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THE PRINCIPLES AND PRACTICE
OF
IRON AND STEEL MANUFACTURE

BY

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Fifth Edition

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1917

PREFACE.

THE author of this book was for fourteen years engaged on the technical staff of iron and steel works, a fact which may account for the attention given to practical details throughout its pages. The intention is to provide—as far as the scope of the work permits—sound instruction and reliable information for technical students, metallurgists, engineers, and others engaged in the various branches of the iron and steel trades.

In plan the book differs from others on the subject. Hitherto it has been usual to consider, firstly, the iron ores, and then the several processes for the production of finished articles. The author has, however, found it better to begin with a consideration of the finished products, as they are more simple in composition and much more familiar than the ores. Some years' experience of each system has convinced the author that the new method is superior to the old. But as each chapter is self-contained, the reader, student, or teacher may follow either plan without inconvenience.

The plant illustrated and described is in use in well-conducted works at the present day.

Several chapters have been revised by acknowledged experts having intimate practical experience of their branches of manufacture. To friends who so kindly helped in this direction the author is grateful. He desires to thank the firms from whom he had permission to take works photographs, and also the firms to whose generosity he is indebted for sketches, blocks, &c.

Thanks are tendered to the Councils of the Institution of Mechanical Engineers, the Iron and Steel Institute (London), the Staffordshire Iron and Steel Institute, the West of Scotland Iron and Steel Institute, and the Cleveland Institution of Engineers; also to the Editors of *Cassier's Magazine* and the *Foundry Trade Journal* for permission kindly granted to copy extracts from their publications.

Special thanks are due to Professor A. Humboldt Sexton, and to Messrs. Alfred Harvey, Westminster; Joseph H. Harrison, Middlesbrough; and Robert Buchanan, Birmingham, for valuable suggestions.

THE MUNICIPAL SCIENCE SCHOOL,
WEDNESBURY, *February*, *1906*.

PREFACE TO THE FIFTH EDITION.

A FEW alterations have been made in the text, and new matter has been added.

STAFFORDSHIRE COUNTY INSTITUTE,
WEDNESBURY, *Sept.* 1917.

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THE PRINCIPLES AND PRACTICE

OF

IRON AND STEEL MANUFACTURE.

CHAPTER I.

INTRODUCTION.

IRON is the most plentiful and most useful of the metals.

In what a variety of useful forms do we daily, hourly, meet with it! In stately steamships, whose records of capacity and of swiftness constitute one of the marvels of our time; in the powerful locomotive careering along the iron way; in machinery, ponderous and powerful, or nimbly delicate and deft; in hammer and anvil, in cannon and shot: the pen, the sword, the ploughshare, and a thousand things more, from the proverbial "needle to an anchor," are fashioned for us from this most useful metal. Our terrible battleships with their tremendous guns and engines are composed mostly of iron. The newest world's wonders have iron for their backbone. The stupendous bridge which spans the Forth; the Eiffel Tower, of "solid yet graceful construction, which rears aloft its fairy-like form, an elegant example of scientific powers and the imaginative genius of French engineering,"* and the Tower Bridge have become possible because of progress in iron (or mild steel) manufacture.

The New World also abounds in stupendous structures of steel and iron. The magnificent bridge at Poughkeepsie, the

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* Sir James Kitson, Bart., M.P.

splendid span of well-nigh 1,600 feet in the Brooklyn Bridge, the Williamsburg and other bridges at New York, the majestic bridge over the St. Lawrence at Quebec, the towering buildings in the chief cities, the appliances and plant for dealing quickly with a gigantic turnover of materials —all these attest the usefulness of iron and steel.

Iron is extensively used for so many purposes, not only because it is abundant, but because of its adaptability to a great range of requirements. It can, with comparative ease, be caused to enter into chemical union with other substances with most remarkable results.

Wrought iron is pliant, tough, and reliable. **Mild steel** is strong and flexible, and, like wrought iron, can be hammered, rolled, or drawn into serviceable shapes, and can be welded. With more carbon in its composition, **medium steels** suited for other purposes, such as rails, axles, and wheels, are produced, while, with still more carbon, **tool steel**, which can be hardened and tempered, is made. Who can count the service to civilisation rendered by tool steel? Iron with still more carbon is adapted to the formation of **castings** of utility and beauty.

When iron is alloyed with such metals as chromium, manganese, nickel, or tungsten, its range of usefulness becomes vastly extended, and if articles consisting mostly of iron are subjected to modified heat treatment during manufacture, wonderful additional strength and endurance are developed.

In its **magnetic properties** iron is unique among the metals.

Because it has been endowed with so many good qualities in well-balanced proportion IRON is the MASTER METAL.

CHAPTER II.

PRELIMINARY CHEMICAL CONSIDERATIONS: DEFINITIONS.

The great gaseous envelope—the atmosphere—which surrounds the globe we inhabit is made up chiefly of two gases, called **oxygen** and **nitrogen**, in proportion nearly approaching to 4 measures of nitrogen to 1 measure of oxygen. There is also a vast amount of oxygen in the rocks and minerals which compose the crust of the earth.

Oxygen is the active agent in the atmosphere. When oxygen enters into chemical union with fuel in our furnaces a high temperature is created, by which the extracting, refining, and working of metals are effected. Its chemical symbol is O.

To extract iron from ore a high temperature is necessary, and if a mass of chemically combined iron-and-oxygen, or iron oxide (which forms the essential constituent of our iron ores), is brought into contact with carbon, or substances which contain much carbon (such as charcoal, coal, coke, or carbon monoxide), at a high temperature, the oxygen leaves the iron and unites with the carbon to form gases which ultimately find their way into the atmosphere. The oxide of iron is *reduced* to the metallic state when that transfer of oxygen takes place.

For the extraction of iron we require ore containing iron; we need substances (fuel) which will combine readily with oxygen and evolve a high temperature,* and we must also have substances which withstand chemical action even at a high temperature. The latter constitutes the refractory materials with which our furnaces are lined. Associated with the iron oxide in the ores we find other matters

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* Electricity generated from water power places us to some extent in an independent position with regard to this.

(gangue) such as sand, lime, clay, &c. Fluxes are required to cause such substances to melt more readily and so become fluid at the furnace temperature.

Three substances have already been mentioned—namely, **oxygen, iron,** and **carbon.** Each is an **element.** An element is a substance which has not been split up into other substances. It has not been found possible to transmute or change any element into another. There are about 78 elements known, and with the advance of science the number is from time to time added to.

Each metal is an element: no one metal can be changed into another. Copper, for example, cannot be changed into tin; tin cannot be changed into copper, or zinc, or any other metal. But two or more metals may be melted together so as to form an alloy differing in its character and qualities from the metals of which it is composed.

There are other elements which are not metals. When a non-metal enters into union with a metal, or when two or more non-metals unite chemically, a **compound** is formed. Compounds, too, differ in character, or properties, from the elements of which they are composed. For example, a piece of iron left exposed is attacked by chemical compounds in the air and is changed into iron rust. The brown, powdery rust differs from the bright, solid metal.

The elements to be considered in this book are not numerous.

Iron (the Latin name for which is *ferrum*) is designated by the symbol Fe. It is a metal of great chemical activity—one which is so quick to combine with substances which come into contact with it that it is difficult to prepare in a state of purity. Chemically pure iron is scarce and costly, and is not of commercial importance.

Three oxides of iron are known:

(*a*) **Ferrous oxide,** a compound in the proportion of one atom of iron with one atom of oxygen. It is therefore represented by the chemical symbol FeO.

(*b*) **Ferric oxide,** a compound in the proportion of two atoms of iron with three atoms of oxygen. Its chemical symbol is Fe_2O_3.

(*c*) **Magnetic oxide,** a compound in the proportion of three atoms of iron with four atoms of oxygen, and represented by the chemical symbol Fe_3O_4. It has magnetic properties.

The student should make a point of seeing and handling samples of iron ores containing these oxides.

Arithmetically, the iron oxides may, for purposes of comparison, be represented thus:

Ferrous oxide, . .	FeO or Fe_6O_6
Magnetic oxide, . .	Fe_3O_4 or Fe_6O_8
Ferric oxide, . .	Fe_2O_3 or Fe_6O_9

Ferrous oxide is eager to absorb oxygen and become converted into ferric oxide. If ferric oxide is heated strongly it loses oxygen and is changed into magnetic oxide.

The chemical symbol for carbon is C. Carbon and oxygen enter into chemical combination with each other in two well-defined proportions, forming either **carbon monoxide** or **carbon dioxide.** In the former, the proportions are *one* atom of carbon to *one* atom of oxygen, the resulting compound having the formula CO. In the latter the proportions are *one* atom of carbon to *two* atoms of oxygen, the resulting compound being correctly represented by the formula CO_2.

When abundance of air is present in a furnace which is hot with glowing fuel containing carbon, the carbon becomes oxidised (or to use the every-day term, "burned") to its fullest extent, and carbon dioxide (CO_2) is formed. But if the air supply is limited, the carbon dioxide, on coming into contact with more hot carbonaceous fuel, is reduced to carbon monoxide (CO). The following equation represents the reaction:—

$$CO_2 \quad + \quad C \quad = \quad 2CO$$

Carbon dioxide and carbon yield carbon monoxide.

Carbon monoxide is very useful in many metallurgical operations, because, at ordinary furnace temperatures, it readily unites with oxygen, as indicated by the equation—

$$2CO + O_2 = 2CO_2$$

Carbon monoxide and oxygen yield carbon dioxide.

The importance of these statements will be apparent on reading the following chapters.

Chemical combination takes place in definite proportions—a number of atoms of one element entering into chemical combination with a definite number of atoms of another element.

Each element has a relative value with regard to each other element; or, to state the fact in other words, each element has its own exchange value or equivalent. And there need be no more mystery in the exchange value of an element than there is in the common fact that 1 shilling is equivalent, or of equal value, to 12 pence, or that 1 pound equals 20 shillings.

The exchange values, or atomic weights, of the elements already named are:—Carbon, 12; oxygen, 16; iron, 56.

12 lbs.* of *carbon* unite with *16* lbs. of *oxygen* to form 28 lbs. of carbon monoxide; *12* lbs. of *carbon* unite with *twice 16* lbs. of *oxygen* to form 44 lbs. of carbon dioxide. The former is represented as CO, the latter as CO_2. 72 lbs. of ferrous oxide (FeO) contain *56* lbs. of *iron* and *16* lbs. of *oxygen.* 80 lbs. of ferric oxide contain *56* lbs. of *iron* and *24* lbs. of *oxygen.* Ferric oxide might therefore be represented as $FeO_{1\frac{1}{2}}$. But to obtain the most simple formula for ferric oxide we must double each element and represent ferric oxide as Fe_2O_3. For similar reasons magnetic oxide is represented by the formula Fe_3O_4. The iron and oxygen in magnetic oxide exist in the proportion of

Iron, 3 times 56 parts, by weight.
Oxygen, 4 „ 16 „ „

The elements to be considered in the earlier chapters of this book and their symbols and equivalent values are—

---

* Any other weight may be substituted for lbs., but that one weight, or unit, must be kept throughout a comparison or calculation.

METALS.			NON-METALS OR METALLOIDS.		
Name.	Symbol.	Atomic Weights.	Name.	Symbol.	Atomic Weights.
Iron, . .	Fe	56	Carbon, .	C	12
Manganese, .	Mn	55	Hydrogen, .	H	1
			Nitrogen, .	N	14
			Oxygen, .	O	16
			Phosphorus,	P	31
			Silicon, .	Si	28
			Sulphur, .	S	32

The chief constituents of our fuels are (*a*) carbon, (*b*) hydrogen, and (*c*) compounds of carbon and hydrogen. The heat effects of their combustion are dealt with in Chapter xxiii.

SILICON.—This is an element of much interest to iron and steel-makers. It is easily oxidised. The only known oxide of silicon is called silica and has the formula SiO_2, which means that each atom of silicon has entered into chemical union with two atoms of oxygen; or, to express the same truth in another way, chemical combination has been effected in the proportion, or ratio, of 28 parts (say 28 lbs.) of silicon with twice 16 parts (say 32 lbs.) of oxygen.

Pure white sand, or quartz, may be taken as fair examples of silica—the oxide of silicon. Silica is the most plentiful substance in the earth's crust. All iron ores, as got from the earth, contain silica. In the process of extracting iron from ores some of the silica is caused to part with its oxygen, and the silicon, thus freed by reduction, associates with the metallic iron. In refining the iron, in subsequent stages, such silicon requires to be removed.

MANGANESE is a metal the oxides of which are frequently found in iron ores. Metallic manganese is a constituent of irons and steels. The readiness with which it combines chemically with oxygen, and with sulphur, is a most useful quality which is freely applied in steel-making.

IRON, when pure, is a silver-white, tough metal which can show the peculiar brightness known as metallic lustre. Its melting point is very high. When melted, or even heated highly, where air has free access to it, the metal becomes oxidised—that is to say, oxygen unites with the iron forming a crumbling mass of "burnt iron." Pure iron (a very rare substance) is more easily burned or oxidised than impure iron; a fact which can be understood when it is remembered that the impurities usually present in ordinary iron are more easily oxidised when hot than iron itself is.

The worst impurities in many manufactured iron masses are sulphur and phosphorus.

Sulphur tends to produce **red-shortness** in iron. The term "red-short" means that it is brittle when at a red heat.

Phosphorus tends to produce **cold-shortness** in iron, the term "cold-short" meaning that the mass is brittle when cold; that is, at ordinary temperature.

Silicon in certain proportions was formerly believed to induce both red-shortness and cold-shortness, but recent researches have shown that silicon cannot be classed among the highly injurious elements.

Iron or steel which is burnt, or is red-short or cold-short, is brittle and unreliable. Burnt iron, or iron which is red-short, cannot be welded—at least not in a satisfactory manner.

Although there are objections to the use of iron or steel containing certain proportions of silicon, sulphur, or phosphorus, it must be kept in mind that presence of these elements in proper proportions is beneficial. For example, some mild steels containing a little over one-tenth of a per cent. of sulphur roll into sheets better than some makes of purer steel. Certain cast irons may be strengthened by judicious addition of sulphur. Pig iron containing a notable amount of phosphorus is more fluid than purer pig iron, and so takes a sharper impression in the mould in which it may be cast.

The common elements which are usually present in mild steel—if not in undue amount—increase the power of the steel to resist rupture by stress.

Arsenic, copper, and other elements were formerly looked on with disfavour, or were held to condemn the steel which contained them, but experiments carried out on a practical scale in works amply disproved the notions held by inspecting engineers. The marvellous qualities imparted to steel by the prudent introduction of chromium, nickel, manganese, tungsten, molybdenum, and other metals have proved most helpful to all classes of engineers. The amount of carbon which is combined with iron has most marked effects on the nature of the steel produced by such combination.

There are certain qualities, or properties, possessed in a marked degree by iron and steel which may, with advantage, be defined here.

Malleability.—The quality which enables a substance to withstand hammering, rolling out, dishing, or flanging, without being cracked or broken.

Extensibility is the term applied to the stretching which takes place before rupture when a metal is subjected to a pulling force in a testing machine, or which may take place when the metal is in use as part of a structure.

Elongation is the term used to denote the act of lengthening, or the length to which a metal has been stretched by the testing machine.

Elasticity is the power which enables a metal to resume its original form on being released from a force tending to alter its form. Thus, a piece of tempered steel may be considerably bent, but, by virtue of its elasticity, it will straighten itself when released from the bending force. A piece of steel may be stretched to a slight extent, and its elasticity will enable it to return to its original length when freed from the power which stretched it. If, however, the stretching is carried to a certain further point, the limit of elasticity is reached, permanent set occurs, and the piece of steel cannot go back to its original dimensions.

Ductility.—The quality which enables a metal, or an alloy, to hold together and conform to intended shape when subjected to squeezing and stretching while being drawn into wire. In practice the wire is drawn through a series of holes, which diminish in size, one by one, in a draw plate. Sometimes a metal which rolls out well is spoken of as ductile.

Tenacity* is the quality which enables a substance to hold

---

*From the Latin *tenax* = to hold.

together when subjected to a force which tends to stretch it. In Britain the tenacity, or tensile strength, of a metal is generally computed in tons per square inch of section, in America in pounds per square inch, while on the European Continent it is usual to state the tensile strength in kilogrammes per square millimetre. Mild steel is more tenacious —has greater tensile strength—than wrought iron. In other words, mild steel will remain unbroken under a tensile stress, or pull, which would rupture wrought iron. For information regarding the mechanical testing of metals see Chapter xiv.

Toughness is that quality which enables a substance to withstand oft-repeated bendings or twistings without breaking.

Welding is the operation by which wrought iron, and the milder varieties of steel, may be firmly joined by placing clean ends together and hammering or pressing while the pieces are at a proper temperature. Wrought iron is at the correct temperature when in a plastic condition.

In a brisk fire, which is urged by a blast of air from a bellows or a fan, the iron pieces which are to be welded are heated till white hot. The surfaces are apt to be more or less oxidised or "burnt," and the oxidised particles must be removed. Some sand is therefore thrown over the white-hot parts in order to flux off the oxides of iron. Sand, as already explained, is essentially silica (SiO_2), which has a strong affinity (or liking) for ferrous oxide (FeO), and, although neither of these substances, separately, could be melted at a temperature far above that of the white-hot iron, they readily combine with each other, at a moderate temperature, to form a compound (ferrous silicate = $2FeO, SiO_2$) which easily melts and flows off, carrying with it the ferric oxide (Fe_2O_3), and leaving clean surfaces to be welded.

CHAPTER III.

THE PUDDLING PROCESS FOR THE PRODUCTION OF WROUGHT IRON.

