During the post war boom, the now proven virtues of low initial cost, faster installation, better yield, improved availability, and lower operating cost, enabled industry—particularly the small, new, independent producers—to locate strategically and profitably to meet the demand of an America that had been starved for new homes, appliances, cars, and highways.

In the Korean *police action*, the arc furnace again proved itself by providing the latest alloys metallurgists could develop to meet the demands that the jet age and the innovations of guided missiles required.

In today's peacetime prosperity, the arc furnace is continuing to provide the economic flexibility required to meet an ever increasing demand for better steel in the face of mounting costs, scrap shortages, and pressure toward decentralized location of industry.

Evolution of Furnace Design

From the original hand-charged, 3-ton capacity furnace of 1906, to the giant, top-charged, cylindrical shell of 1956, with its semi-spheroidal hearth rated at 200-ton capacity, the arc furnace has seen many interesting design changes.

Before it was a year old, the low-roofed, oblong-shelled prototype saw its first basic change when the roof was raised almost a foot from the hearth surface. A later prototype of furnace shell was cylin-

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drical and mainly of the flat bottomed, single-phase type.

Melters devised chutes and peels to speed charging through furnace doors, and ability of the arc furnace to be tilted helped to distribute the scrap. In some instances, electric furnaces were built alongside existing open hearths, and where door space permitted, they were charged by the open hearth charger. It appears possible that the traffic burden thus imposed may have served as a factor in the development of top charging.

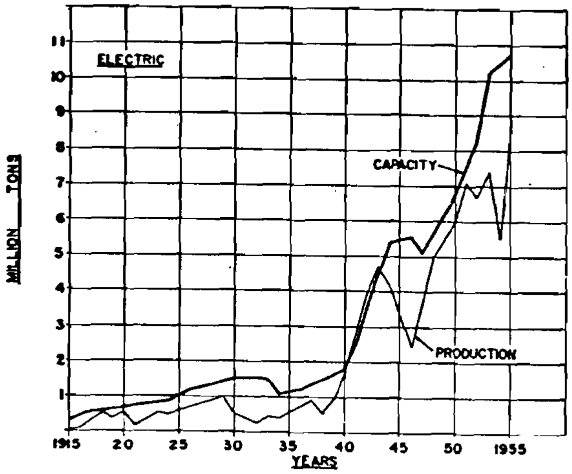
As early as 1910, U.S. Steel installed a three-phase electric furnace. But, while development of cylindrical tilting shells and three-phase equipment began the design trend toward larger furnace sizes, the greatest single impetus was afforded by top charging.

About 1920, the Snyder *coffee-pot lid furnace* appeared. It was designed to cant the electrodes and roof upwards and back, thus exposing almost half of its top to charging pans. Damage to roof and electrodes minimized the powerful effect of decreased charging time, yet this did mark a step forward.

In 1924, Swindell engineers devised the first top-charged electric furnace in which the horizontal position of the roof was maintained while it was raised and moved aside. This furnace consisted of a stationary electrode system and a two-shell turntable, one shell being tapped and charged while the other shell was in melting position beneath the electrodes. At least two of these units are still in operation.

Considerable apprehension was voiced by industry concerning the ability of the hearth, refractories, and furnace unit to withstand the impact of dropping a charge of cold metal into the open top of an arc furnace. Experience quickly showed that the hearth actually compacted if reasonably protected by *cushion* scrap placed in the bottom.

With the impetus thus afforded by a faster charging method, the number of furnace installations increased greatly. Various engineering approaches to top charging evolved the gantry type furnace, wherein the roof was lifted and swung clear of the shell by a gantry method. This method was employed by Heroult for many years and led to European versions wherein the roof was lifted while the shell was transferred for charging.



The above chart gives ample reason for optimism about the *second* half century of electric furnace steel.

Door charged units converted to top charged units in 1935 indicated that capacity was increased 11 pct, number of yearly heats increased 12.5 pct, savings in scrap cost were 5 pct, and annual production increased 25 pct with a saving of 10 pct in operating costs. In terms of manpower, the top charged furnace produced 87 pct more steel per man hour than its door charged counterpart.

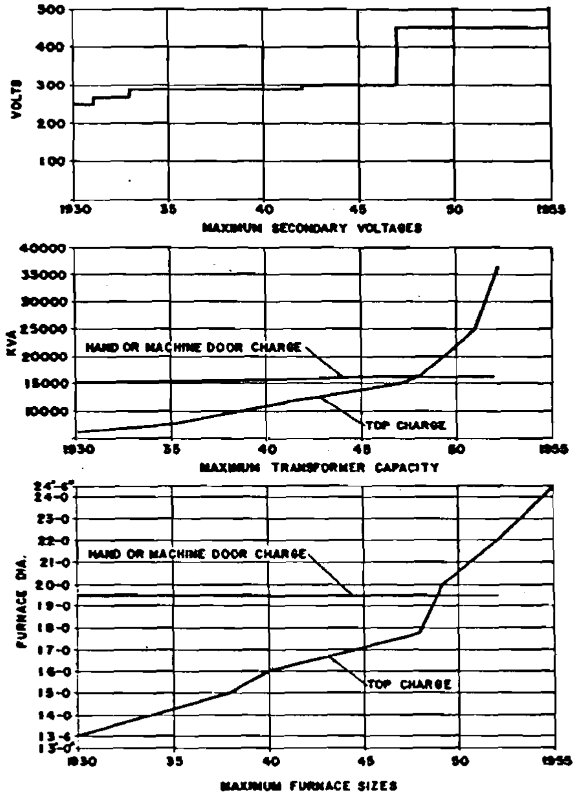
There was also a development in shell height. This 1937-1956 trend—based on 50-ton furnaces supplied to an eastern steelmaker—shows a 70 pct increase in shell height brought on by top charging.