WROUGHT iron possesses many valuable qualities. It is strong, tenacious, tough, malleable, and ductile;* it possesses that remarkable and valuable property which enables it to be welded. It is not altogether free from the slag which accompanies its production, but even that is an advantage, as it enables a *fibrous* structure to be developed, and this fibrous structure hinders dangerous crystallisation. For certain important purposes it is unsurpassed, and it commands a higher price than is paid for mild steel. For these and other reasons its manufacture continues, although its practical extinction was prophesied many years ago.

Wrought iron—often called malleable iron—is still produced, although in amount which is relatively small, by methods which have the attractive title of *direct* processes. But by far the greater quantity of wrought iron is made by the indirect method. In the latter-named method pig iron is first produced, which is afterwards, by the puddling process, converted into wrought iron. Pig iron is the chief product of the blast furnace; in it is concentrated more than 90 per cent. of iron—even if the ore from which it was extracted contained only 33 per cent. of that metal. It is the business of the puddler to purify the pig iron, and thereby change it from a somewhat brittle, unweldable mass into metal having the useful qualities mentioned at the opening of this chapter.

Present-day puddling is of two kinds—(*a*) dry puddling, and (*b*) wet puddling.

Wet Puddling or Pig Boiling.—A comparison of the percentage composition of the pig iron used and the wrought

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***These terms are explained in the previous chapter.**

iron produced may convey an idea of the work to be done by the puddler:—

Constituents	Chemical Symbols.	Forge Pig Iron.	Wrought Iron Produced.
Graphitic carbon, . . .	C	2·0	...
Combined carbon, . . .	C	1·5	0·05
Total carbon, . .	C	3·5	0·05
Silicon, ...	Si	1·3	0·20
Phosphorus, ...	P	1·3	0·15
Sulphur, ...	S	0·1	0·03
Manganese, ...	Mn	0·5	0·01
Cinder or slag, . . .	...	none	2·30
Iron (by difference), . .	Fe	Δ	Δ
		100·0	100·00

Graphitic Carbon is not in chemical combination. From rich, grey pig iron it is sometimes possible to detach flakes of graphite (which, chemically, is carbon) from a fractured part. Combined carbon cannot be separated in this manner.

These figures show that the impurities in the pig iron are largely, indeed in some instances almost entirely, removed during puddling. The removal is effected by burning out the impurities, or, to express the idea more scientifically, the impurities are removed by oxidation. Fortunately, the oxidising action is *selective;* the impurities which we wish to eliminate* are, under the conditions set up by the puddler, more readily oxidised than the iron, and they therefore become separated from the iron.

Briefly put, the puddling process consists in melting suitable pig iron† in a properly-prepared puddling furnace, and stirring and rubbing it, or, to use the trade term, "rabbling" it, so as to bring the melted pig iron into intimate contact with the oxides (chiefly oxides of iron) which constitute the "fettling"—including the fluxing oxide—in the furnace. The carbon,

---

*This long word is from the Latin, and, in plain English, means "to thrust out of doors."

†It is one of the merits of the puddling process that a great range, or variety, of pig iron can be successfully dealt with during the process.

silicon, manganese, phosphorus, and sulphur are, as previously stated, attacked by oxygen and almost completely removed from the pig iron. The products resulting from the oxidation of the carbon, being gaseous, escape by the chimney; the other oxidised products enter into the slag.

It may be accepted as one of the fundamental principles in metallurgy that when an element—such as carbon, silicon, sulphur, or phosphorus—existing in chemical union with a metal, combines chemically with oxygen, the resulting oxidised product must, when melted, separate itself from the remaining metallic portion. Metals which become oxidised are subject to the same general law. To this principle, or law, there are a few well-known and easily explained exceptions.

And if oxidised metal parts with its oxygen—becomes deoxidised, or *reduced* to the metallic state — the newly liberated portion joins the metal in the furnace.

These are important points. If, for instance, a pig iron contains 1 per cent. of silicon, it is clear that there must be 1 per cent. less iron in the pig iron, and it might be inferred that, provided the other impurities are the same in amount in each case, the yield of wrought iron from a pig iron containing 2 per cent. of silicon must be less than the yield from a pig iron with only 1 per cent. of silicon. That is not so, however. One ton of pig iron containing 1¼ (= 1·25) per cent. of silicon is *theoretically* capable of liberating nearly 1 cwt. of iron from the ferrous oxide in the fettling, or the cinder, in the furnace, and pig iron with double that percentage of silicon is capable of liberating 2 cwts. of iron. The theoretical increase in yield is never attained in practice. But if the greater part of the oxygen for purifying the pig iron is obtained from metallic oxides, such as in the fettling and the cinder, the weight of wrought iron produced will be considerably greater than the weight of pig iron charged.

The silica (SiO_2) formed by the oxidation of silicon (Si) unites with iron oxide (FeO) and together they go into the slag. Certain pig irons are known as "**hungry pigs**," because they "eat" so much of the fettling. The yield from such pig iron is great, the consumption of fettling is great, and the labour is severe.

The oxidation of carbon and of phosphorus by oxide of iron also leads to increased yield.

The Puddling Furnace is an oblong structure of firebrick strengthened by cast-iron plates, and tied by iron rods which extend along and across the furnace, and are fastened by large nuts at each end. Each plate is thus tightly braced against the brickwork. The furnace is of the type which is known as **reverberatory**—that is, one in which the fuel is burned in the fire-grate at one end and the flame from which is drawn towards the chimney at the other end. The under surface of the brick roof—which is a slanting one—is thus heated, and it is chiefly the heat which is *reflected from the roof*, or, as the word reverberatory means, is *beat back*, which causes the high temperature in the working part of the furnace. **The fuel does not come into contact with the "metal" in**

Fig. 1.—General View of Puddling Furnace.

the furnace — an arrangement which leads to substantial advantages.

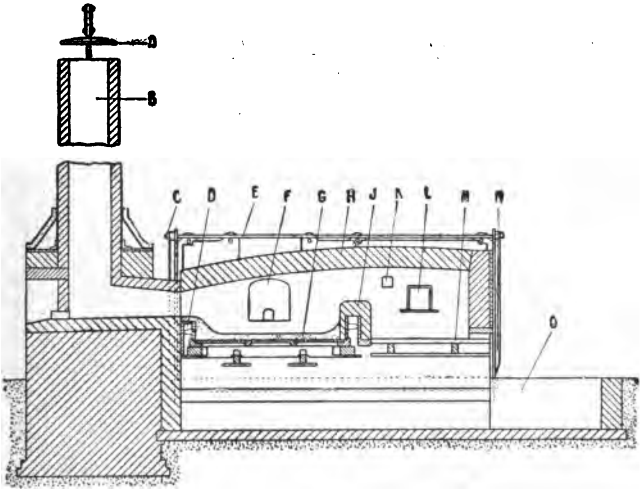

Fig. 2.—Vertical Longitudinal Section of Puddling Furnace.

A, Damper. B, Stack.
C, Nut at end of tie-rod.
D, Flue-bridge. E, Plates.
F, Working door.
G, Fettling.
H, Reverberatory roof.
J, Fire-bridge. K, Staff-hole.
L, Coal-firing opening.
M, Grate-bars.
N, Buckstave. O, Ashpit

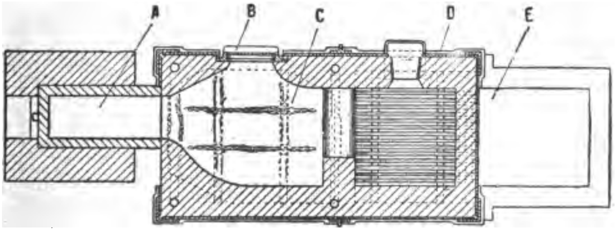

Fig. 3.—Plan of Puddling Furnace.

A, Flue. B, Forehearth.
C, Working part.
D, Iron plating.
E, Ashpit.

At a convenient height above the ground level the iron castings which support the fettling of the working bed of the furnace are so laid that air can circulate freely underneath to keep the iron-work cool. Separating the fire-grate from the working bed is the **fire-bridge**—a hollow iron casting under which air can be caused to pass. At the other end of the working bed is the **flue-bridge**, which is of similar design. The flue, which is a sloping passage, connects with the **chimney**, or **stack**, as it is often called. The chimney, which is sometimes 50 feet high, is built of bricks braced by angle irons up the corners: these are bound to each other by tie-rods and nuts. It is surmounted by a damper which is hinged and controlled by means of a chain, the lower end of which can be easily reached.

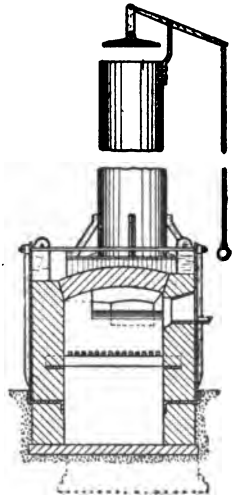
Fig. 4.—Puddling Furnace—Cross - section through Grate.

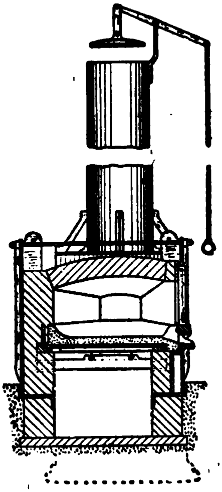
Fig. 5.—Puddling Furnace—Cross-section between Fire-bridge and Flue-bridge.

Instead of a heavy brick stack for each furnace it is now not unusual to arrange for four puddling furnaces to be worked by one stack consisting of a tall cylindrical steel casing lined with suitable bricks.

As a high temperature is required in the puddling furnace the area of the fire-grate is larger in proportion to the working part than is usual in reverberatory furnaces. The area of the grate is generally more than one-third the area of the working part. The grate-bars are of wrought iron, and are supported on iron bearers. The bars are rolled in long lengths of suitable section, and are cut into shorter pieces to fit the grate. They can be readily removed when required. An injector—a pipe with a widened end into which a jet of steam is injected—may be provided. The force of the steam induces air to enter the pipe, through which it is conveyed to the furnace.

In front of the furnace are four openings known respectively as the **firing-hole**, the **staff-hole**, the **door**, and the **cinder-notch** or **cinder-hole**. These are all shown on figs. 1 and 2.

Through the **firing-hole** fuel is fed to the fire-grate. It is customary to partly close it by placing lumps, and some small pieces, of coal on the sill. A useful purpose is served by the gases from the gentle distillation of this coal. These gases are drawn into the furnace.

The largest opening—the one for the door—has a heavy iron projecting sill, called the **foreplate**. The working door consists of large firebricks or slabs set in an iron frame suspended from one end of a lever. It is raised when required by pulling down the other end of the lever by means of a chain. When the chain is released the door slides down and closes the opening. At the centre of the lower part of the door is a small opening known as the **stopper hole** or **stopper notch**. Under the foreplate is the cinder-hole, and through it the cinder or slag is tapped off.

The surface of the fire-bridge and flue-bridge, and the plates which support the working bottom, are all carefully covered with firebrick, or with fettling, where they would be otherwise exposed to the heat of the furnace.

The chief materials used for fettling are:—

Best Tap, the cinder or slag from reheating furnaces which are worked with (basic) cinder bottoms;

Bull-dog, puddler's cinder or slag which has undergone roasting to render it less fusible (not so easily melted);

Purple Ore, the rich residue of ferric oxide (with about

4 per cent. of other compounds) left after the treatment of iron and copper pyrites;

Hematite Ore, a rich hematite ore mined in the North-west of England;*

Pottery Mine,† an iron ore mined in the pottery district of North Staffordshire.

AVERAGE COMPOSITION OF FETTLING MATERIALS.

Constituents.	Chemical Formulæ.	Best Tap.	Bull Dog.	Purple Ore (Dried).
Ferrous oxide, .	FeO	68·1	3·8	...
Ferric oxide, . .	Fe_2O_3	26·5	69·6	96·0
Manganous oxide, .	MnO	1·2	0·7	...
Silica, . . .	SiO_2	2·9	24·3	2·0
Phosphoric acid, .	P_2O_5	0·9	0·8	...
Sulphur, . . .	S	...	0·8‡	Other constituents in small quantities.
Lime, . . .	CaO	0·3		
Magnesia, . .	MgO	0·1		
		100·0	100·0	100·0
Metallic iron, . .	Fe	71·52	51·68	67·20

Preparation of the Puddling Furnace for Work.—On the top of the iron bed-plates little lumps of "best tap" are charged so as to form a coating about 3 inches thick. The temperature of the furnace is then raised to such a pitch that the best tap begins to soften. The coating is covered over with a layer, about 2 inches thick, of scale or other fettling, such as ground bull dog, purple ore, or hematite ore. These are varied to suit the class of pig iron which is used, and the quality or the purpose for which the wrought iron is to be produced. The purer the pig iron the more fusible must the fettling be: the less pure or more "hungry" the pig-iron the less fusible must be the fettling. The sides are also well fettled, the fettling being firmly rammed into the recesses formed by the firebricks which project over the fire- and flue-bridges. A light charge of scrap iron is then charged,

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* See analysis on p. 178.

† See analysis on p. 242.

‡ By difference.

raised to a welding heat, oxidised, and rolled over the fettling so as to glaze it with rich oxide of iron.

The Puddling Process.—The furnace, when fettled and hot, is ready for charging. Through the open door about ¾ cwt. of hammer slag, or other fusible iron oxide, and 4½ or 5 cwts. of pig iron are thrown as shown in fig. 6. The door is then lowered, a small iron plate is set in front of the stopper hole, and a little quantity of fine ore is placed on the foreplate so as to prevent access of air through any worn-out parts.

Fig. 6.—Charging a Puddling Furnace.

The puddling process may conveniently be described as divided into four stages. The first stage merges quietly into the second stage, which in its turn glides into the succeeding one.

The First or Melting-down Stage.—In the course of about

20 minutes after charging, the exposed parts of the pig iron will have become red hot. The "pigs" are then turned over so as to be heated more uniformly. Melting begins soon after, and the melted portions drip and flow into the lowest part of the working bed, where it is well stirred. The tools for turning over the pig iron and for stirring the melted materials are inserted through the stopper notch.

During the melting down much silicon and manganese are oxidised, and a considerable quantity of phosphorus is also oxidised. All the oxidised products leave the pig iron and combine with some of the melted fettling to form the slag or cinder. This stage occupies about 30 minutes in all.

Fig. 7.—Pig Iron in Puddling Furnace.

The Second or Clearing Stage occupies about 10 minutes. In it the remainder of the silicon and manganese and a further quantity of the phosphorus are oxidised and removed from the pig iron. A high temperature is maintained, and the charge is vigorously rabbled (that is, stirred or worked with an iron tool called a rabble), so as to promote a more rapid and intimate contact between the pig iron and the slag and fettling; thus hastening the oxidation of the impurities in the pig iron by the oxides in the fettling and the fluxes, and by the air which is passing through the furnace.

Fig. 8.—Puddler Rabbling a Charge.

In the Third or Boiling Stage, which occupies about 30 minutes, nearly all the carbon is removed and most of the remaining phosphorus is eliminated. The temperature is regulated as required, and the charge is still vigorously rabbled. As the carbon at this stage is oxidised and forms carbon monoxide (CO), which is a gas, the efforts of the gas to reach the surface of the now somewhat pasty mass cause repeated risings and subsidings and an appearance suggestive of boiling. When the bubbles of carbon monoxide reach the surface, they are met by a current of air which oxidises the carbon monoxide (CO) into carbon dioxide (CO_2). The blue flames seen at the surface of the bath of metal and slag, when the burning of the monoxide takes place, are known as "**puddlers' candles.**" The charge swells considerably, and "boilings"—the most frothy part of the cinder—are tapped off. It is at this stage that the metal "comes to nature." Bright specks of metal appear, and become more numerous and larger.

Fig. 9.—Drawing Puddled Ball from Furnace.

The Last or Balling Stage occupies about 20 minutes. It is the heavy duty of the puddler to gather together the metal, with only a little slag, into balls of convenient size. He, therefore, raises the metal, which is now in a spongy condition, and divides it into pieces of about 75 to 100 pounds each. He then rolls each piece into a ball, and as each **puddled ball** is finished it is kept away from oxidising influences as much as possible, and, while as hot as the furnace can be kept, is withdrawn by means of tongs over the foreplate, and is usually dropped on to an iron trolley which is ready to receive it. If, however, the furnace is not far from the site of the next operation no trolley is used, but the hot puddled ball is bodily dragged across the well-swept "race"—the iron plates which constitute part of the flooring. The puddled balls are quickly conveyed to the shingler, whose business it is to **shingle** the ball either by squeezing or hammering. The appliances for shingling are described on pp. 29 and 30.

During shingling there is a copious flow of cinder from the mass. The compressing of a porous lump of metal (such as a puddled ball) causes a great rise in the temperature of the mass. This favours expulsion of the slag, but the expulsion is never complete. If the puddled ball is shingled by a hammering action, the shingler turns over the mass from time to time between the strokes. Sometimes an additional ball, or balls, are welded together during shingling. This operation is known as "**doubling**." When the mass has been sufficiently worked and shaped into a somewhat rough, oblong block, it is taken to the **forge rolls**, where it is rolled into a **puddled bar**.

The further treatment of the puddled bar is described on p. 28, and the forge rolls (or forge train) on p. 32.

The foregoing is but a brief and bare outline of a process which is most interesting to watch. The procedure varies somewhat according to the pig iron provided, and the whole operation is one which calls for strength of arm and soundness of judgment.

The furnace requires to be fettled before each charge, but especially at the commencement of each shift. Slag is tapped off, when required, into a suitable little truck—the **cinder truck**—as shown in fig. 10. The waggon is also shown, full of cinder, in the foreground of fig. 1.

A puddler and his underhand between them work through six heats of about 5 cwts. each in the course of a working day, with a yield of about 30 cwts. of puddled balls.