Scrap under 90 lb per cu ft was once considered economically unusable, but the advantages of top charging allowed the arc furnace to take advantage of this less dense material. In today's accepted furnace design, the roof is lifted and swung aside hydraulically or mechanically, enabling 75-ton units to be charged in 5 to 10 min with scrap density as low as 30 lb per cu ft.

Development of Electrical Equipment

The first melters would have been better able to cope with their jobs if they had been born with three arms. Early regulators were handwheels or cranks. Motor driven winches to hoist electrodes soon appeared, and the job of raising and lowering electrodes was done by push buttons with electric lamps connected between the electrodes and ground to indicate voltage. Thus, input was shoddy, and abuse to electrodes and electrical equipment was severe.

The first three-phase furnace transformer promoted increases in furnace size and number during the early 20's. From 500 kw units and early units with single voltages of 90, 95, and 100 v, the first



Factors contributing to increased production of electric furnace steel are shown above. Note the importance played by the change-over to top charging.

no-load tap changer evolved in 1925 with a voltage range of 90 to 135 v.

During this time, oil circuit breakers, designed for transmission purposes, were used to switch power off and on, but the increasing repetitive duty brought on by tap-changing, furnace short circuits, and top charging, forced development of a true arc furnace circuit breaker, with changes in mechanical design, rupturing capacity, and interlocking.

By 1928, kva ratings increased to 7500 kva, and secondary voltages were on the order of 275 v. Delta Delta to Delta Star switching made the voltage range more flexible, and attempts were made in 1930 to use 300 v with a special bus arrangement for 500 v.

Strides in transformers and circuit breakers were being matched by developments in regulation. Push button control was replaced by the early Seede (contact making ammeter) type regulators with no consideration given to voltage. This, at least, took the 100 pct human element, represented by all manual operation, out of the equation.

Later, the AU type balanced beam regulator was developed; it is still seeing service. This regulator balanced current and voltage on a mechanical arm. It offset the ever-increasing electrode burn-off rate and the more severe melting conditions that were developing as furnaces grew bigger, transformer ratings increased, and scrap conditions grew worse.

A similar increase was developing in kva ratings for a given furnace size, and as these ratings increased, the impedance of the secondary path grew to such an extent that difficulty was encountered getting power into the furnace charge. To surmount this condition, secondary voltages were increased beyond prior bounds, and the furnace circuit was redesigned to lower its impedance. Resultant high voltages caused excessive arc lengths, and refractory costs sky-rocketed. A long period of trial and compromise between voltage and impedance resulted, but improvements in refractories and furnace proportions helped in finally solving the problem.

In 1940, the first rotary regulators were tested and installed. These regulators, based on the Ward-Leonard principle, responded instantaneously to conditions inside the furnace, and moved electrodes at the speeds necessary to combat these conditions. Since they consisted of motor generator units, they had few moving parts, thereby greatly reducing maintenance costs. Today, this type regulator is an accepted standard and affords electrode hoisting speeds up to 160 in. per min.

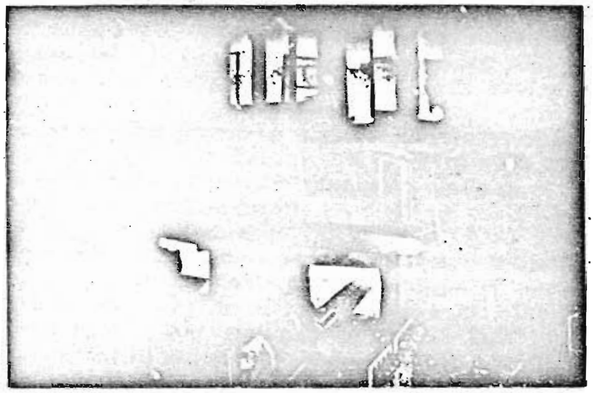
After World War II, the arc furnace air circuit breaker came into its own. Its design carried it into voltage ranges up to 34.5 kv, with rupturing capacities up to 1 million kva I.C. Being specifically designed for the highly repetitive duty demanded by today's practice, the air breaker has almost entirely satisfied the bulk of recent arc furnace breaker sales.

When furnaces of over 100-ton capacities were developed, there was little use in applying voltages under 300 v to achieve an imput of say 20,000 kva, since the impedance was such that, with increased current, input could fall below normal as the power factor dropped off. Thus, the furnaces were redesigned to lower impedance, voltages were raised, and although a study of changing frequency was considered, this trend never really got started.

Other Developments Speed Operation and Cut Downtime

As furnace diameters became larger, two doors were installed to permit ease of repair to the bottom and banks. During the 1930's, the shell also evolved from the side door type, tapping away from the vault (when deslagging was done through the spout), to a type where the furnace tilted forward for tapping, and deslagging was done at the slag door opposite the spout. A side door at 90° to the tilting axis provided the furnace with an opening for additions and hearth maintenance.

Drop-leaf, rope-tie charging buckets replaced older charging pans. In large shops, these were replaced by a trip latch mechanism, which eliminated the rope tying operation as well as the interminable delay of the bucket over the furnace while waiting for the rope to burn.


A 100-ton, elliptical shell furnace with six electrodes is shown being serviced by an open hearth charger. It was installed in 1927 at Timken Steel and Tube Div.

In the early 1950's Harold Phelps, of Rotary Electric, made a major contribution to the charging of electric furnaces with his adaptation of the old clam-shell design to scrap buckets. This eliminated rope expense in the amount of $75,000 per year in large shops, permitted faster more controllable charging, eliminated the closing stand and tying operation, and the bucket once closed could be used as a leveling device.

Faster electrode hoisting, tubular-bus, water-cooled electrode holders, oversized roof rings, replaceable panel type shells, water cooling, and a flush door operating mechanism, were all vital factors in improving production and reducing downtime to give the electric furnace the notable production rate and availability factor it currently enjoys.

Electrodes—of amorphous carbon, usually of square or semi-octagonal cross section—were first imported from Sweden. Early American counterparts were still made of amorphous carbon, but they had a circular cross section. Self-baking Soderberg electrodes were tried but never fully accepted on top charged units, partially because of their bulk.

In the early 1920's, a definite trend to the denser and more conductive graphite electrode became evident, since its greater current capacity per unit diameter enabled the electrode circle to be decreased. This gave better electric characteristics and a definite improvement in refactory life. These smaller graphite electrodes also decreased radiation and oxidation losses and did much toward lessening the inertia problem then evident in the fast reversal requirement of raising and lowering the electrodes.

Later improvements in electrodes were in terms of concentricity, tolerance of diameters, column strength, nipple joints, and tightening techniques.

The Second Half Century

The arc furnace has an impressive future. With its inherent advantages of flexibility to changes in production schedule and changes in the steel market, and its relative geographical independence, allowing plants to be placed near markets, it is hard to tell how fast electric furnace steel production will grow, but grow it will. The last six newcomers to the steelmaking industry use arc furnaces as their melting medium.

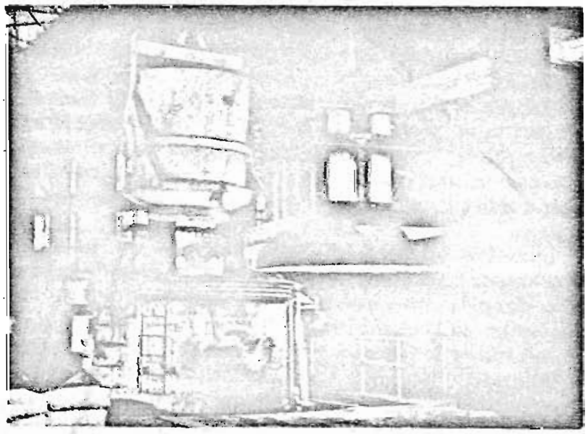
Fuel costs, the big factor favoring the open hearth today, can be expected to favor the arc furnace in the future. It is foreseen by experts that by 1975, open hearth fuel costs may increase 20 to 25 pct in terms of 1956 dollars, whereas, the constantly increasing efficiency of electric generating plants is expected to lower the cost of electric power.

The percentage increase in electric furnace capacity since 1925 closely parallels the climb in total U. S. generating capacity during the same 30 year period. On the basis of relative dollar values, kwhr costs for the total electric consumption in the U. S. have decreased 33 pct since 1920, and, for the large industrial consumer, they are down to an average of 10 mils per kwhr, a decrease of more than 50 pct since 1937. Generally, industrial power costs have fluctuated between 9 and 10 mils per kwhr for the past four years, but indications are that further reductions are entirely possible through the introduction and advancement of new generating and distributing techniques.

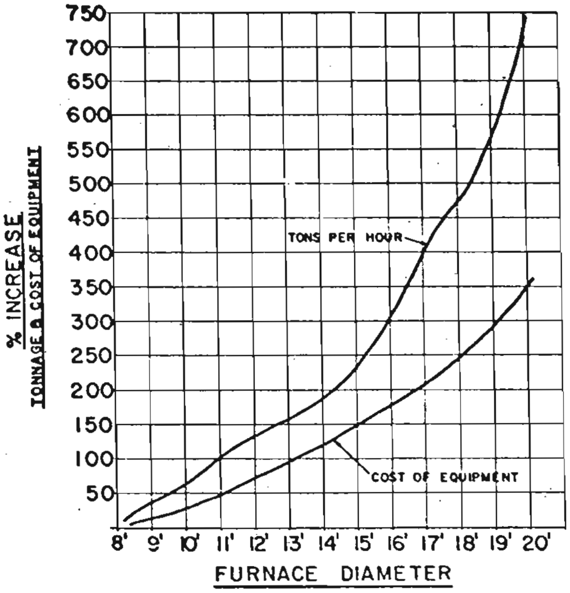
Regarding metallics, the arc furnace is now favored in cold melting, because of the use of pig iron and selective scrap for the open hearth. The spread between the arc furnace's scrap charge and the expensive metallics of the cold melting open hearth charge should continue, because of the growing scarcity of high grade iron ore and the relatively high costs of taconites.