The fuel used is a bituminous coal (see analysis on p. 226), which yields a long flame. About 24 cwts. are required for each ton of puddled balls produced.

In many, probably most, instances the weight of puddled balls produced is about equal to the weight of pig iron charged, but there is often a notable increase of iron, especially when the pig iron and the fettling are judiciously selected so as to suit each other. It is clear that the increase of iron is derived from the iron oxides with which the furnace is liberally fettled, and especially from that which the puddler looks on as a flux—namely, from the hammer scale or other iron oxides which are thrown into the furnace before charging the pig iron. And it is also clear from the composition of tap cinder, and the quantity sold, that the ferric oxide (Fe_2O_3) which predominates in much of the fettling material must, during the puddling process, have been reduced to magnetic oxide; the liberated oxygen doing useful work in oxidising the metalloids, as substances such as silicon, phosphorus, &c., are called. The composition of

Fig. 10.—Tapping Cinder from Puddling Furnace.

magnetic oxide is Fe_3O_4, which is sometimes looked on as Fe_2O_3, FeO. Adopting the formula introduced, for convenience of comparison, on p. 5, ferric oxide may be regarded, for purposes of comparison, as Fe_6O_9. This, on giving up oxygen, is reduced to magnetic oxide, which may be noted as Fe_6O_8.

There is good reason for believing that some part of the fettling, or the flux, acts as an *oxygen carrier*—the lower iron oxide becoming highly oxidised (peroxidised) by the oxygen of the air passing through the furnace, and readily giving up the newly-acquired oxygen. See chemical equations on pp. 27 and 28.

Average Composition of Slags or Cinders from the Puddling Process.

Constituents.	Chemical Formulæ.	Average Tap Cinder.	Boilings.	Hammer Slag.
Ferrous oxide, .	FeO	61·5	62·7	54·6
Ferric oxide, . .	Fe_2O_3	8·3	7·1	19·5
Manganous oxide, .	MnO	2·2	2·6	2·1
Silica, ...	SiO_2	20·3	20·9	17·5
Phosphoric acid, .	P_2O_5	5·3	6·2	5·1
Sulphur, . . .	S	0·7	1·5*	1·4*
Lime, ...	CaO	1·5		
Magnesia, . .	MgO	0·2		
		100·0	100·0	100·0
Metallic iron, . .	Fe	53·64	53·74	56·12

Theoretical Considerations.

Of the **elements eliminated** during puddling the only one to become gasified is carbon, which, combining with oxygen, forms carbon dioxide (CO_2), and escapes by the stack into the air. All the other elements, when oxidised, go into the cinder. The cinder must be of such a composition that it will become, and remain, fluid, or at least semi-fluid, during the operation. One of the first elements to be eliminated is silicon (Si), which is easily oxidised and forms silica† (SiO_2).

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*By difference.

†White sand is almost pure silica.

Now, silica is prone to unite with oxide of iron (FeO). The union, or chemical combination, of the two results in the formation of ferrous silicate ($2FeO . SiO_2$); a compound which fuses, or melts, with comparative ease. Hence some of the fettling or cinder must contain excess of ferrous oxide in order that free silica may not interfere with the process. The quaint idea of the late W. Mattieu Williams, that the fluid cinder may be compared to soap suds, and assists in the cleansing of the pig iron, is not far-fetched.

Into the intricacies of **acids and bases** the size and scope of this book forbids entrance, but it may convey sufficiently clear ideas at this point to say that the bases commonly met with in metallurgy can enter into chemical union with the metallurgical acids, and that the resulting compound has a much lower melting point than either the acid alone or the base alone. The union of the acid silica (SiO_2) with the basic ferrous oxide (FeO) is a case in point.

The following are classed as acids by metallurgists:—

Phosphoric acid or phosphoric anhydride,	(P_2O_5)
Titanic oxide, ...	(TiO_2)
Silica, ...	(SiO_2)
Carbonic acid (carbonic anhydride or carbon dioxide), ...	(CO_2)

The chief bases which are of interest to the iron and steel metallurgist are—

Ferrous oxide, ...	(FeO)
Manganous oxide, ...	(MnO)
Lime, ...	(CaO)
Magnesia, ...	(MgO)

Alumina (Al_2O_3) may act either as an acid or a base, according to circumstances.

The method by which phosphorus is eliminated during puddling was discovered by Geo. J. Snelus in 1872, and his theory is now universally accepted. It is this: The phosphorus (P_2) is oxidised to phosphoric acid (P_2O_5), which enters into chemical union with the basic ferrous oxide (FeO) in the cinder, and is held there.

Dephosphorisation, or the elimination of phosphorus, cannot be successfully conducted unless under oxidising conditions, and in presence of plenty of hot material of a basic nature. The manganese (Mn) which is oxidised becomes converted into manganous oxide (MnO), which increases the basic nature of the slag. The sulphur which becomes oxidised may escape in the gases or be caught in the slag.

The functions of the fettling and cinder are five-fold.

(*a*) To protect the iron plates and other castings at the working bed.

(*b*) To supply oxygen for removal of the impurities.

(*c*) To bind the grains together and to prevent the oxidation of the surface of the grains—"to nourish the iron."

(*d*) To provide a base for the phosphorus and other impurities.

(*e*) To increase the output.

The chief chemical reactions which take place during puddling are—

OXIDATION BY ATMOSPHERIC OXYGEN.

C	$+$	O_2	$=$	CO_2
Carbon	*and*	*oxygen*	*yield*	*carbon dioxide.*
Si	$+$	O_2	$=$	SiO_2
Silicon	*and*	*oxygen*	*yield*	*silica.*
$2Mn$	$+$	O_2	$=$	$2MnO$
Manganese	*and*	*oxygen*	*yield*	*oxide of manganese.*
$4P$	$+$	$5O_2$	$=$	$2P_2O_5$
Phosphorus	*and*	*oxygen*	*yield*	*phosphoric acid.*

The phosphoric acid unites with the (basic) ferrous oxide in the cinder or slag.

OXIDATION BY FERRIC OXIDE, WITH PRODUCTION OF MAGNETIC OXIDE.

C	$+$	$3Fe_2O_3$	$=$	CO	$+$	$2Fe_3O_4$
Carbon	*and*	*ferric oxide*	*yield*	*carbon monoxide*	*and*	*magnetic oxide.*

$$Si + 6Fe_2O_3 = SiO_2 + 4Fe_3O_4$$

Silicon and ferric oxide yield silica and magnetic oxide.

$$Mn + 3Fe_2O_3 = MnO + 2Fe_3O_4$$

Manganese and ferric oxide yield manganous oxide and magnetic oxide.

$$2P + 15Fe_2O_3 = P_2O_5 + 10Fe_3O_4$$

Phosphorus and ferric oxide yield phosphoric acid and magnetic oxide.

Other chemical reactions also take place.

Treatment of Puddled Bars.—The puddled bar* formed, as described in previous pages, by rolling the hammered or squeezed puddled ball, is rough on the surface and ragged at the edges. The slag which it contains is in splatches and not well distributed throughout the bar. To remedy these defects and to produce a bar more uniform in composition, with less slag, and the remaining slag more evenly distributed—in fact, of a quality sufficiently good for smiths and engineers—the puddled bars are cut into short lengths, made into oblong piles, reheated to a welding pitch in a reheating or mill furnace, and rolled out to a finished section in a set of rolls known as the "**mill train**" into "**merchant bar.**"

Piles for reheating are built up on puddled bars, or merchant bar, or old wrought iron, and the pile is arranged with due regard to the intended shape of the finished material.

Scrap wrought iron is piled, brought to a welding heat in a ball furnace or scrap furnace, and hammered into a half-finished mass called a bloom. The bloom is reheated in a mill furnace and rolled in the mill train into finished shape.

Best best and treble best iron is specially made from carefully selected materials which are puddled, shingled, rolled, cut, piled, reheated, and rerolled. The products are systematically tested, and the iron is of superior quality.

FORGE PLANT.

For consolidating puddled balls and expelling slag **squeezers** are sometimes employed. Of these, the **crocodile squeezer**

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* Known in America as "muck bar."

may be taken as an example. There are other appliances, but squeezing is a system which does not appear to be in favour.

A primitive, but effective, appliance for shingling the puddled ball is **the helve** (fig. 11), which has a heavy iron beam carrying a hammer head which can be easily replaced. The beam rests on a fulcrum at one end, and the other end is lifted by projections (cams) on a rotating cylinder. When the nose of the beam has been raised to the highest point to which a projection can carry it, the beam and hammer head fall heavily on the puddled ball which has been placed on the anvil block. The next projection on the revolving cylinder quickly raises the beam and hammer head, and again a heavy blow is dealt when the hammer head falls on the puddled ball. The nose may be raised about 20 inches, and about 60 blows per minute are delivered. The shingler keeps turning over the puddled ball between the strokes. To stop the working of the helve a prop or sprag is inserted, which keeps the nose of the beam above the action of the arms or projections. When a fresh ball has been placed on the anvil block, a piece of iron is laid on the upcoming arm. This causes the nose to be lifted higher; the prop is withdrawn, thereby allowing the helve to resume work.

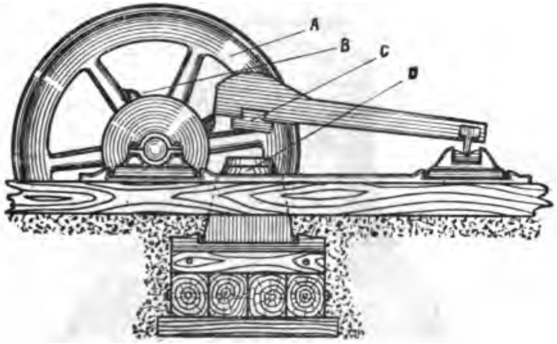

Fig. 11.—Helve.

A, Flywheel.
B, Cam.
C, Hammer head
D, Anvil.

The Steam Hammer (fig. 12) consists essentially of an upright stem or frame supporting a vertical steam cylinder, in which works a piston having a long rod with a hammer head

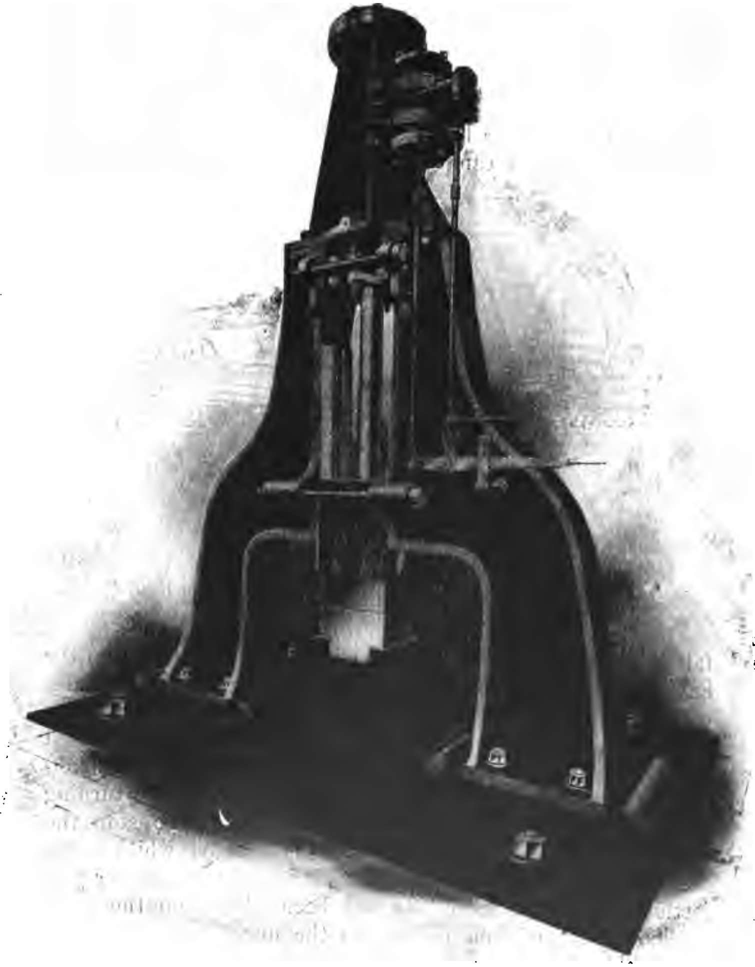

Fig. 12.—Steam Hammer.

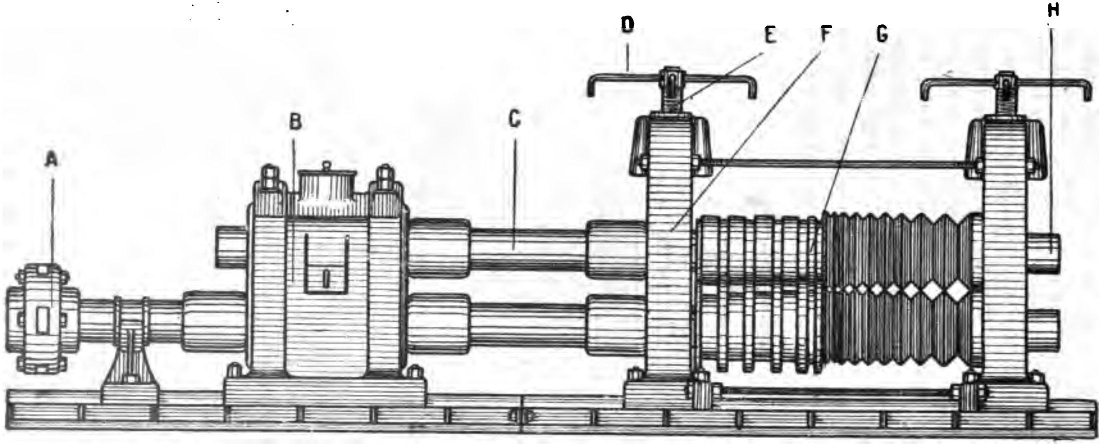

Fig. 13.—Forge Train—Front View.

A, Flanged driving coupling.
B, Pinion housing.
C, Coupling spindle.
D, Spanner.
E, Adjusting pins or screws.
F, Roll housings.
G, Forge rolls.
H, Wobbler.

or tup at its lower end. By means of a lever controlling the admission of steam to the upper or the lower part of the cylinder, the rate and force of the blows can be easily regulated. An anvil block is set immediately below the tup. Both block and tup can be readily replaced when required.

The Forge Train, in which the shingled blooms from the helve or hammer are rolled into puddled bars, is sketched in fig. 13. This train comprises helical-teeth pinions fitted in enclosed housings, also one pair of forge rolls with housings, chocks, brasses, pins, boxes, couplings, &c., and the whole train is mounted upon a massively-designed girder-section bed plate. The advantages of this design are that the mill is always kept perfectly in line, and the time occupied in changing rolls is considerably reduced.

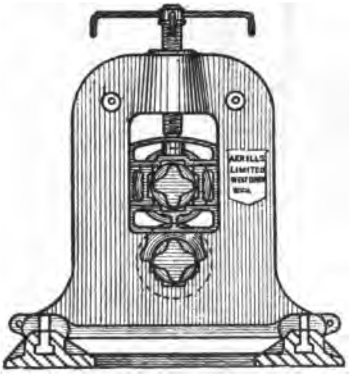

Fig. 14.

Fig. 14 shows an end view of the forge train.

Fig. 15 illustrates a 10-inch **merchant bar mill, or guide mill,** so called because a set of guides are provided for guiding the oval section into the finishing round groove of the finishing rolls. The merchant mill is designed for the purpose of rolling wrought iron from a pile of 4-inch puddled bars into any desired section. The rolls shown are for flats, 1½-inch and 1¾-inch broad, of such thickness as may be required. For producing rounds or squares, the rolls for flats marked D would be removed and a set of rolls with oval and diamond openings substituted.

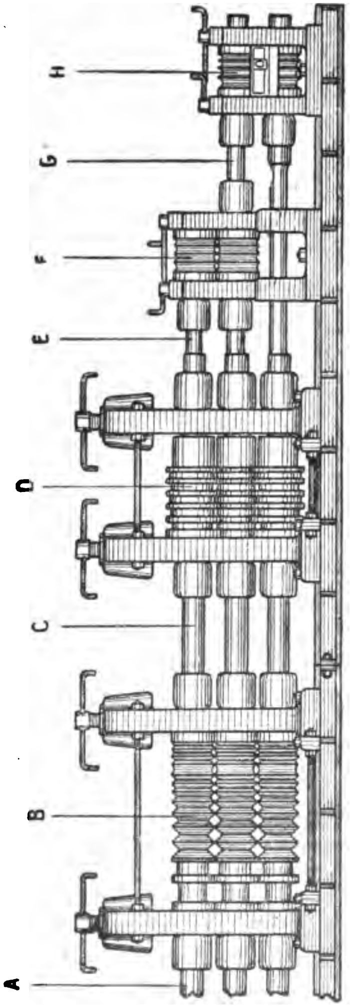

Fig. 15.—Merchant Bar Mill or Guide Mill.

A, Coupling spindles.
B, Bolting or roughing rolls.
C, Coupling spindle.
D, Second bolting or roughing rolls.
E, Coupling spindle.
F, Guide rolls with oval grooves.
H, Guide rolls turned for producing round bars.

The mill comprises flanged couplings, leading spindle and carriage, double helical-teeth pinions fitted into housings, with a separate gland cover constituting an oil bath in which the pinions revolve. The bolting rolls and strand rolls are fitted with housings, chocks, brasses, and necessary wrought-iron work, guides, guards, &c., and two pairs of chilled guide rolls are provided for giving a good finish to round and square bars. These guide rolls also are fitted with necessary housings, glands, stools, brasses, wrought-iron work, guides, &c., and the whole mill is mounted on a girder-section bed-plate. For the sake of clearness, some of the usual fittings have been omitted from the sketch.