In hot metal practice, the arc furnace is just entering the field. Because of the high cost of thermal energy in the arc furnace, it would appear that it might currently stand to gain further from the use of hot metal that was melted with cheaper fuel. As fuel and power costs equalize, the trend to arc furnace duplexing should increase.

Development work for processing molten iron in the arc furnace is currently being carried on. One American electric-steelmaker has installed blast furnaces and is using a European method to rid the iron of impurities by a top blown method. Costs might be improved with a combination converter-arc furnace, whose electrodes could be swung aside to permit the blow of oxygen, and returned over the bath to adjust temperature and final analysis.



A 20-ton Swindell furnace is shown above, ready to be charged by a clamshell bucket.



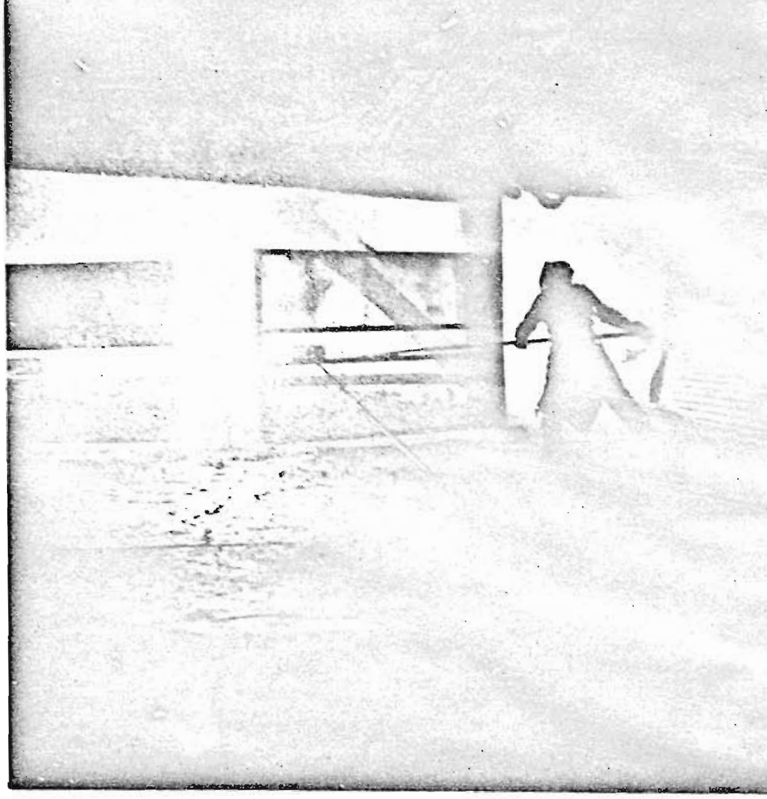
As furnace diameters increase up to 20 ft, production goes up at a more rapid rate than does equipment cost. But as size increases beyond this point, production should begin to level off.

Furnace diameters are increasing to match open hearth capacities, and furnaces up to 24½-ft diam have been installed. As the size of furnaces and transformers increases, their cost increases proportionally at a given rate. It can readily be seen, however, that up to a certain point, production also increases, but at a much greater rate. There is an optimum diameter and input rate somewhere in the progression, where the production profits, as opposed to investment and operating costs, level off and finally descend.

There are indications that returns on larger diameter circular arc furnaces are not as promising as on 100-ton units, due to refractory expense, downtime, electrode consumption, and melting rate. Certainly there appears to be a definite limit on the melting effect of a three-electrode system on a furnace larger than 200-ton capacity. A close electrode circle on a unit larger than 25 ft diam would result in cold metal around the banks, and a normal electrode circle in proportion to diameter might result in poor melt-in characteristic. This, coupled with the fact that the impedance of extremely large furnaces results in dangerous secondary voltages, and long arc length, gives indication that it is entirely feasible that tomorrow's arc furnace of 200 tons or better might be a reversion to the elliptical shell with its six electrode system. Research and experience will point this up.

The need of arc furnaces in both the alloy and carbon fields is as acute as ever. Newer steel processes have certainly made their presence felt in estimating future arc furnace production. Yet, absolute control of temperature, better control and greater range of fuel input, control of atmosphere and alloy losses, better ability to deoxidize slag and metal, ability to shut down and start up at will, minimum space and labor requirements, and relatively low capital expenditure, forecast the growing future for the electric furnace that economic experts predict.

Up to the beginning of World War I, the American ferro-alloy industry was in its infancy and largely dependent on Europe. During that War, capacity was over expanded. Later recovery and commercial and scientific development have resulted in an industry which in 1957 produced 1.8 million tons of ferro-alloys.



ELECTRIC-FURNACE FERRO-ALLOY INDUSTRY IN AMERICA

by J. H. Brennan, H. E. Dunn, and C. M. Cosman

THE ferro-alloy industry is today an important element of the industrial structure of the United States. Its output is valued at almost half a billion dollars annually and its products are basic not only to National defense but also to the peacetime standard of living.

This has not always been so. The ferro-alloy industry from late in the last century has grown from small beginnings, nurtured by the demand for stronger, tougher materials; by the search for steels capable of absorbing severe impact loads and resisting corrosive media and high temperatures; and also by the need for electrical and electronic specialties. Conversely, the ferro-alloy industry has grown because it developed improved steels and alloys by extensive research, and because it was able to show to steel makers the advantages accruing from the more extensive and the more economical use of alloying elements.

The industry has grown in scope from producing a few grades of ferro-alloys of the more common metals—manganese, chromium, vanadium, silicon, titanium, tungsten, and molybdenum—until there are today some 150 compositions of ferro-alloys available to the steel maker, including such elements as columbium, zirconium, and boron. In 1912 the industry produced 360,000 tons of alloys valued at about $12,000,000, while 1957 production figures show an output of 1.8 million tons worth $440,000,000.

In the United States, the history of an industry is largely the history of the companies making up this industry; hence, this paper will briefly trace the development of the most important ferro-alloy-producing companies.

Quite varied have been the reasons that caused the different companies to move into the ferro-alloy field; the Willson Aluminum Co., seeking methods of producing aluminum, succeeded with the production of calcium carbide, and their developing electric furnace skills led them to the production of ferrosilicon and ferrochromium alloys. Willson was the predecessor of the Electro Metallurgical Co. of Union Carbide. Two Pittsburgh undertakers, interested in vanadium as an alloying agent for steel, set about to find a mine and, ranging as far as Peru, fathered American Vanadium Co., the predecessor of Vanadium Corp. of America. Experiments of the

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Electric Reduction Co. to produce magnesium during World War I led to the formation of the Molybdenum Corp. of America which successfully produced a number of ferro-alloys.

Electro Metallurgical Co.

Blast furnace production of ferromanganese, spiegeleisen, and silvery iron was well established in the United States in the last decade of the 19th century. The beginnings of the electric-furnace production of alloy compositions beyond the range of the blast furnace were initiated by James Turner Morehead as an outgrowth of his attempts to establish the production of calcium carbide. The Willson Aluminum Co. at Spray, N. C., working toward the production of metallic aluminum, discovered the electric-furnace method of producing calcium carbide in experiments which were intended to yield metallic calcium. In his expansion of the new industry, Morehead acquired power rights at Holcomb Rock, Va., and at Glen Ferris, W. Va. At Holcomb Rock, du Chalmot produced the first electric-furnace ferrosilicon made in America. A variety of silicon alloys was produced, beginning in 1895. A considerable, early expansion of the ferro-alloy industry, however, came through the production of ferrochromium needed for projectiles and armor plate in the Spanish-American War. Morehead established the production of calcium carbide at Niagara Falls in 1896 and at Sault Ste. Marie, Mich., in 1900. In 1906, the Electro Metallurgical Co. began producing ferro-alloys at Niagara Falls as an extension of its predecessor companies in Virginia and West Virginia.

Frederick Mark Becket joined the Niagara Falls organization in its beginnings, and his early work resulted in the silicon reduction methods employing silicon or silicides for the production of low-carbon alloys, particularly low-carbon ferrochromium. Variants of Becket's methods are still used for the bulk of the low-carbon ferrochromium produced today.

During World War I, Electro Metallurgical Co. was producing all types of ferro-alloys used by the steel industry, including ferrosilicon, ferrochromium, ferromanganese, ferrovanadium, ferromolybdenum, ferrotungsten, and siliconzirconium alloys.

During the early thirties the Electro Metallurgical Co. started installing both hydro-electric and thermal power in West Virginia, and a ferro-alloy plant came into production in 1932 at Alloy, W. Va. Subsequently, plants were built at Sheffield, Ala., in 1940; at Portland, Ore., in 1941; at Marietta, Ohio, in 1951; and, for the United States government, a ferrosilicon and magnesium metal plant at Spokane, Wash. in 1942 and at Ashtabula, Ohio, in 1943. The Ashtabula plant was acquired by Electro Metallurgical Co. from the Government in 1946.

At Marietta, Ohio, an innovation in the production of very low-carbon ferrochromium started with the Erasmus-Bagley process for the vacuum decarburization of ferrochromium in a solid state reaction. Here, too, the operations were broadened in the pure metal fields with the installation of electrolytic plants for chromium and manganese. At the Ashtabula, Ohio, plant the production of titanium metal by sodium reduction was instituted in 1956.

Vanadium Corp. of America

Vanadium Corp. of America owes its inception to the discovery of vanadium deposits in the Peruvian Andes in 1905 to 1906 and the chance meetings of the Flannery brothers of Pittsburgh with metallurgists and South Americans that caused them to become interested in supplying Peruvian vanadium to the United States' steel industry. As a result, James M. Flannery went to Peru in 1906 to negotiate with a Señor Fernandini, who controlled the then recently discovered vanadium deposit at Mina Ragra. He had to act fast to obtain an option, since other interests were competing for the property. With a flair for drama, Flannery won out by converting his capital into gold pieces and spreading them before the Peruvian. That was the beginning of the American Vanadium Co.

The availability of a source of vanadium came just in time to meet the demand for this alloying metal which arose from the use of vanadium steel in automobile construction. Henry Ford in particular believed in the value of vanadium-containing steel in this application and placed large orders with the steel mills.