These mills are of the type manufactured by Messrs. Akrill, Limited, West Bromwich.

Best Yorkshire Iron is made from special (cold blast) pig iron which undergoes a refining process before being puddled in small charges. Its manufacture is conducted with great care, the puddled iron is conscientiously examined, the blooms, &c., are heated well, and a large amount of work is put upon the iron. The qualities which have given it a world-wide reputation are its reliability even under most exacting conditions, its capability of standing repeated reheatings, and its power of enduring without deterioration much punishment in the hands of the smith and engineer.

CHAPTER IV.

STEEL: CRUCIBLE CAST STEEL FOR TOOLS AND CUTLERY.

Of the services rendered to civilisation by the production of good tool steel, it would be difficult to speak too highly.

Steel is essentially a compound of iron and carbon. It contains other elements, some intentionally added to confer certain qualities on the steel; others are unavoidably present, but cannot be tolerated in more than small percentages.

The best quality steel for tools and for cutlery is known as **crucible cast steel.** The process is still carried on—chiefly in Sheffield—with slight variations in the details of the system devised, after many trials, by Benjamin Huntsman about the year 1740.

High-class crucible cast steel is made by the application of intelligent experience to the correct treatment of carefully-selected materials of high quality—of such experience as has been practically acquired through generations of skilful working.

Outline of the Process of Manufacture.—The iron used is brought from Sweden,* where the pig iron is smelted from the purest ores by the purest fuel. The pig iron is worked into wrought iron in a type of furnace which originated in the north-west of England, and, being adapted to Swedish requirements, is named the Swedish-Lancashire hearth.† The wrought iron is hammered into long flat bars, and these bars are supplied to steel-making firms. From the bars crucible cast steel is manufactured in two definite stages. Firstly, the bars are subjected to a cementation process by being heated for several days in contact with charcoal in boxes, the tops of which are *cemented* to exclude air.

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* Some American steel-makers believe that Swedish iron is not necessary. A high degree of purity is always required.

† The famous Dannemora bar iron is produced from pig iron by the old Walloon fining method.

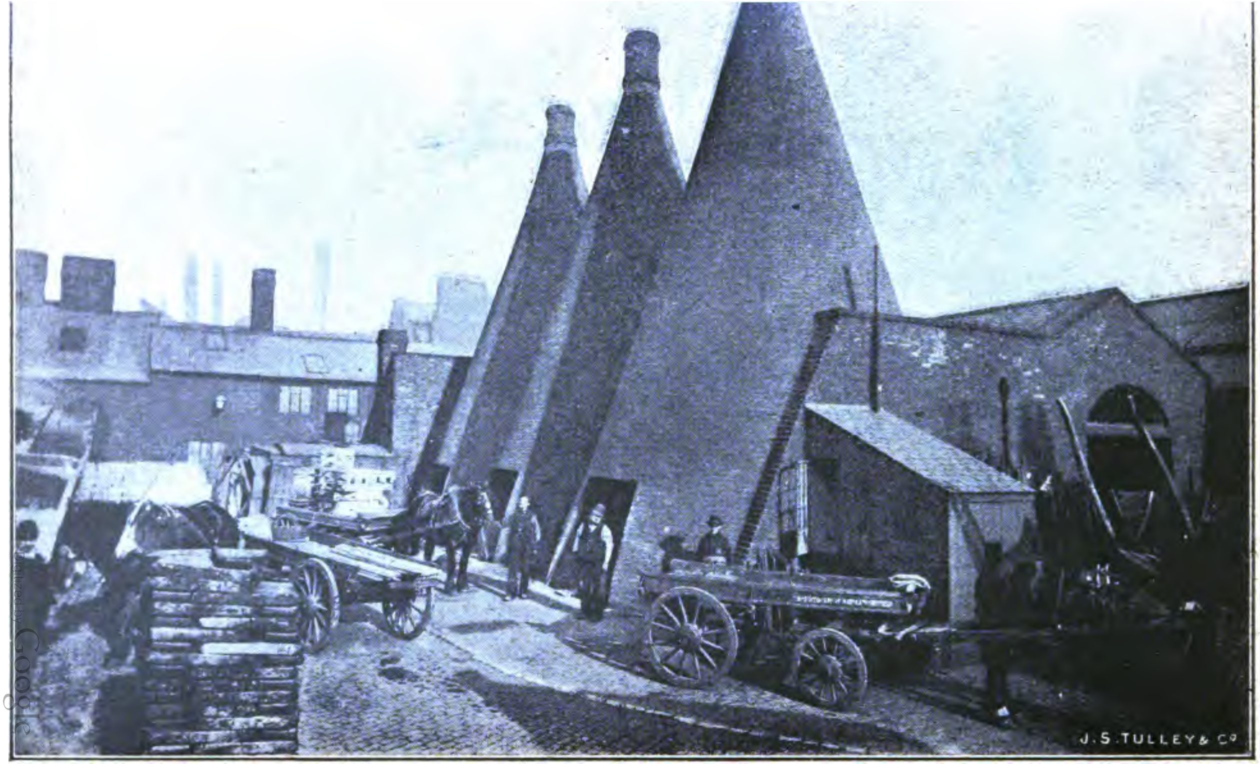

Fig. 16.—Cementation Furnaces—Messrs. Thomas Firth & Sons, Norfolk Works, Sheffield.

Secondly, in order to produce steel in masses which are free from slag and of the same composition and qualities throughout, the "cemented bars" are broken, graded, melted in a crucible at a white heat, and, with proper precautions, poured into prepared moulds so as to form ingots which can be worked into the shapes desired.

The cementation furnace is externally a tall, tapering structure (the stack), which is sometimes square at the base and circular towards the top. Fig. 16 shows a view of the stacks of steel furnaces at Messrs. Thomas Firth & Sons' Norfolk Works, Sheffield.

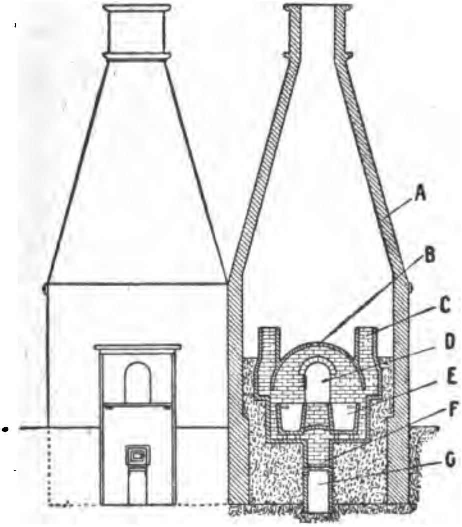

Fig. 17.—Cementation Furnace—Elevation and Section.

A, Stack.
B, Arch.
C, Chimney.
D, Manhole.
E, Cementation pots.
F, Fire-grate.
G, Ashpit.

Inside the stack, at its base, a fire-grate extends from front to back; and alongside the fire-grate two long troughs—or "cementation boxes"—are placed. These are shown in section on fig. 17, and a plan is shown on fig. 18. In order that the heat from the fire-grate may find free and fairly equal access to all parts of the outside of the cementation boxes, they are set on bearers, and passages are arranged leading to short chimneys. Between the walls in which the short chimneys are set, a brick arch is built at some little distance above the boxes, or "pots," as they are sometimes called.

The inner walls and arch are of good firebrick; the lower part of the stack is also of good firebrick, while the upper part may be of more common bricks. The stack—which is generally about 50 feet high—prevents excessive radiation from the arch, and also serves the usual purposes of a chimney. A manhole is provided in the brickwork, and "trial holes" are left in the brickwork, which correspond to similar holes in the ends of the boxes.

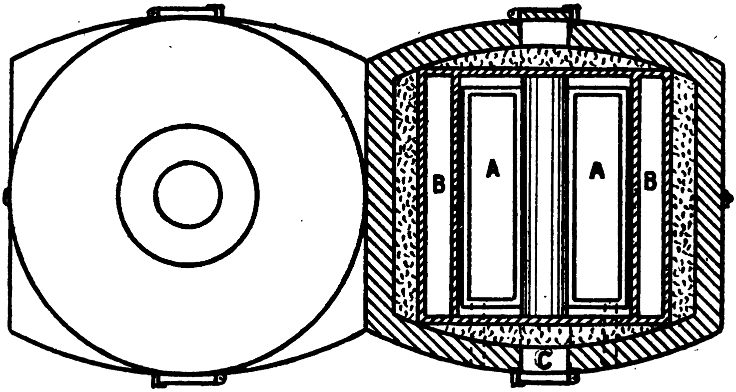

Fig. 18.—Cementation Furnace—Plan.

A, Cementation pots. | B, Passage to flues. | C, Fire-grate.

The Cementation Boxes, or Pots, are of firestone slabs cemented with a mortar of good fireclay. They are from 8 to 16 feet in length, a fair average size being 12 feet long, 4 feet deep, and 4 feet wide. The capacity of a furnace is from 15 to 30 tons. The boxes are packed by placing in each a layer of selected hardwood charcoal, which has been sifted to exclude pieces generally smaller than half-inch. Some old charcoal is used along with the new. A layer of the flat bars—which are frequently 3 inches broad by three-quarters of an inch thick—is placed on the charcoal, and completely covered at sides, ends, and on top with charcoal. Alternate layers of flat bars and charcoal are packed in, the uppermost one being of charcoal. This is covered with a thick coating of clay or of **wheelswarf.** Wheelswarf is collected from the troughs of the Sheffield grindstones, and consists of the worn-away material of the grindstones, mixed with the steel dust which has been ground away. The dust "sparks" as it is ground; that is, it becomes oxidised, so that the wheelswarf is really a mixture containing iron, iron oxide, and silica from the grindstone. A coating of wheelswarf is sufficiently porous to permit the escape of air from the pots while the contents are being heated, but which readily fuses even at a moderately-high temperature, and so forms an air-tight cover. Iron (or steel) in the wheelswarf is incidentally oxidised during the rise of temperature, and iron oxide and silica, when heated, easily fuse, as mentioned in the paragraph on welding and the chapter on puddling.

When the pots are packed and duly covered, the front of the furnace is bricked up, and a fire is kindled in the grate. The long grate of the furnace is fed from both ends; a free-burning coal which does not "clinker" being used. A non-clinkering coal is one which leaves a white ash in fine powder. In the course of 24 hours or so a red heat is attained, and the full heat, a bright orange (about 2,120° F., or 1,160° C.), is reached in about 48 hours. The full heat may be maintained for a week or more, according to the degree of carburisation, or "temper," aimed at. *The chief effect of this treatment is the penetration of carbon into the solid iron bars.*

While packing a box, a few "tap bars," or "trial bars," are set with their ends protruding through the slot left in one end of the box. When there is reason to believe that the correct carbonisation (or conversion) has been arrived at, one of the tap bars is withdrawn, and the vacated space in the end slab of the box is carefully filled with white coal ash or other suitable material. The tap bar, when cold, is broken, and the fracture is examined. The experienced eye can judge such fractures with great accuracy. When conversion is thus judged to have gone far enough—allowance being made for further carburisation during part of the time of cooling—the firing, or stoking, is stopped, and the fire is banked. The furnace cools slowly, as otherwise the pots would be liable to crack, and in the course of a week or more the furnace is cold enough to allow the entrance of the workmen by the manhole, which has been opened. The wheelswarf cover is broken and removed, and the bars are taken out of the pot.

The charging, converting, and unpacking occupy about three weeks: for higher carbonisation more time is required than for lower temper bars. About 25 tons of coals will be consumed during the conversion of an ordinary 30-ton lot of bars.

During conversion the bars gain in weight through carbon being taken up. The "converted" or "cemented" bars differ in appearance from the bars as packed. Originally they were fibrous and tough. As taken from the boxes they are crystalline[*] and brittle, and are covered with blisters—hence the name "blister steel." If the blisters are small and evenly distributed over the surface, it is assumed that the iron was good and that the conversion is satisfactory.

The blister steel bars are broken across; the fracture is examined, and each piece is stacked according to its "temper" or degree of carburisation. The bars which were nearest to the fire are more highly carburised than those which were in the centre of the pot, and there must necessarily be more than one temper from each pot.

In the trade the blister steel is classed thus—

No.	1	or	spring heat,	containing	½	or	·5	per cent. of carbon.
,,	2	,,	country heat,	,,	⅝	,,	·625	,,
,,	3	,,	single shear heat,	,,	¾	,,	·75	,,
,,	4	,,	double shear heat,	,,	1			,,
,,	5	,,	steel-through heat,	,,	1¼	,,	1·25	,,
,,	6	,,	melting heat,	,,	1½	,,	1·5	,,

No. 1 is not called "spring heat" to indicate that it is suitable for making springs (it is not suitable), but because of

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[*] In the lower tempers the centre portion remains uncarbonised and is called "sap"; the crystals of sap have lost their brilliancy—the sap is said to be killed and no longer looks "raw" or "stares."

so much "sap." The term "Irish temper" is also applied and the term "country heat," by which No. 2 is known, are all suggestive of verdancy. In the lower numbers the conversion has not proceeded far, and the broken bars show much unaltered iron in the centre. In "double shear heat" bars about one-half of the area, in the centre, has not been changed, while in the highest number the whole of the bar has been converted, all the fibre has gone, and the entire area of the fracture is crystalline.

Even with experience and the exercise of care accidents occasionally happen, and the cemented bars are more or less spoiled. **Aired bars** are those to which air has had access through a crack or cracks in the pot or the covering. **Glazed bars** are those which, during conversion, have been overheated, and the edges of which are generally melted in the converting pot. **Flushed bars** are those resulting from overhurried conversion, and which show too plainly the lines dividing converted from unconverted portions. Tradition tells of "pots" which were so badly cracked that the charcoal had been burned and the intense local heat had caused the bars to become welded together. But the bars, as a rule, successfully run the gauntlet of possible mishaps, and the product is good for the intended purpose. The majority of the blister steel bars are meant to be melted in crucibles. Some, however, are to be used otherwise, and they are subjected to different treatment.

"**Bar Steel** is the name given to blister steel which has been tilted or rolled down to the size required.

"**Single Shear Steel** is produced by welding six bars of blister steel which are unconverted in the centre, and rolling them down so as to have a fairly uniform mixture of iron and steel—a material which combines great tenacity with the capability of carrying a moderately hard shearing or cutting edge." Or bars of blistered steel may be heated and hammered into plates, an operation known as **plating**. Seven or eight plates are piled together, heated, and hammered into shape. In some instances they are finally rolled down into single shear blades.

"**Double Shear Steel** is produced by rolling down single shear steel to suitable-sized bars and rewelding two of them together so that the mixture of iron and steel may be more perfect."* Or hammered shear steel is bent over on itself, and again hammered down.

The bars or plates require to be raised to a welding heat, and must be protected to prevent undue and uneven loss of carbon. For this purpose the bars or piles are covered with gypsum or other suitable material which will melt and form an even coating capable of remaining intact while in the furnace.

Cast or Crucible Steel.—Blister steel bars contain slag, and no bar is uniform in composition throughout. The outer portions of each contain more carbon than the inner portions. To obtain a homogeneous† steel, from which the slag has become separated, it is necessary to melt the blister steel.

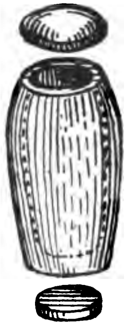

Fig. 19.—Crucible, with Lid and Stand.

Melting is carried on in **crucibles or "pots,"** which are carefully made from judicious mixtures of suitable fireclay. A crucible is about 17 inches high and 7 or 8 inches diameter at the top. They are seasoned for a fortnight or so and "annealed" before being used.

The "steel-melting house," in which the making of crucible cast steel is carried on, is a building which contains a number of "steel-melting holes," and the necessary arrangements for casting the steel into ingots. Fig. 20 shows a view of a steel-melting house at the works of Messrs. Samuel Osborn & Co., Sheffield—so long associated with the Mushets. The steel-melting holes are ranged along the sides of the building but under the floor level. They are covered, as shown in the illustration, by covers composed of firebrick slabs set in iron frames and having iron handles.

A section of a steel-melting hole is shown in fig. 21. Each "hole," or furnace, is lined with ganister so as to form an

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* Seebohm, *Iron and Steel Inst. Journal*, 1884, ii., p. 379.

† From Greek words signifying *of one kind.*

Fig. 20.—Steel-melting House—Messrs. Samuel Osborn & Co., Sheffield.

oval of about 36 inches in depth, 26 inches in its longest diameter, and 19 inches across, so as to hold two crucibles or pots. Access to the fire-bars, &c., is from the cellar. Ten or more holes constitute a set, the flues from which lead to long stacks.

The fuel used is a specially hard burned coke, and the draught from the furnace is regulated in a simple manner which is quite effective. If the temperature requires to be moderated, the brick which is used for closing the inlet from the cellar flue (see fig. 21) is removed, thus allowing an inrush of cold air through the flue to the chimney. The

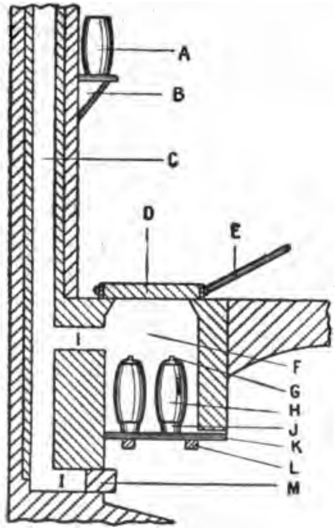

Fig. 21.—Section of Steel-melting Hole.

A, Crucible being gently dried.
B, Shelf and support.
C, Stack.
D, Cover of melting-hole.
E, Handle of cover.
F, Furnace.
G, Lid.
H, Crucible.
I, I, Flues.
J, Stand.
K, Fire-bar.
L, Bearer.
M, Brick for regulating the draught.