It was, however, a far road for the ore to travel from the heights of the Andes to the United States' automobile plants, not only geographically, but also technologically. Product problems beset the operations of the American Vanadium Co., until B. D. Saklatwalla, who joined the company in 1909, designed methods of extracting vanadium from ore and special electric furnaces to produce ferrovanadium. A new plant and laboratory were put up at Bridgeville, Pa., near Pittsburgh.

In 1919 Vanadium Corporation of America was organized and acquired the properties of the American Vanadium Co. It expanded from a single product operation by acquiring, in 1924, the assets of the U. S. Ferro Alloys Corp., which included important facilities at Niagara Falls. This plant had been established by Robert Turnbull, who was an early leader of the ferro-alloy industry. At Niagara Falls, Vanadium Corp. of America produced ferrochromium, chromium-silicide, and ferrosilicon, as well as other products.

Another important step in the development of the Vanadium Corp. of America was the introduction into the United States of the French Perrin process for the production of ferrochrome of low-carbon content. To manufacture this product, large, new facilities were provided at Graham, W. Va., in 1953 and at Vancoram, near Steubenville, Ohio, in 1958. The obsolete facilities at Bridgeville have been abandoned and replaced by a modern plant and research center at Cambridge, Ohio, which began to operate in 1953.

Vanadium is a co-product of uranium in many United States' ores. The significance of the Peruvian vanadium deposits declined as the Vanadium Corp. of America became more extensively engaged in domestic mining.

Titanium Alloy Mfg Co.

Titanium Alloy Co. was established in 1906 to develop the patents and processes of Auguste J. Rossi relating to titanium and its compounds.

The production of ferrocarbotitanium was undertaken in an electric-furnace plant at Niagara Falls, and the product found extensive application in the manufacture of steel rails, especially from bessemer steel. This application declined when open-hearth steel took over, but titanium found other uses in the manufacture of special steels.

In 1948 the company became the Titanium Alloy Mfg. Div. of National Lead Co. It operates mines in

Early view of Electro Metallurgical plant at Kanawha Falls, Glen Ferris, W. Va.

Florida and Australia and produces titanium- and zirconium-base products for a great many industries.

Pittsburgh Metallurgical Co.

Pittsburgh Metallurgical Co. was established in 1913 and built a reduction facility at Monaca, near Pittsburgh. During World War I, the local power company refused to provide sufficient electrical energy, and the plant had to shut down. As a result, the company moved to Niagara Falls in 1919. This plant has expanded from its original three furnaces to a current capacity of eight.

In 1941 a new plant was established at Charleston, S. C., with four furnaces. This facility now comprises 11 units.

A further plant, added by the company in 1949 at Calvert City, Ky., originally consisted of three furnaces. Later expansions have brought the equipment to a total of 12 units. This plant is the most modern and largest of the company.

Products of this company include silicomanganese, ferrosilicon, ferrochromium, and ferrochrome-silicon.

Molybdenum Corp. of America and Keokuk Electro Metals Co.

In 1915 a group of consulting engineers formed the Electric Reduction Co. This company failed in its attempt to produce magnesium by a distillation process, but it then began to reclaim tungsten from high-speed steel scale, and later expanded this operation to smelt ferrotungsten and ferromolybdenum from ores and concentrates at Washington, Pa.

About 1920 a substantial molybdenum property was acquired at Questa, N. M., and the name of the company was changed to Molybdenum Corp. of America. Recent exploration by Molybdenum Corp. has resulted in a very large expansion of their ore reserves at Questa.

About 1951 a huge deposit of rare earths was acquired and a number of interesting applications of these elements to steel manufacturing problems were developed. As far as is known, the deposit represents the major world source for rare earths.

Keokuk Electro Metals Co. started the manufacture of ferrosilicon at Keokuk, Iowa, in 1916. In 1948, they acquired Government facilities at Wenatchee, Wash., which had been constructed in 1942.

Keokuk is a producer of ferrosilicon, ferrochromium, and silicon metal.

Climax Molybdenum Co.

During World War I, which stopped the flow of molybdenum to the United States and stimulated demand, attempts were made to develop a domestic source of supply. Accordingly, the Climax Molybdenum Co. was founded in 1917-1918 to exploit the long-known, huge Bartlett Mountain deposit. Climax soon could assure the world markets of a continuous supply of molybdenum from a single source and was ready for business.

Business, however, was not ready for Climax; the advent of peace left the company without a market. Then an extensive sales development program was launched, and, as a result, molybdenum began to be used in many new alloying applications that have remained major outlets. Mining was resumed in 1924, and conversion operations began in 1926 at Langeloth, Pa., where production facilities for ferromolybdenum and other molybdenum products were provided. Since then, Climax's single mine has accounted for between one-half and two-thirds of the world's output of molybdenum. The hundred millionth ton of ore was mined in February 1957, and known reserves of ore are sufficient for decades to come.

Climax's position in the ferro-alloy field has been based on molydenum. However, a byproducts recovery plant, installed in 1948, permits recovery of associated mineral values, including tungsten. In 1950, Climax diversified by moving into the mining and milling of uranium-vanadium ores.

The company has successfully developed molybdenum from a rare metal to one of the most important steel alloying elements, as well as for many other uses. It was merged in 1957 with the American Metal Co., Ltd., under the name of American Metal Climax, Inc., retaining its identity as a division.