"draught" is thereby lessened. When a higher temperature is needed the brick is inserted in the inlet. Only hot products of combustion, or hot air which has passed between masses of glowing coke, can enter the flue, and, as the chimney thereby becomes and continues to be filled with hot gases, the draught is increased. Live coals are used to kindle the coke required as fuel in the melting holes.

The crucibles employed in steel melting are carefully prepared beforehand, and are subjected to a long course of gentle drying. Before being used they are kept, mouth downwards, in an annealing furnace which is at a red heat. The pot, which has thus been tempered, is set on a stand in a hot melting hole and coke is packed round it. In the course of an hour the pot is ready for the charge. To charge the pot, one workman holds a wrought-iron funnel or charger, while another empties a weighed charge of blister steel—of selected temper—which is in small pieces. The charge also contains some fluxing material and some "physic." Physics are compounds containing manganese, a metal which acts beneficially in steel-making. The lid is then put on the crucible. The next one is charged in like manner, the remainder of the hole is filled in with coke, the cover is placed over the hole, and the draught is regulated. When the fire has burned some time the remainder of the coke in the hole is pottered down towards the fire-bars, and more coke is added.

From time to time the head melter examines the condition of the furnaces and gives orders for the further making-up of the fires, the regulation of the draught, &c. By and bye he has the covers moved, and, feeling with an iron rod the contents of the crucibles, he gives final instructions with regard to the fires and the time of teeming. The head melter must have ripe experience and sound judgment. When ready, the "puller-out," wrapped in "clothes" which are soaked in water to protect him from the heat, lowers a pair of tongs, with a broadened and ribbed ending, into the furnace and with them grips one of the crucibles, pulls it up, and sets it on the floor of the melting house. The slag is quickly skimmed off, and the steel is poured into the moulds. The moulds are of cast iron and each formed of two halves tightly held together by rings and wedges. The moulds must be previously "reeked" (smoked) or covered with a fine deposit of soot by exposing the inner surfaces to the smoky flame of burning coal tar. Or the steel may be prevented from adhering to the moulds by wiping the inner parts with oil or with fireclay in water. The moulds must be dry and warm before teeming the steel into them. They are set in a slanting position in recesses—known as "teeming holes"—in the floor, and the steel is poured into them. The crucible is then put back into the furnace, or hole, and heated before receiving the next charge.

The first crucible charge for the day may be 60 lbs., the second one 54 lbs., and the third one 48 lbs. These three charges constitute the round for the day and finish the life of the crucible, which cannot, with a reasonable degree of safety, be trusted to melt more. Each crucible is placed in a hot oven about 24 hours before being required so that it may be well annealed before receiving its charge. Owing to chemical action which cuts a groove into the crucible where the slag is—on the top of the melted steel—it is necessary to diminish the weight of the second and third charges in each pot.

Inferior steel must be "teemed" into the mould as soon as possible after it has become perfectly fluid and as hot as the pot is likely to stand the strain of "pulling out." Higher class steel requires "killing"—that is, it requires to be kept in the furnace for about half an hour (more or less as the judgment of the head melter decides) after it has become fluid, and it must be poured at a proper temperature. The higher the quality of the steel the more killing it will require. If not "killed," or if too hot when poured, the steel boils over in the mould, the fracture of the ingot when cold shows a series of bubbles like a sponge. "If the steel be not long enough in the fire, it will teem fiery and produce a honeycombed ingot, and the same result will follow if it be too hot when it is poured. If it remain too long in the fire it will teem 'dead,' the fracture of the ingot will look scorched, and though exceptionally sound it will be brittle if hard, and wanting in tensile strength if mild. If the molten steel be chilled before it is poured into the mould, which may be detected by the stream skimming over as it is teemed, the fracture of the ingot will appear dull in colour, and full of small holes and honeycombs." *

The steel ingots are carefully reheated and hammered or rolled into the bars required. Bars for certain purposes are straightened by reeling.

The best crucible cast steel is made from Swedish iron, smelted from ores containing a small quantity of phosphorus.

There are four methods of making crucible steel, and they are as under :—

I. Select cut bar iron and "fetch it up" by addition of charcoal. Melt and teem.

II. Use broken pig iron and "let it down" to the required temper with cut bar iron. Melt and teem.

III. Select or "take up" blister steel of the desired percentage of carbon. Melt, dead melt or kill, and teem.

IV. Select blister steel which is a little too hard and "let it down" with a small quantity of milder cast steel scrap. Melt, dead melt or kill, and teem.

Some steel-makers believe that only by methods III. and IV. can best quality steel be made in crucibles.

TABLE OF THE COMPOSITION OF THE "METAL" IN THE VARIOUS STAGES OF THE MANUFACTURE OF CRUCIBLE CAST STEEL.

Constituents.	Chemical Symbols.	Swedish Pig Iron.	Swedish Wrought-iron Bars.	Cemented Bars, or Blister Steel.	Crucible Cast Steel.
Graphitic carbon,	C	0·12	...	...	...
Combined carbon,	C	3·86	0·05	varies†	varies†
Silicon, . .	Si	0·15	0·02	0·02	0·17
Phosphorus, .	P	0·03	0·02	0·02	0·02
Sulphur, . .	S	0·02	0·01	0·01	0·05
Manganese, .	Mn	0·29	0·07	0·07	0·18
Iron, . . .	Fe	Δ	Δ	Δ	Δ
		100·00	100·00	100·00	100·00

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* Seebohm, *Iron and Steel Institute Journal*, ii., 1884, p. 385.

† The percentage of carbon varies according to the treatment in the cementation process, as previously explained.

The chief points in the foregoing table are:—

> The Swedish pig-iron contains little phosphorus and less sulphur. The carbon, silicon, and manganese—and to a slight extent the sulphur—are reduced in amount during the working of the pig iron into wrought-iron bars, and it may here be explained that it is absolutely necessary to remove the excess silicon, which is unavoidably present in the pig iron. It is not practicable to get rid of even that small quantity of silicon without removing carbon and manganese.
>
> The only change effected during the cementation stage is the combination of carbon with the iron—with production of blister steel. While in the crucible the steel is increased in manganese, sulphur, and silicon.

The increase in sulphur arises from the presence of that element in the coke used as fuel. Sulphur can, singularly enough, penetrate the hot crucible, and combine with the metal. The additional manganese is derived from the ferro-manganese* or other physic used. Manganese acts on the oxide of iron remaining in the steel, liberating the iron and becoming oxide of manganese—a reaction indicated by the equation—

$$\begin{array}{ccccccccc} \mathrm{FeO} & + & \mathrm{Mn} & = & \mathrm{Fe} & + & \mathrm{MnO} \\ \textit{Iron oxide} & \textit{and} & \textit{manganese} & \textit{yield} & \textit{iron} & \textit{and} & \left\{\begin{array}{c}\textit{oxide of} \\ \textit{manganese.}\end{array}\right. \end{array}$$

The oxide of manganese rises to the top of the metal and attacks the silica of the crucible, manganese silicate being formed. During dead melting or killing, this silicate is acted on by carbon in the steel with liberation of silicon. The reaction may be represented thus—

$$\begin{array}{ccccccccc} \mathrm{2MnO,SiO_2} & + & \mathrm{C} & = & \mathrm{Si} & + & \mathrm{CO_2} & + & \mathrm{2MnO} \\ \left.\begin{array}{c}\textit{Silicate of} \\ \textit{manganese}\end{array}\right\} & \textit{and} & \textit{carbon} & \textit{yield} & \textit{silicon} & \textit{and} & \left\{\begin{array}{c}\textit{carbon} \\ \textit{dioxide}\end{array}\right\} & \textit{and} & \left\{\begin{array}{c}\textit{oxide of} \\ \textit{manganese.}\end{array}\right. \end{array}$$

This silicon passes into the steel, and effects, or at least hastens, the elimination of gases. The small quantity of silicon which is taken up is beneficial, but more than that

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* See composition on p. 237.

amount would be deleterious. The small percentage of manganese does not adversely affect the quality of the steel, while it is helpful in keeping down the evil influence of the sulphur which has entered the steel. Good crucible steel cannot be made from iron containing more than ·03 per cent. of phosphorus; hence the great value of the comparatively pure Swedish irons.

For cheap cutlery or for constructive purposes "steel" is often made in crucibles from materials other than cemented bars with a judicious addition of black oxide of manganese along with a little carbon, or the addition of spiegel-eisen—which is a fairly pure white pig iron containing much manganese—or the still richer ferro-manganese. Then there is the unchallenged statement of the late Sir Henry Bessemer that "at least one-half of the crucible steel made in Sheffield is made from Bessemer scrap, simply remelted."* For some purposes such steel scrap is remelted in graphite (plumbago) crucibles. Puddled steel—a semi-puddled product—is also used in making crucible steel, and steel is made from unconverted bars by melting a charge and adding carbon and spiegel-eisen.

Besides such "physics" as spiegel-eisen and ferro-manganese, quite a number of nostrums have been proposed at various times and used in attempting to make superior steels from common iron.

A large quantity of steel is made, the chief quality of which is the possession of an enduring cutting edge. Some crucible steel ingots are required to be solid; some mild steels must be weldable.

The first successful attempt to improve the quality of crucible cast steel for tools was made by R. F. Mushet, whose "self-hardening" tool steels (steels containing chromium, tungsten, and a notable amount of manganese) held the field until the advent of the "rapid-cutting" tools of Messrs. Taylor & White, of the Bethlehem Company's Works, Pennsylvania, U.S.A., paved the way for further considerable advances in the quality of quick-cutting tools.

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* *Iron and Steel Journal*, 1884, vol. ii., p. 397.

Analysis of Special Tool Steels.—Mushet's self-hardening tool steel contains carbon, 1·65; silicon, 1·36; manganese, 2·12; tungsten, 5·80; and chromium, 0·45 per cent.

Quick-cutting steel, as made by Messrs. Whitworth, Armstrong & Co., Manchester, contains carbon, 0·55; tungsten, 13·5; and chromium, 3·5 per cent.

To all steel users the good advice given in Metcalfe's excellent *Manual for Steel Users* can be commended: "The best way for a steel user to do is to tell the steel-maker what he wants to accomplish and put upon him the responsibility of selecting the best temper. It costs no more to make and to provide one temper than another; therefore the one inducement of the steel-maker is to give his patron that which is best adapted to his use."

The most useful tempers of tool steel are included in the following list, compiled by the late Mr. H. Seebohm:—

Razor Temper (1½ per cent. Carbon).—This steel is so easily burnt by being overheated that it can only be placed in the hands of a very skilful workman. When properly heated, it will do twice the work of ordinary tool steel for turning chilled rolls, &c.

Sawfile Temper (1⅜ per cent. Carbon).—This steel requires careful treatment; and, although it will stand more fire than razor-steel, should not be heated above a cherry-red.

Tool Temper (1¼ per cent. Carbon).—The most useful temper for turning tools, drills, and planing-machine tools in the hands of ordinary workmen. It is possible to weld cast steel of this temper, but only with the greatest care and skill.

Spindle Temper (1⅛ per cent. Carbon).—A very useful temper for circular cutters, very large turning tools, taps, screwing dies, &c. This temper requires considerable care in welding.

Chisel Temper (1 per cent. Carbon).—An extremely useful temper, combining, as it does, great toughness in the unhardened state with the capacity of hardening at a low heat. It is consequently well adapted for tools when the unhardened part is required to stand the blow of a hammer without snipping, but where a hard cutting edge is required, such as cold chisels, hot setts, &c.

Sett Temper (⅞ per cent. Carbon).—This temper is adapted for tools where the chief punishment is on the unhardened part, such as cold setts, which have to stand the blows of a very heavy hammer.

Die Temper (¾ per cent. Carbon).—The most suitable temper for tools where the surface only is required to be hard, and where the capacity to withstand great pressure is of importance, such as stamping or pressing dies, boiler cups, &c. Both the two last tempers may be easily welded by a mechanic accustomed to weld cast steel.

CHAPTER V.

TREATMENT OF TOOL STEEL.

SPECIAL CHAPTER BY H. W. WALDRON.

WHEN a steel containing more than about 0·2 per cent. of carbon is heated to redness, and suddenly cooled by quenching in water or other suitable medium, it becomes hard. The degree of hardness depends to a certain extent upon the rapidity of cooling and the temperatures used, but to a much greater extent upon the percentage of carbon contained in the steel. Steels containing 0·2 per cent. of carbon can only be slightly hardened by the above treatment, while those containing from 1·00 to 1·75 per cent. become intensely hard and somewhat brittle.

Several theories have been advanced in explanation of the phenomenon of hardening, but whatever may be the precise function of the carbon, it is agreed that the presence of that element is essential to the hardening of ordinary commercial steel.

The changes observable during the heating and cooling of steel may be thus briefly summarised:—When a piece of almost carbonless iron, heated to about 900° C. (full cherry red), is allowed to cool slowly, and its temperature continually recorded by a sensitive pyrometer, it is found that a "retardation" in the rate of cooling takes place at three distinct points, indicating that a chemical or physical change has taken place with evolution of heat. These critical points—which occur at temperatures of about 825° C. (cherry red), 720° C. (low red), and 650° C.*—are known by the formulæ Ar 3, Ar 2, and Ar 1. In the case of steels containing a considerable percentage of carbon, there is only one critical point, Ar 1, at about 670° C.* The reverse changes take place during the heating up of steel, there being an absorption of heat at the

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* 825° Centigrade = 1,517° on the ordinary (Fahrenheit) thermometer.

720°	,,	= 1,328°	,,	,,	,,
670°	,,	= 1,238°	,,	,,	,,
650°	,,	= 1,202°	,,	,,	,,

points Ac 1, Ac 2, Ac 3, which occur about 30° C. above those observable on cooling down the steel.

The retardation taking place at Ar 1 is accompanied by a change in the condition of the carbon from the state of "hardening carbon," as it exists in hardened steel, to that of "cement carbon," or the definite carbide, Fe_3C, which is present in normal and annealed steel. In order to convert cement carbon into hardening carbon, it is necessary to heat the steel to a temperature above the critical point Ac 1.

Brinell, in his famous researches on the heat treatment of steel, used the terms W and V to indicate the points Ac 1 and Ar 1 respectively, and, for the sake of simplicity, Brinell's formulæ will be used in the remainder of this chapter, which will deal only with steels containing ·7 per cent. and upwards of carbon, unless otherwise stated.

If steel, heated to any temperature above W,* is suddenly cooled by quenching, the carbon is retained as "hardening carbon" (no time being given for the change to "cement carbon" to take place), and hardened steel is the result.

Hardening of Steel in Practice.—It would appear from the preceding paragraph that the process of hardening steel by quenching from any temperature above a red heat is an extremely simple operation. It is true that steel containing a sufficient amount of carbon may be made quite hard by the above means without any precautions whatever, but nothing has yet been said about the strength, durability, freedom from defects, and general fitness of a tool so hardened. As a matter of fact, for the successful hardening of tool steel considerable skill and care are needed.

Brinell noted that when steel is heated to the temperature W, and either quenched or slowly cooled, an extremely fine grain is produced, and that, if heated to any temperature above W, the grain becomes coarser and coarser with each increment of heat. No matter how coarse the fracture is before the treatment, it becomes as fine as it is possible for that steel to be when it is heated to the temperature W.

In hardened steel the finest structure is accompanied by the greatest strength.

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* The temperature indicated by W is about 700° C. with steels containing 1¼ to 1½ per cent. of carbon, and gradually rises as the percentage of carbon decreases.

The following experiment is very instructive:—Take a bar of tool steel ($\frac{1}{2}$ inch × $\frac{3}{8}$ inch × 12 inches long is a convenient size), notched with a chisel at intervals of 1 inch throughout its length, and heat it in such a manner that one end is at a bright yellow heat, gradually decreasing to a temperature below redness at the other end. Then quench the bar in cold water, break off at the notches, and compare the fractures. It will be found that the part which has been heated to the highest temperature will have a coarse granular fracture, and that the size of the grains gradually decreases in the parts less highly heated, until the point heated to the temperature W is reached, when a fine fracture like that of porcelain will be exhibited.

Although steel may be hardened by quenching from any temperature above W, it will be readily understood that the temperature which gives the finest grain and the greatest strength, together with sufficient hardness, must be the best to quench from. The correct hardening heat for any steel may easily be experimentally determined by quenching samples from different temperatures and observing the fractures.

For the successful hardening of tool steels, means must be at hand for gradually bringing up the metal to the required temperature, allowing sufficient time for it to become uniformly heated throughout, but without permitting any part of it to exceed the correct hardening heat. Excessive oxidation should be carefully avoided.

The means used for heating are too numerous to be detailed here; any appliances may be used which will bring about the conditions named above. They include various forms of coal- and gas-fired furnaces and muffles, lead baths, charcoal and "breeze" fires. The temperature may be judged with the eye with surprising accuracy by an experienced hardener, but in some cases a pyrometer may be used with advantage. If a pyrometer is not used, the light in the hardening shop should be subdued and as uniform as possible, all bright sunlight being carefully excluded. Steel which looks red hot in diffused daylight will appear almost black in bright sunlight. Excellent hardening is continually being done from an ordinary blacksmith's hearth, but much experience and judgment are necessary in order to obtain good results by this method.

Quenching.—For most purposes, water is the best quenching medium. The tool should be kept moving rapidly in the water, otherwise bubbles of steam may collect on the surface of the steel, and greatly retard the cooling action. The water should be, as near as is practicable, to the temperature which is known to give good results with the class of steel being hardened. Hardening in very cold water at the commencement of a day's work will often result in an unusual number of cracked tools.

Brine has a greater quenching power than pure water, and with some tools (notably files) gives better results.

Mercury is a quicker cooling medium than either water or brine, and is sometimes used for small articles required to be extremely hard.

Quenching in Oil.—Some articles, such as springs and saws, which are required to be very elastic and tough without possessing very great hardness, are quenched in oil. Whale oil and lard oil are frequently used for the purpose.

Defects Produced by Hardening.—Improper hardening, or the use of inferior steel, will often cause "**water cracks.**" These cracks are the direct result of the enormous stresses to which the hardened steel is subjected by contraction during the sudden cooling. The stresses vary in extent and direction according to the shape and size of the tool, the temperature of the steel and of the quenching medium. Sometimes a corner of the steel will fly off when in the water, while in other cases the cracks can only be detected by a very minute examination of the polished surface of the metal. If the steel has been tempered before the crack is detected, the surface of the fracture where the water crack occurs will be covered with an oxide film of the usual temper colour, even if the crack is so minute as to require the aid of a magnifying glass to see it.

The necessary conditions for the prevention of water cracks may be obtained—

(1) By the use of steel of such a quality as to give the greatest strength, together with sufficient hardness.

(2) By minimising, by careful treatment in the forging and hardening processes, the magnitude of the stresses to which the steel is subjected by sudden contraction when quenched.

Tool steel should be low in phosphorus and manganese. The effect of phosphorus in causing brittleness in mild steels is well known, and this effect is much accentuated in high carbon steels, in which about 0·02 per cent. only is permissible. It is quite usual to have 0·4 or 0·5 per cent. of manganese present in mild steel, but in steel containing 1 per cent. of carbon, 0·2 per cent. of manganese is sufficient for most purposes, and in some cases an additional 0·1 or 0·15 per cent. of manganese will lead to numerous water cracks, although the forging qualities of such a steel may be excellent.

Assuming that the quality of the steel is right, and that the forging has been carefully done, it is for the hardener to see that the steel is in the best possible condition to resist the stresses put upon it, at the moment it is put into the water. If water cracks are to be avoided, the steel should be quenched at that temperature which gives the finest fracture—*i.e.*, the lowest temperature at which the steel will properly harden—as it is then in the best possible condition to resist the contraction stresses. The corners of a tool should not be allowed to reach a higher temperature than the rest of the steel. If by accident any part of the tool is got too hot, it should not be allowed to cool down to the proper temperature and afterwards quenched, as the steel will then have a coarse grain corresponding to the highest temperature reached, with a proportionate loss of strength. The remedy in this case is to let the steel cool down slowly and completely, and then again gradually bring it up to the correct hardening heat, by which means the grain will be restored to the required degree of fineness. With a tool that has thick and thin parts, it is advantageous to heat the thick part first, in order to prevent the thin part becoming overheated, and the method of putting it into the water may also be modified to suit various shapes.

Tempering.—The hardness produced by quenching in water is generally accompanied by an undesirable amount of brittleness, which may be removed by the process of "tempering." This is effected by reheating the hardened steel to a temperature very much below that required for hardening, and varying in practice between about 220° C. and 320° C.*

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*220° C. = 428° on the ordinary (Fahrenheit) thermometer.
320° C. = 608° ,, ,, ,, ,,

The degree of temper is generally judged by an observation of the oxidation tints which appear on the bright surface of the metal when heated, and which succeed each other in the following order :—Light straw, dark straw, brown, brown with purple (pigeon wing), purple, blue. Professor Turner* has shown that the whole of these tints may be produced in succession by keeping the metal at a constant temperature as low as 220° C. for a sufficient length of time, a very light straw being produced in two minutes, and a dark blue in 128 minutes, at that temperature.

After tempering, the article may either be allowed to cool naturally in the air, or may be quenched in water. With some tools, such as chisels, the point only is hardened, and the tempering is effected by allowing the heat from the hot, unhardened portion to travel to the point until the desired colour is obtained, when the tool is quenched to prevent the point becoming softened. The tint cannot therefore be regarded as a reliable indication of the temperature obtained when tempering a tool, and the use of a thermometer is to be preferred where practicable.

Oil-hardened tools are usually tempered by heating up until the oil begins to char or burn, this being an indication of the temperature reached.

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* *Trans. of the Birmingham Philosophical Society*, vol. vi., Part 2.

CHAPTER VI.

MILD STEEL.

Mild steel contains much less carbon than is found in tool steel. To avoid cold-shortness and red-shortness (see p. 8), the percentage of phosphorus and of sulphur must each be kept under 0·05 per cent. for good quality steel. In regard to these elements, mild steel is not so pure as steel for cutlery and tools, which, it may be remembered, contain only 0·03 per cent. of each of these.

It differs from wrought iron in percentage composition, and, in a more marked degree, in its structure. Mild steel is finely crystalline, and is free from slag; wrought iron is fibrous, and contains a considerable bulk of slag in a state of irregular intermixture. Owing to the high temperature at which mild steels are finished, the metal is so fluid as to allow of the ready separation of the slag; indeed, it was owing to its being "poured" in a state of fluidity that the term "steel" was applied to it. The name "ingot iron" was proposed, but did not prove acceptable.

Composition of Wrought Iron Compared with Steel.

Constituents.	Chemical Symbols.	Good Wrought-Iron Shaft.	Mild Steel for General Engineering Purposes.
Carbon, ...	C	trace.	0·18
Silicon, ...	Si	0·12	0·02
Sulphur, ...	S	0·04	0·05
Phosphorus, . .	P	0·21	0·05
Manganese, . .	Mn	trace.	0·50
Cinder or slag, . .	...	1·30	none.
Iron (by difference),	Fe	Δ	Δ
		100·00	100·00

Phosphorus in the Cinder, 0·05.

Sir William Siemens showed the relative bulk of iron and cinder in wrought iron by a cube of 4½-inch side representing the iron, and one of 2-inch side representing the cinder. Presence of cinder seriously impairs the tensile strength of wrought iron. Wrought iron has considerable compensation in its fibrous character, which cannot be imparted in the absence of cinder.

Mild steel is produced in large quantities by the following processes:—

Bessemer process, . .	either acid or basic.
Siemens process, . .	
Martin process, . . .	
Siemens-Martin process, .	

It has largely taken the place of wrought iron because—

(*a*) It can be produced in larger masses,
(*b*) It is more uniform in composition throughout its mass,
(*c*) It has greater tensile strength, and
(*d*) Its price is lower.

BESSEMER PROCESS.—The history of the **Bessemer process** is most interesting, but cannot be dealt with here further than to state that BESSEMER at first intended to improve the strength and character of cast iron for cannons. His investigations led him to attempt to make tool steel. That, however, was not continued. The manufacture of a material suited to general engineering purposes offered a much larger field, which he proceeded to occupy. Signal failure followed his first success, but by persevering he ultimately triumphed, and produced the useful material now known as mild steel.

We must admire in Sir HENRY BESSEMER his ingenuity in following up and improving on the results of his investigations, the genius displayed in devising suitable contrivances for carrying on the process, his quiet determination, his honesty, thoroughness, and business capacity, as well as his generous acknowledgment of the assistance of R. F. MUSHET and WM. HENDERSON in helping him to perfect his method of making mild steel.

Briefly, the **Bessemer Process** consists in blowing air through fluid pig iron, and "finishing" the metal according to requirements. The metalloids (see p. 7) are oxidised, and thereby separated from the iron. It is a beautiful process, and is fully described in the following chapters.

Sir Henry Bessemer.

The **Siemens Process** consists in melting pig iron, and, when the silicon and, incidentally, the manganese have been oxidised, feeding suitable ore into the mass of melted metal in the furnace. The oxygen in the ore hastens the burning out of the carbon. At the same time the iron oxide in the ore is reduced, the iron thereof adding to the weight of ingot produced.

The skilful adaptation of the regenerative system introduced in the **open-hearth furnace** designed by Mr. FREDERICK SIEMENS (brother of Sir WILLIAM SIEMENS) has deservedly won most hearty commendation.

Martin Process.—The steel-making process with which the name of M. Martin is associated consists in melting together scrap steel, or good scrap wrought iron, with a quantity of pig iron, and allowing oxidation to proceed. It may have been suggested by the method devised by Reaumur in the year 1722.

The Siemens-Martin process is a combination of the two methods briefly described above. Siemens-Martin steel is often called Siemens steel, and as it is always produced in open-hearth furnaces it is known as open-hearth steel.

Sir William Siemens.

Unless basic steel is specified it is generally understood that acid steel is meant—just as Mr. Smith (the senior) is meant unless Mr. Smith, junior, is mentioned. This remark applies alike to Bessemer and Siemens steels.

SIEMENS-MARTIN STEEL is in great demand because it is a reliable material possessing valuable properties. It is made from the same class of pig iron as acid Bessemer steel; and, so far as the content of carbon, phosphorus, sulphur, and manganese is concerned, the two steels are frequently identical in composition.

Owing to the comparative slowness of the working of a Siemens-Martin charge (which may occupy about ten hours) the Siemens-Martin process is well under control and may be more deliberately finished; it has also been urged that it is not, during manufacture, so highly oxidised as Bessemer steel.

Siemens-Martin steel is in high repute and favour in Britain, while in the United States of America Bessemer steel is more abundantly produced.

ACID STEEL.—Both Bessemer and Siemens processes were originally conducted in plant lined with material in which silica largely predominated. Chemically, silica (SiO_2) is of an acid nature (see p. 26), and only those pig irons which contained small quantities of phosphorus (and sulphur) could be converted into good mild steel under these conditions.

BASIC STEEL.—As most of the iron ores at home and abroad contain a notable amount of phosphorus, and as the phosphorus is, with few exceptions, all carried into the pig iron during the smelting in the blast furnace, it was most desirable that a workable process should be found for expelling the phosphorus, so that a good steel (not cold-short) might be obtained from phosphoric pig iron. It has already been explained (see p. 27) that if phosphorus is to be got out of pig iron, certain conditions must be complied with, including the presence of plenty of *base*. A *basic slag* is necessary, and that slag must, during the process, be contained in a basic-lined plant, or disastrous results would follow. (See p. 84 for further information on this important point.)

Good acid steel, whether Bessemer-acid or Siemens-acid, is made from pig irons, scrap, &c., comparatively low in phosphorus. Only pure, costly ores can be used in the manufacture of such pig irons, and the supplies are not equal to the fast-growing demand for more steel.

On the other hand, good basic steel may be made from pig iron produced from cheap and plentiful materials containing much phosphorus, but the phosphorus must, during conversion into steel, be eliminated, so that less than ·05 per cent. of phosphorus remains.

The pursuit of a process by which steel could be made from highly phosphoric materials was most fascinating, and the promised results were most important. For not only would the output of trustworthy steel be vastly increased, but large deposits of iron ores could then be utilised. The problem, and its importance, were fully realised in the latter seventies. Some of the best metallurgists in the chief countries of the world were at work on the question. Success was won in a most unexpected quarter. **Sidney Gilchrist Thomas**, who had sought relaxation from his prosaic duties as clerk in an East London police court by attending evening classes, solved the problem.* He was assisted by his cousin, **Percy Carlyle Gilchrist**, who was then metallurgist at Blaenavon, and he had most kindly encouragement from E. P. **Martin** and E. **Windsor Richards**, who arranged for trials of the process on a practical scale. The embodying of the ideas of **Geo. J. Snelus** and **Edward Riley** completed the success of the method.

Sidney Gilchrist Thomas.

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* See the interesting *Memoir of Sidney Gilchrist Thomas*, by R. W. Burnie.

Steel-making flourishes in certain districts because local raw materials have been made available by the working of the basic, or Thomas-Gilchrist, process.

The great rise in the German steel trade is due to the successful working out of the basic process on a commercial scale by the untiring perseverance of SIDNEY GILCHRIST THOMAS. America, also, has profited immensely by the work of the same genius. Vast ore-bearing territories in the United States have been developed for the supply of ore for the manufacture of pig iron, which is worked into steel by the basic open-hearth system.

Basic steel, corresponding in chemical composition to acid steel, is regularly made.

CHAPTER VII

PLANT AND APPLIANCES FOR THE ACID BESSEMER PROCESS OF STEEL-MAKING.

THIS process aims, in the first instance, at the purifying of melted pig iron (of selected quality) by quickly blowing air through it in a vessel called a converter. At the hands of Bessemer the converter underwent many changes in design. At first he tried a fixed converter; afterwards he employed converters which could be rotated into positions which facilitated the charging and discharging of the metal. In shape, too, the converter has been modified. In the earlier forms the upper part (the hood or nose) was very much contracted and sloped, with the idea of preventing, as far as practicable, the ejection of metal and slag during the "blow."

Improvements were introduced by Alexander Lyman Holley, of New York, who arranged that the mouth should be concentric, so as to permit of charging from two positions—a distinct advantage for steel-making. He also carried into practice the idea of building up the converter of three separate parts fixed together by means of hinged flaps and cotter bolts—an arrangement which helps in the quick replacement of rapidly-worn parts by corresponding ones which have been lined anew, properly dried, and got into good condition for work.

The modern Bessemer converter is a capacious vessel of mild steel plates firmly rivetted together and lined with a refractory material to withstand the very high temperature, the intense chemical action, and the wear and tear incidental to the work done. The converter is somewhat barrel-shaped. At one end is the opening through which it is charged and discharged; at the other end are numerous openings (the tuyere holes) through which the strong air-blast is injected.

Encircling the converter at its widest part is a heavy cast-steel ring, to which two trunnions are firmly attached. The trunnions may be said to be short axles. They rest on suitable bearings, and not only support the converter but serve other useful purposes. Attached to one is a large toothed wheel which gears into a horizontal rack.* The rack is, when required, actuated by a horizontal double-acting hydraulic ram, and as the rack is moved backwards or forwards it causes the toothed wheel to revolve, and with it the converter to rotate to any desired inclination or position. The other trunnion forms part of the blast pipe through which the tremendous air-blast is sent from the blowing

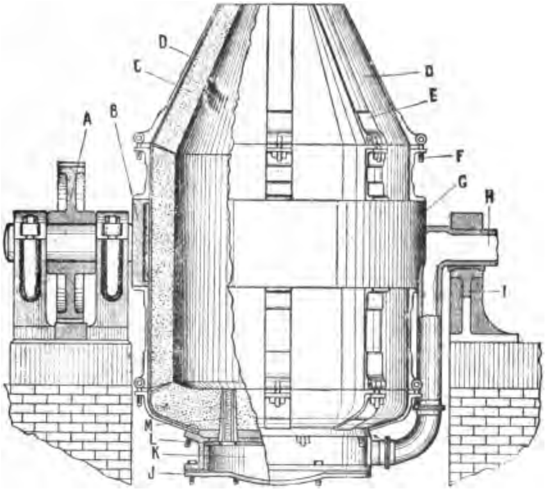

Fig. 22.—Bessemer Converter—Part Elevation, part Section.

A, Toothed wheel.
B, Trunnion belt.
C, Ganister lining.
D, Iron shell.
E, Brackets for bolts.
F, Pin for cotter bolt.
G, Trunnion belt.
H, Blast pipe.
I, Support for blast-pipe trunnion.
J, Blast-box plate.
K, Blast box.
L, Guard plate for keeping tuyeres in position.
M, Tuyere.

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* Sometimes the rack is vertical.

engine to the tuyere box (under the bottom of the converter) to be distributed to the several tuyeres.

The Tuyeres, with the necessary number and size of tuyere holes for acid-lined converters, are carefully moulded, dried, and kiln-fired, and are supplied ready-made to most steelworks. They are slightly tapered so that they may be more easily fitted into, and held fast in, the openings which are left in the tuyere plug of the converter bottoms. The tuyeres are pushed into the openings, luted with moistened fireclay or ganister, and held firmly in position by means of the guard plate, which is a large disc with openings corresponding to, but a little smaller than, the larger end of each tuyere. The tuyeres may be held in position by metal "lugs" which can be turned round on their pivot studs to permit removal.

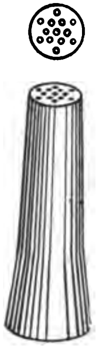

Fig. 23. Bessemer Tuyere.

In one works the 18-ton converters have each 24 tuyeres, and each tuyere has 19 holes of $\frac{5}{16}$ inch diameter. This equals 35 square inches of tuyere hole area, and may be accepted as fairly representing British Bessemer (acid) practice in this particular. The bottom may last for twenty blows, and the hood and body of the converter may need relining after twelve months; these figures representing average working.

The material used for lining the converter is good **ganister,** which may have the following composition:—

Constituents.	Chemical Formulæ.	Percentage.
Silica, ...	SiO_2	94·3
Alumina, ...	Al_2O_3	1·5
Iron oxide, ...	FeO	1·2
Lime, ...	CaO	0·5
Magnesia, ...	MgO	0·2
Alkalies, ...	Na_2O and K_2O	0·1
Water, ...	H_2O	2·2
		100·0

To line a vessel with ganister the three pieces—namely, the hood or nose, body, and bottom—are each dealt with separately. The rivetted sheathing for the hood or nose is inverted on a platform; a wooden core or plug of the internal size and shape is placed correctly, and the space between the plug and the sheathing is filled and rammed with crushed and moistened ganister; or tar may be used as a binding material. The bottom part is also rammed with ganister, openings being left for the insertion of the fireclay tuyeres. The body is generally lined with suitably curved silica bricks. These are built within the rivetted plates which make up the shell, and are carefully cemented with a thin slurry of ganister. The body is lined while the shell is in its ordinary position; the other parts are rammed in a separate building in the work. The parts are placed in position by overhead cranes, or by trolleys carrying hydraulic lifting (and lowering) appliances, and are fastened by hinged, slotted flaps and cotter bolts.