Ohio Ferro-Alloys Corp.

Ohio Ferro-Alloys Corp. had its beginning in 1927 when a number of industrialists of Canton, Ohio, formed the Electric Pig Iron Corp. and built a small electric furnace at Philo, Ohio. They first made ferrophosphorus and then, in 1928, adopting the present name for the enterprise, started producing ferro-alloys.

By 1941 the company was operating a second plant located at Tacoma, Wash., on behalf of the United States government. Again, in 1951, the Corporation expanded by building a plant at Brilliant, Ohio, and in 1958 a new plant at Powhatan Point, Ohio, was opened. The Corporation produces a full line of silicon, chrome and manganese ferro-alloys.

Chromium Mining & Smelting Corp.

In 1929 Robert Turnbull founded Algoma Smelting Co. at Sault Ste. Marie, Ontario, Canada, in cooperation with Francis Fitzgerald and Peter Bennie, to produce ferro-alloys. In 1934 Algoma was taken over by Chromium Mining & Smelting Corp. which was originally organized to process low-grade domestic chrome ores. Developing the processes of M. J. Udy, the company entered the field of exothermic alloys.

In 1947 additional processing facilities were completed at Riverdale, Ill., for the production of exothermic products, followed by the leasing from the United States government of the idle magnesium plant at Spokane, Wash., in 1948. This plant, run by the subsidiary, Pacific Northwest Alloys, Inc., was originally used to supply metal for the Riverdale unit and was later converted to the production of low-carbon ferrochrome.

In 1951 an arc furnace plant was built by another subsidiary, the Montana Ferro Alloys Corp., at Woodstock, near Memphis, Tenn., for the production of standard chromium and silicon alloys.

Tennessee Products & Chemical Corp.

In 1940 Tennessee Products, which had been producing pig iron, charcoal, coke, and chemicals, began production of blast furnace ferromanganese at Rockdale, Tenn. Operations were soon expanded by the addition of electric furnaces and the manufacture of ferrosilicon. Further blast furnace manganese facilities were acquired at Rockwood, Tenn. in 1942. With the end of World War II, operations were reorganized and continued only at Rockwood. In 1947 the company adopted the name of Tennessee Products & Chemical Corp. and purchased the Southern Ferroalloys Co., which had two electric furnace plants at Chattanooga, Tenn., making ferrosilicon and ferromanganese. It was while working at Southern Ferroalloys that Andreae conceived his theory of electroperipheral resistance, now known as *Andreae's ratio*.

A subsidiary, the Tenn-Tex Alloy & Chemical Corp., was formed together with Texas steel interests shortly thereafter, and three submerged arc furnaces were built at Houston, Texas, where ferromanganese has been produced since 1952.

Late in 1955 construction of the Roane Electric Furnace plant at Rockwood was started, and operation began in August, 1956. The plant has eight submerged-arc and four tilting furnaces making alloys of manganese, chrome, and silicon.

Interlake Iron Corp.

In 1955 Interlake Iron Corp. acquired the assets of the Globe Iron Co. Globe was founded in 1872 and engaged primarily in the manufacture of silvery pig. Although Globe installed an electric furnace as early as 1933, the amount of power available at Jackson, Ohio, was inadequate to sustain a full-size electric-furnace operation. In 1952, sufficient power became available, and an electric furnace was installed to produce ferrosilicon. The construction of a new plant was undertaken in 1954 at Beverly, Ohio, which now comprises four furnaces for the production of ferrosilicon, ferrochrome-silicon, high- and low-carbon ferrochrome, and silicomanganese.

Other ferro-alloy producers

About the end of the 19th century, Theo Goldschmidt developed the possibility of substituting aluminum for carbon in the reduction of iron and other metallic oxides. This process, originally intended for welding purposes, was introduced from Germany into the United States by the Goldschmidt Thermit Co., which was formed in 1904. A substantial volume was achieved during World War I when the method was applied to the production of chromium, manganese, vanadium, and tungsten alloys. Today the principal alloy produced by Metal and Thermit, the successor to the original company, is ferrotitanium, as well as chromium metal and minor amounts of ferroboron.

The Anaconda Copper Co. has been an intermittent producer of electric-furnace ferromanganese since World War I, basing their operations on Montana ore.

Hanna Nickel Smelting Co. at Riddle, Ore., has adapted the electric furnace to the production of ferronickel from low-grade garnierite ore. This installation began operations in 1954.

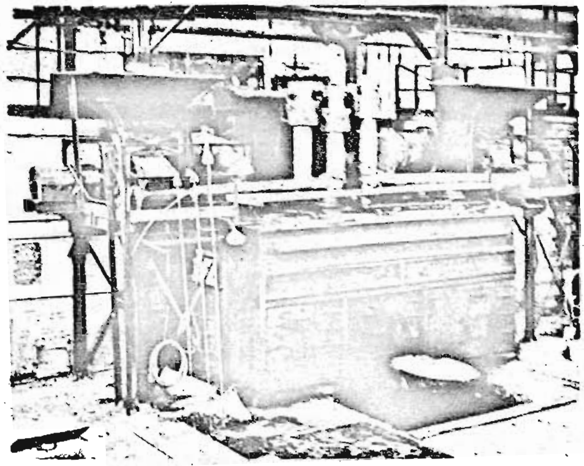
E. J. Lavino & Co., which is an important producer of ferromanganese, recently celebrated their 70th anniversary as a company. When they purchased four blast furnaces in the Lebanon Valley of Pennsylvania and in Virginia at the beginning of World War I, they became the first non-captive producers of ferromanganese in this country.