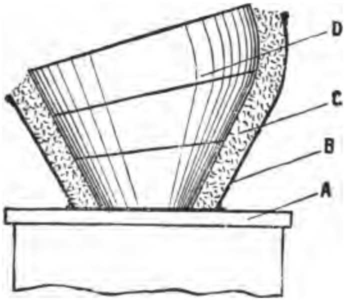

Fig. 24.—Arrangement for Ramming Converter.

A, Platform.
B, Iron shell.
C, Ganister lining.
D, Plug.

The several parts having been lined and bolted, each to its adjoining part, live coal may be put into the converter and a gentle air current sent through it so as to thoroughly dry the lining. The converter having been thus dried and warmed, is rotated till the mouth is downwards and the ash and unburnt fuel fall out. It is then ready to receive the charge.

The Air-blast is urged by powerful blowing engines and is delivered at a pressure of 25 lbs. per square inch.

On an elevated **platform, or pulpit,** as the workmen call it, is a range of levers—like those in a railway signal box—by which the "pulpit man" controls the duration of the blow, the position of the converters, and the pouring of steel and slag as directed by the "blower" who is in charge.

The Bessemer Ladle enables the steel *free from slag* to be poured into the ingot moulds, even if steel and slag have been poured into it from the converter. These, by reason of the fluidity of each, and of the decided difference in density, soon separate from each other; the slag, being much lighter, rising to the top. A layer of slag floating on the top of the steel protects the latter from chilling and from oxidation. Then, when the steel is run out through the nozzle in the bottom of the ladle, it is—all except the last of it at least—free from slag.

The Bessemer ladle consists of a shell or sheath of mild steel plates rivetted together. It is lined within with rammed ganister or with thin firebricks of good quality which are carefully cemented in position by a mortar of ganister. At the lowest part of the ladle there is a space for receiving the fireclay **nozzle** through which the metal is poured. Into this a fireclay **stopper** at the end of a rigid iron or steel rod is carefully adjusted. The rod is covered with fireclay **sleeves**, in short lengths, which are fitted to each other from the stopper up to above the lip of the ladle (see fig. 25). These are all fitted with care and well-dried before being attached to the arrangement at the top for actuating the rod, and adjusted to the nozzle at the bottom. The arrangement at the top may consist of cranks worked by the action of an outside rod which is guided by sockets fixed on the outside of the ladle. The outside rod is moved up or down, as required, by means of a hand lever fitted to a pivot stud. Instead of the crank arrangement the outer rod may be bent over so that the inner rod, with the sleeves, &c., can be attached.

The ladle must be hot and the stopper rod and nozzle set to a nicety before the steel is poured into it. The ladle is carried at the end of a platform which is pivoted at or near the centre so that it can be swung in a circle from its point under the converter to the semi-circular casting pit where a set of ingot moulds have been placed to receive the steel. The nozzle of the ladle having been brought over the centre

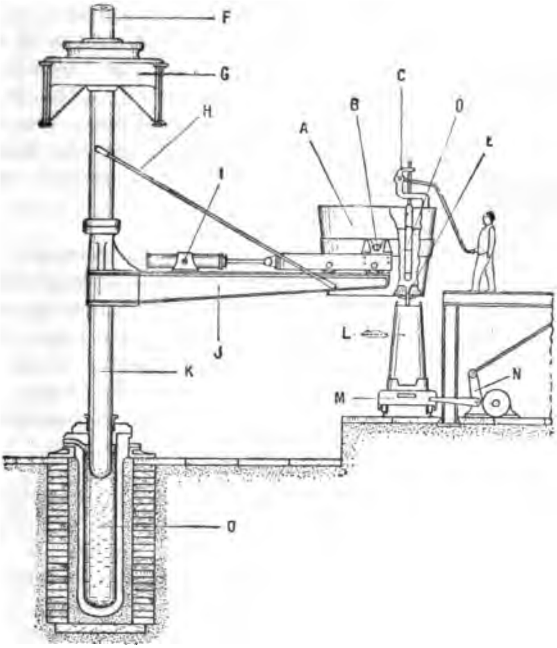

Fig. 25.—Teeming Bessemer Steel into Ingot Moulds.

A, Ladle.
B, Trunnion.
C, Support for rod.
D, Sleeves covering iron rod.
E, Nozzle or outlet.
F, Top of crane stem projecting through roof support.
G, Brackets for crane stem.
H, Stay rod.

I, Hydraulic ram.
J, Staging.
K, Piston of crane stem.
L, Ingot mould.
M, Trolley.
N, Arrangement for regulating the position of the trolley during teeming.
O, Cylinder.

of the first mould of the series, the hand lever is unfastened and the free end is moved so as to push the rod upwards, thus opening a passage between the stopper and the nozzle and permitting the outflow of the steel into the ingot mould. When the mould is sufficiently filled the stopper is pressed down and the ladle is swung over the next ingot mould, which in turn is filled with the steel. And so the "teeming" is continued till all the steel has been poured. The ladle is then turned over so that the slag is emptied out. The nozzle is then knocked out and a new one fitted in, to which, in due course, a covered stopper rod will be carefully set.

Instead of the ladle being swung over each individual mould, it is not an unusual arrangement to have the moulds mounted on low trolleys (see fig. 25) and to push the trolleys one by one up to the pointer which regulates the position under the ladle. The "teeming" from the ladle is regulated by the stopper as described above.

Fig. 26.—Ingot Mould.

Ingot Moulds are strong hematite-iron castings with wrought-iron or steel lugs at the upper end, as shown in fig. 26. They are usually open both at top and bottom,* and they are broader at the bottom than at the top so that they may be more easily stripped from the steel ingot when the latter is cool enough. Stripping is performed by inserting in the lugs hooks attached to a chain which is moved by a crane, as shown in fig. 51, p. 120.

The Bessemer Crane, for lifting and conveying ingots, moulds, &c., is worked on the hydraulic system, and is in principle similar to the hydraulic ram, &c., shown in fig. 25. It consists essentially of a strong hydraulic cylinder in which a long upright stem works smoothly without being too loose. The stem sometimes extends to the roof by which it is braced;

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* The moulds are set on heavy cast-iron slabs before "teeming" the steel into them.

if not, a counterpoise is fitted to another arm corresponding to the jib. From the stem there projects an arm or jib along which a little trolley runs easily. From a hook attached to the trolley the ingot or mould to be moved is suspended. By admitting water under the bottom of the stem the stem may be raised, lifting with it the weight, be it ingot or mould, which can then be swung round and run along the jib. Then on allowing the water to escape from the cylinder the suspended article can be lowered.

There are other kinds of cranes in extensive use in steel works. Hydraulic and electric arrangements for stripping the moulds from off the ingots are also used.

The **fluid metal** required for the Bessemer process may be obtained by remelting the pig iron in a cupola, or by conveying in a ladle the molten pig iron,* in the condition in which it comes from the blast furnace, direct to the converter.

There is a newer and a better method—namely, that of conveying the pig iron as it runs from the blast furnace into a metal mixer—which may be described as a cistern—and taking off from the mixer, in such quantities and at such times as needed, the fluid metal for use in the converter. Storing in a mixer tends to yield a more uniform quality of metal throughout the working week.

A **cupola** is a shaft furnace open at the top. It is of mild steel plates rivetted together, and is lined with firebricks set in a grouting or mortar of fireclay. A working bottom is made by ramming sand or ganister into the required shape.

Near the top is a platform and an opening for charging. On one side, near the bottom, is an opening† by which the slag and unburnt coke may be drawn when the cupola has ceased work; it is also useful for repairs, for making up the sand bottom, and for putting in the coke and the kindling material when beginning or resuming work.

When a cupola is in working order, pig iron and coke are

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* As a matter of convenience, we consider the "metal" which is tapped from an iron-smelting blast furnace to be pig iron whether it is formed into "pigs" or not. With regard to "pigs" see p. 208.

† This opening is closed, and is covered with an iron plate during the melting of the charge.

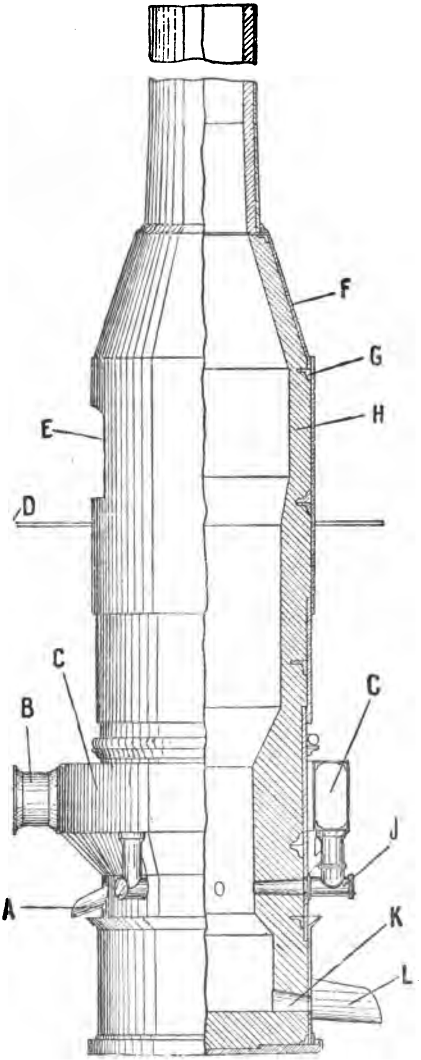

Fig. 27.—Steel Work Cupola—Half Elevation, Half Section.

A, Slag spout.
B, Blast pipe from blower.
C, Air or blast belt.
D, Charging platform.
E, Charging door.
F, Iron shell.
G, Angle iron for supporting bricks.
H, Firebrick lining.
J, Tuyere.
K, Taphole.
L, Spout or lander for melted metal.

charged in, along with a little limestone. An air-blast is forced in through tuyeres, which may be in one row or more. The burning of the coke raises the temperature, and melts the

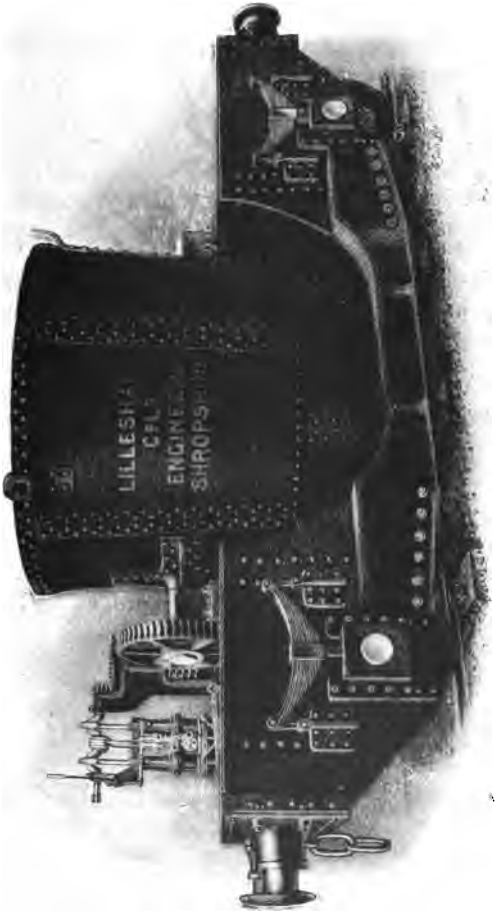

Fig. 28.—Mounted Ladle for Hot Metal.

pig iron and the slag which is formed. These descend, and are taken off through their respective tapholes.

During the descent a little loss occurs through oxidation of iron, manganese, and silicon, and the "metal" takes up a small amount of sulphur from the fuel.

The cupola shown in fig. 27 is of the following dimensions :—

Height to charging platform, . . .	22 feet.
Internal diameter at widest part, . .	8 "
" " " middle " . .	5 "
" " " lower " . .	6 "

There are seven tuyeres, each 5 inches diameter, set 4 feet 6 inches above the floor level, and the blast is supplied at a pressure of about $1\frac{3}{4}$ lbs. per square inch. The slaghole is 3 inches below the tuyeres.

Such a cupola melts 500 tons of pig iron in 24 hours, and requires repairs to its lining after working about 60 hours.

When needed, the melted pig iron is tapped from the cupola into a ladle of the kind shown in fig. 28, which conveys it to the Bessemer gantry—that is, the platform at the converters—and by a side lip it is poured into the converter.

CHAPTER VIII.

THE ACID BESSEMER PROCESS.

By the successful working of this process, suitable molten pig iron is purified and converted into either medium or mild steel by the action of a rapid current of air which is forced through it. This causes the oxidation, or burning, of certain elements, which are thereby removed from the pig iron. The "blown metal" is then finished by the judicious addition of hot spiegel-eisen or ferro-manganese. The steel is then poured from the converter into a ladle, from which it is tapped into ingot moulds. The steel ingots are afterwards rolled into the shapes required—such as plates, angles, girders, bars, springs, tyres, axles, &c.

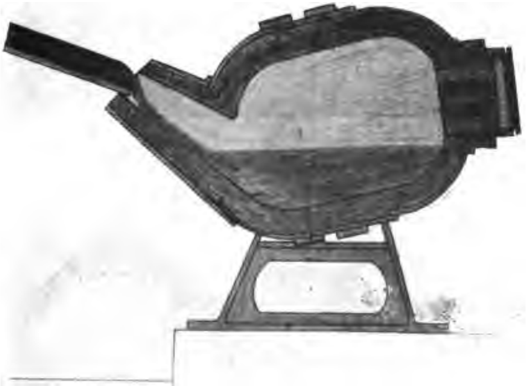

Fig. 29.—Pouring "Metal" into a Converter.

Working an Acid Bessemer Blow.—The Bessemer converter, lined as described in the previous chapter, being in good condition and hot, is rotated till it is nearly horizontal. The position must be such that the melted metal cannot flow into the holes of the tuyeres. The charge of

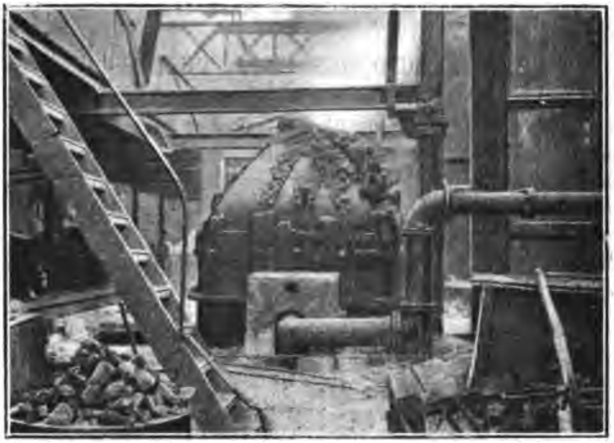

Fig. 30.—Bessemer Converter while Blowing.

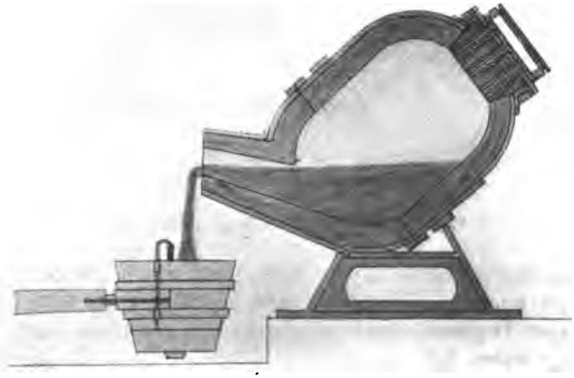

Fig. 31.—Pouring Steel from Converter.

fluid pig iron is run into the converter* from the ladle which conveyed it, and, if too hot, scrap steel is thrown in. An alarm—a loud whistle from a jet—is sounded, so as to warn the workmen to get out of the way of the flame and sparks which are ejected when the blast is turned on. The vessel is then rotated till nearly vertical, the blast being continued until it is judged that the silicon and carbon have been oxidised—a point indicated by a change in the sound of the blow and by the difference in the flame when it "drops." The alarm is again heard, and the converter is turned down to a safe horizontal position. The converter then contains metal and slag. By reason of its much lower density, the slag soon separates by rising to the surface. The metal at this stage is highly oxygenated. Addition of a weighed quantity of hot ferro-manganese or spiegel-eisen soon deoxidises the metal, and converts it into mild, medium, or hard steel by giving to it the desired percentage of carbon. All being ready, the steel is poured into a Bessemer ladle, and from thence it is teemed into the ingot moulds.

When the steel ingot has become cold enough to safely bear removal, the mould is stripped off (as shown in fig. 51), and the ingot is gripped by "dogs" on the end of a chain, hoisted by a crane, and conveyed to be reheated or stocked. The weight of the ingot tends to pull the dogs, and the grip is thereby tightened. The ingot is thus firmly held until released when it ceases to be suspended.

The further treatment of steel ingots is dealt with in Chapter xiii.

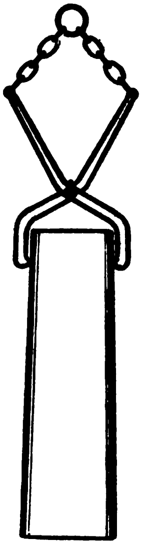

Fig. 32.—Steel Ingot and Dogs.

The Principles of the Bessemer Process may be gathered from a study of the appended table of composition, and a consideration of the chemical changes which take place during the course of conversion into mild steel:—

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*For historic reasons the old-fashioned type of hood is shown.