On occasion, the major steel producers have all made blast-furnace ferromanganese for home consumption; US Steel and Bethlehem have produced it continuously.

The industry as a whole

In the foregoing, the history of the more important companies of the United States' ferro-alloy industry has been described briefly. A good many of them have not only grown enormously since they were first established, but have also changed their name and character. During the lean periods they have lost many competitors, and these companies are the survivors. But there have been many more that are now only names and memories, and yet many of them have made substantial contributions to the art, for it is the men that make the companies.

The ferro-alloy industry is based upon the important discoveries of men, such as Sir Humphrey Davy who produced the first continuous arc in 1800, and Sir William Siemens, who operated the first direct and indirect arc furnaces in 1878. Henri Moissan experimented with the electric arc 12 years later and produced most of the metals, carbides,



Electric furnaces of World War I era at Bridgeville plant of America Vanadium Co., now Vanadium Corp. of America.

borides, and silicides made today. His publication *The Electric Furnace,* published in 1897, summarized his researches and gave impetus to the development of the electric-furnace industry. His student, Heroult, based his successful arc-furnace design on these experiments. Then followed the great French metallurgists, Gin and Coutagne, and the German, Goldschmidt, who established the metallurgy of ferro-alloys based on the electric furnace and on aluminothermy.

Up to the beginning of World War I, the American industry was in its infancy and largely dependent on Europe. Nevertheless, Andreae, Becket, du Chalmot, Morehead, Price, Rossi and Saklatwalla, and Tone and Turnbull, were even then pioneering new processes.

It was World War I that established a domestic ferro-alloy industry; until 1914, substantial amounts of ferro-alloys were imported from Europe. During that War, capacity for the production of ferro-alloys was so expanded that at its end many companies had to close down, while some took up the manufacture of other products.

In 1914 there was only one American company making ferrosilicon; in 1917 there were five. A similar growth pattern is indicated for ferrochrome. During World War I ten different firms made ferrovanadium and only six lasted into the peace.

It was the rumor that the Germans were using molybdenum in their heavy guns that caused a feverish search for sources of supply in the United States, and brought about our dominant world position in this metal.

A sizeable stock of zirconium ore was assembled on the basis of a similar rumor, relating to the use of zirconium in light armor plate. When it was turned over to Dr. Becket, he solved the difficulties of production within two months, and substantial quantities of the hitherto unknown ferrozirconium became available.

The post World War I adjustment in the Twenties caused many fatalities among United States' ferro-alloy companies and saw the ferro-alloy industry established in locations where cheap power was available. Up to the end of World War II the industry placed its plants near hydro-electric stations. Since then, they have moved to places where cheap thermal power can be obtained.

A slow recovery began only about 1924. From 1928 on, the growth of the molydenum industry was nothing short of spectacular. Actually, the ferro-alloy industry as a whole suffered less during the depression of the thirties than the steel industry, a testimony of the increased significance of alloy steel.

World War II was a period of new growth in the industry, and under Government sponsorship it was more orderly and organized than in 1914-1918. The wartime and postwar demand for ferro-alloys has raised US productive capacity to the highest point in history.

The availability of low-cost oxygen after World War II has occasioned considerable modifications in steelmaking. The ferro-alloy industry has felt the effects of this development in the changed pattern of raw material requirements in the production of stainless steel.

From the point of view of the ferro-alloy industry, the most significant development of these war years was the introduction of vacuum technology on an industrial scale. New processes have been based on this advance not only for making low-carbon ferrochromium pellets, but also in producing high-purity metals, such as columbium, zirconium, and titanium.

The utilization of minute additions of elements to achieve specific effects has brought about the application of small amounts of boron, magnesium, and rare earths in ferrous metallurgy. A concurrent trend has been the introduction of new dimensions in purity requirements. Also the requirements of the atomic energy program have resulted in the development of ultrapure metals. Such techniques are being applied to special problems in ferro-alloy metallurgy, and are now used also to meet the requirements of the new titanium and zirconium industries, among others. As a result there has been a considerable re-equipping of production facilities of the ferro-alloy industry especially with vacuum and consumable electrode furnaces.

Conclusions

No history of the United States' ferro-alloy industry should be closed without paying special tribute to the pioneers who laid its technological foundations.

James Turner Morehead established the industry in Spray, N. C., and later at Holcomb Rock, Va., and Glen Ferris, W. Va., at the end of the last century. His pioneering efforts still endure in the current operations of Union Carbide and Electro Metallurgical Co.

Frederick Mark Becket devised the silicon reduction processes for the manufacture of the low-carbon alloys of the strong carbide formers. His basic method was of extreme importance in the development of stainless steel.

Frank Jerome Tone was the first to produce elemental silicon in the electric furnace. While most of his technical contributions were made in the abrasive industry, his early work was of great importance to the developing ferro-alloy industry.

Byramji Saklatawalla developed the extraction and smelting of vanadium from its complex ores and made numerous and significant contributions to the ferro-alloy industry.