Constituents.	Chemical Symbols.	Hematite Pig Iron before Blowing.	Hematite Pig Iron after Blowing.	Mild Steel Produced after Addition of Ferro-Manganese.
Graphitic carbon,	C	3·42	None	None
Combined carbon,	C	0·46	Trace	0·20[*]
Silicon, . .	Si	2·20	None	0·02
Phosphorus, . .	P	0·045	0·048	0·05
Sulphur, . .	S	0·045	0·048	0·048
Manganese, . .	Mn	0·47	Trace	0·50
Oxide of iron, .	...	None	Present, but not estimated.	None
Iron, . . .	Fe	Δ	Δ	Δ
Total, . .		100·000	100·000	100·000

Chemical Considerations.—The force and volume of the powerful air-blast, which is urged by the blowing engine at high pressure into the tuyeres, can support the heavy mass of metal, and keep it dancing, as it were, on a cushion of air, so that it cannot run down and choke the tuyere holes. The air finds its way up through the mass of hot, fluid metal; there is a violent commotion and sharp chemical action. Even in that brief passage the oxygen of the air exerts its chemical power with much effect. Fortunately, it is selective in its action.

For, as in the puddling process, one metalloid is attacked by oxygen in preference to another, so is it in the Bessemer process. Generally the silicon is first attacked; nearly at the same rate the carbon is also attacked. The manganese in due course is also oxidised, so that at the time the flame "drops" these three elements are all practically absent. Considering the large quantity of iron present the oxidation of that metal is small. It is more than probable that the resulting oxides of iron assist in the rapid oxidation of other elements.

There is no elimination of phosphorus or of sulphur, and, as the quantity of these elements originally present is, at the end, concentrated in a smaller *weight* of metal, the *percentage* of each of these elements is higher. The percentage increase is slight but is important.

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[*] The percentage of carbon is easily adjusted so as to suit the purpose for which the steel is made.

The chemical reactions involved may briefly be explained thus :—

(*a*) Carbon (C) is oxidised, partly into carbon monoxide (CO) and partly into carbon dioxide (CO_2), and the changes may be concisely indicated by chemical symbols :—

$$C + O_2 = CO_2$$

Carbon and oxygen yield carbon dioxide.

$$2C + O_2 = 2CO$$

Carbon and oxygen yield carbon monoxide.

The gases, carbon monoxide and carbon dioxide, escape into the air.

(*b*) Silicon (Si) is oxidised into silica (SiO_2)—a reaction noted in the chemical equation :—

$$Si + O_2 = SiO_2$$

Silicon and oxygen yield silica.

Silica forms the chief component of the slag.

(*c*) Manganese (Mn) is oxidised to manganous oxide (MnO), as symbolised in the following equation :—

$$2Mn + O_2 = 2MnO$$

Manganese and oxygen yield manganous oxide.

The manganous oxide goes into the slag.

(*d*) The iron which suffers oxidation is changed partly into ferrous oxide (FeO) and ferric oxide (Fe_2O_3)—changes represented in chemical symbols thus—

$$2Fe + O_2 = 2FeO$$

Iron and oxygen yield ferrous oxide.

$$4Fe + 3O_2 = 2Fe_2O_3$$

Iron and oxygen yield ferric oxide.

These oxides find their way into the slag.

Oxidation and Deoxidation of Bessemer Metal.—A belief is current that a lower oxide of iron exists, and that the lower oxide clings to the melted iron and causes that condition which makes ordinary blown Bessemer metal worthless. The existence of that lower oxide has not been proved. There is also a belief that oxygen is dissolved in blown Bessemer metal. In either case the mischievous oxygen is removed by the addition of hot manganese which takes over the oxygen from the iron and becomes converted into oxide of manganese, which is quickly carried into the slag.

In the absence of definite information concerning the composition of the supposed lower oxide of iron, the chemical change by which deoxidation is effected may be represented thus—

FeO	$+$	Mn	$=$	MnO	$+$	Fe
Iron oxide	*and*	*manganese*	*yield*	*manganous oxide*	*and*	*iron.*

The following table shows the composition of certain grades of the "triple compounds of manganese, carbon, and iron" used in the manufacture of Bessemer and other steels.

Constituents	Chemical Symbols.	Spiegel-eisen.	Medium Ferro-Manganese.	High Grade Ferro-Manganese.
Manganese, . .	Mn	15·12	53·36	79·85
Carbon (combined), .	C	4·43	6·12	6·64
Silicon, . . .	Si	0·47	0·46	0·71
Sulphur, . . .	S	0·02	0·01	0·01
Phosphorus, . .	P	0·23	0·11	0·20
Iron, ...	Fe	Δ	Δ	Δ
		100·00	100·00	100·00

For additional analyses see p. 237.

Spiegel-eisen is generally known in works as "spiegel"; ferro-manganese is known as "ferro" or "manganese." All such materials are known in works by the common name of "physic."

In the Bessemer process the **functions of these materials** are threefold.

(*a*) To "restore the nature" of the metal by removing the combined or dissolved oxygen.

(*b*) To add the necessary amount of carbon required in the steel to suit its intended purpose.

(*c*) To add a certain amount of manganese to the finished steel—in which it acts to some slight extent as a "corrective" to the phosphorus, and more especially to the sulphur which is always present.

Recarburising.—The quantity and kind of material added are determined by the percentage of carbon required in the finished steel. Thus, if a mild steel (that is, one low in carbon) is ordered, ferro-manganese is used; if a steel containing a higher percentage of carbon is wanted, spiegel-eisen is used. Why this is so is explained in Chapter xxiii.

Coke and other substances rich in carbon are occasionally used for recarburising.

The ferro-manganese is broken into little lumps (say about 4 inch cubes or even smaller pieces), and is usually red hot when charged into the molten metal in the converter. It soon melts, and time is allowed for its diffusion through the "metal." When spiegel-eisen is used it is charged into the converter in the fluid condition, as such a large quantity would, with difficulty and uncertainty, melt in the metal in the converter.

If the blow is stopped before all the carbon is burned out, less recarburising material will of course be needed. Swedish Bessemer practice is interesting in this particular. Carbon may be added directly to the metal at the end of a blow, or grey hematite pig iron may to some extent be used. Other materials for promoting soundness in steel contain aluminium or silicon in notable proportions.

Heat evolved during a Bessemer Blow.—The molten pig iron which is run into the converter is red hot, and, although a large volume of ordinary cold air is forced through it, the metal is much hotter at the end of the blow. The decided rise in temperature is due to the rapid burning of the carbon, the manganese, some of the iron, and especially the burning of the silicon. Much of the heat evolved by the oxidation of the carbon is carried quickly away in the gases which escape by the mouth of the converter, whereas the silica resulting from the oxidation of the silicon remains in the converter (as a component of the slag) until it is poured off after the end of the blow. The silica, it may be well to explain, unites chemically with oxide of iron and other bases, forming at the high temperature attained during a "blow" a slag so very fluid that it can contain a considerable quantity of chemically free silica and yet remain fluid.

The British Bessemer blower mainly relies on the percentage of silicon for the maintenance of the heat needed to keep his metal in the condition 6f fluidity required.

When the metal is too hot at the finish it is apt to be "wild" in the moulds and to produce unsound ingots. On the other hand, metal which is too cold is apt to lead to an insufficient intermingling of the ferro-manganese or spiegeleisen; there is also a serious risk of steel solidifying in the ladle and forming a "skull," of the teeming not being smooth, and the ingots being unsatisfactory.

The best cure for cold blows is hotter and more highly siliceous pig iron. If a supply of such cannot be had a greater volume of blast through wider tuyeres should be arranged for.

For blows which finish too hot, quite the contrary conditions should be set up, and a plentiful supply of suitable scrap steel, which should be liberally thrown into the converter before running in the melted pig iron, would go far to remedy matters.

Bessemer Slag from the blowing of ordinary Hematite Pig Iron may contain the following components in the percentages stated :—

Constituents.	Chemical Formulæ.	Percentage.
Ferrous oxide, ...	FeO	10·4
Ferric oxide, ...	Fe_2O_3	0·5
Oxide of manganese, . .	MnO	14·4
Silica, ...	SiO_2	69·8
Alumina, ...	Al_2O_3	2·9
Lime, ...	CaO	1·7
Magnesia, ...	MgO	0·3
		100·0

Although slag of this composition contains 8·34 per cent. of iron and 11·15 per cent. of manganese—each in an oxidised state—no profitable method of extracting these metals has yet been devised, and the slag is thrown down as worthless on slag heaps.

The percentage of oxide of manganese (MnO) given in the above analysis is much lower than that stated in many text books, but it accurately represents present day practice.

CHAPTER IX.

THE BASIC BESSEMER PROCESS.

The intention of the basic Bessemer process is to produce good malleable metal (mild steel) from pig iron containing much phosphorus.

In the ordinary (acid) Bessemer process all the phosphorus in the pig iron is concentrated in the steel which is made from it. Presence of more than 0·05 per cent. (that is, equal to 5 in 10,000 parts) of phosphorus in steel makes it "cold short" and therefore useless for some purposes for which steel is used. Clearly, then, if good, reliable steel is to be made from pig iron containing a high percentage of phosphorus some means must be found for eliminating phosphorus from the metal.

The conditions for dephosphorising pig iron are:—

(*a*) Fluid metal, and, when formed, fluid slag.
(*b*) An active oxidising atmosphere.
(*c*) Intimate intermixture of metal and slag during working.
(*d*) Abundance of suitable base to hold the phosphorus which is liberated from the pig iron. [Phosphorus when liberated is oxidised and forms phosphoric acid (P_2O_5).]
(*e*) The presence of abundance of highly heated base necessitates a *basic lining* for the chamber in which the operation is conducted.

Because basic Bessemer slag contains all the phosphorus from the pig iron the slag has a high commercial value.

The chief difference in the basic Bessemer plant, as contrasted with the acid Bessemer plant, is the lining of the converter for the former with basic material. And as a much greater bulk of slag results from the basic process, the converter, for a given amount of metal, must be larger.

The cupolas and ladles are the same in size and in lining as for the acid process, and the blowing engines, cranes, ingot moulds, &c., are also the same. They are described in Chapter vii.

For the manufacture of basic steel, machinery and appliances are required for making basic bricks and for preparing the basic linings. Machinery for grinding the slag from the basic process is also required unless the slag is sold in its rough state to merchants.

Materials for Lining.—The basic Bessemer converter is generally lined with a prepared mixture of ground calcined dolomite and special tar free from water.

When limestone, which contains calcic carbonate ($CaCO_3$ or CaO, CO_2), is calcined, or, as the works' phrase goes, "burnt," the carbon dioxide is liberated, and lime (or quicklime) is left. Lime mixed with tar would make a tolerably good basic lining, but magnesia—which is left on strongly calcining magnesite or magnesic carbonate—is a better substance. It is, however, much more costly. Fortunately there exist large accessible deposits of dolomite* (or magnesian limestone), which is a compound carbonate of lime and magnesia. Prepared dolomite is freely used as the material for lining the basic converter. Where magnesite is plentiful and cheap, magnesia is used. In Russia, chrome iron ore is used and a lining of that substance lasts a very long time.

COMPOSITION OF BASIC REFRACTORY MATERIALS.

Chief Constituents.	Chemical Formulæ.	Calcined Limestone.	Calcined Magnesite.	Calcined Dolomite.
Lime, ...	CaO	95·7	1·8	59·5
Magnesia, . . .	MgO	1·2	94·4	33·1
Alumina, . . .	Al_2O_3	0·9	2·3	2·8
Silica, . . .	SiO_2	1·9	0·6	3·7
		99·7	99·1	99·1

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* Named after Dolomieu, a famous French geologist.

These are derived from—

Chief Constituents.	Chemical Formulæ.	Limestone.*	Magnesite.*	Dolomite.*
Carbonic acid and other volatile matters, .	CO_2, &c.	42·7	51·2	46·3
Lime, ...	CaO	54·8	0·9	31·9
Magnesia, . . .	MgO	0·5	46·3	17·8
Alumina, . . .	Al_2O_3	0·5	1·1	1·5
Silica, ...	SiO_2	1·2	0·3	2·1
		99·7	99·8	99·6

Preparation of the Materials for Lining.—The dolomite, in lumps as quarried, or broken into smaller pieces, is calcined by being placed in a kiln, along with the necessary fuel, which, when burning, expels the carbon dioxide. The calcined dolomite—which shrinks very much during the "burning"—is ground in a pan mill, and enough hot anhydrous† tar (or pitch) to make a mass of the proper consistency is added, and thoroughly mixed with it in the pan mill. About 8 per cent., by weight, of the water-free tar may be needed. The tar acts as a binding material, and protects, to some extent at least, the lime, which would otherwise quickly take up moisture from the air.

The mixture of calcined and ground dolomite and water-free tar (or pitch) is known in the works as **basic material**—a term sometimes applied to the burnt dolomite without the tar addition. It may be used in the form of bricks, or may be hand-pressed by hot rammers.

To make basic bricks a press is employed. The press has a table which can be rotated about its centre. The table carries three moulding boxes, which are arranged at equal distances from the centre and from each other. Each box in turn is filled with the basic material, a strong iron plate is placed over it, and the table is moved until a box is right under the hydraulic ram, which descends and presses the basic

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* These are not *basic* until calcined.

† Anhydrous means "*free from water.*"

material until it half fills the box. The table is moved again till the first box is over another but less powerful ram; the ram, on rising, lifts the pressed brick, which is moved by hand and carried to a warm place. Meanwhile, the other boxes have been filled, and the second one has been under the press. And so the succession is kept up, three bricks being on the way at one time. The bricks, having been kept in a warm place for some days, may then be packed in a kiln and kept at a high temperature for a few days, or they may, while in the green state, be built into position in the converter.

Lining the Basic Converter.—The converter is of three parts—the hood or nose, the body, and the bottom.

The body is generally lined with basic bricks, made as previously described, and set in plenty of basic material. The hood, being the part least subjected to severe usage, is often lined with a mixture made from clean portions of old lining ground fine and mixed with more anhydrous tar. When in need of renewal the hood is turned upside down on a platform, and detached by undoing the cotter bolts. It is then taken to that part of the works—popularly called the plug shop—where relining is done. The old lining is removed, and a core or pattern is placed in position. Rammers—long iron bars with flattened enlargements at one end—are made hot at the broad end. Some of the mixture is thrown in between the shell and the core, and workmen press firmly the hot rammers on it, and cause it to cohere. More of the mixture is supplied and similarly pressed, relays of hot rammers being supplied to the men.

The bottom is similarly rammed, but in two parts. In the first place, a "plug" is prepared, and, secondly, the plug is fixed in the centre of a converter bottom. To prepare the plug, an iron plate or disc, surrounded by an iron cylinder, is provided. Round, tapered iron rods about 21 inches long, of the number and diameter of the intended tuyere holes, are fixed to the plate (see fig. 33). Between these upright rods a small quantity of ground burnt dolomite, mixed with melted anhydrous tar, is thrown in, and carefully pressed with hot iron rammers of a special shape. More of the mixture is emptied in, and cemented to the previous portion by means of the hot irons. In this manner, little by little, the plug is built up, generally to a thickness of about 18 inches. When completed, the plug is lifted up on the iron bottom plate and the upright iron rods are each struck a smart blow. As they are slightly tapered they are easily caused to fall, and each leaves a vacant space for a tuyere hole. The plug, contained in the metal cylinder, is then carefully dried and kiln-fired. It is then set in the centre of the space enclosed by the iron work which constitutes the sheathing of the "bottom," and the space between the sheath and the plug is filled in with basic material, which is cemented by ramming in the usual way.

The size and number of the tuyere holes vary in different works, but 70 openings, each ¾ inch diameter—giving an area of 31 inches—may be accepted as a fair average for a 15-ton basic converter.

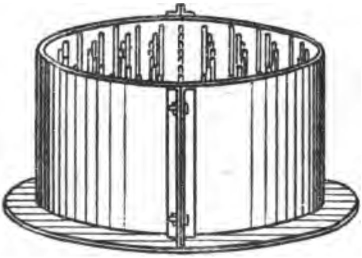

Fig. 33.—Plate, Cylinder, and Rods for Basic Plug.

The plug, as a whole, may be rammed by hydraulic pressure instead of by hand. At the North-Eastern Works, Middlesbrough, this is regularly done, and with most advantageous results. In some works fireclay tuyeres—same as for the acid Bessemer process—are used. They soon become worn, but are easily replaced by pushing them into a setting of basic material in the tuyere openings of the plug.

A plug lasts, as a rule, about 17 blows; the body needs relining after about 120 blows; and the nose may stand from 50 to 300 blows before requiring relining.

Bessemer Converters in Leeds Steel Works with Broadbent Overhead Crane.

CAPACITY:
Main Bogie,
30 tons.

Aux. Bogie,
10 tons.

SPAN:
40-ft. 0-in.

The three parts of the converter are fixed to each other by means of cotter bolts, a junction of basic material in a plastic condition being placed between each before pressing the parts together prior to fixing.

A fire is kindled and kept going in the converter till it is hot.

The regular supply of fairly uniform "metal" to the converters conduces to smooth working and helps in the production of steel of uniform quality. As in the acid process, the pig iron may be re-melted in cupolas, or the "metal" as tapped from the blast furnace may be taken directly to the converter, or it may be supplied through a mixer. Many mixers are shaped like open-hearth tilting furnaces, and have gas producers and regenerators. In some instances a considerable diminution in the percentage of silicon and of sulphur takes place in the mixer. Scrap steel can be melted in the mixer and "metal" sufficiently hot for comfortable flowing may be delivered as required.

Mechanical contrivances which facilitate the conveyance of metal are advantageously adopted. The more rapid production resulting from their adoption more than compensates for the cost of installing and working. Fig. 34 shows a double-bogey ladle crane of the substantial type made by Messrs. Thomas Broadbent and Sons, Huddersfield. This crane is fitted with five electric motors. The illustration shows the molten metal being poured into a converter, the rear chain and pulley being brought into action to tilt the ladle.

Working a Basic Bessemer Blow.—When a basic-lined converter is in good working condition, and hot, it is turned with its mouth towards the upper gantry, from which a quantity of calcined or "burnt" lime is shot into it (see fig. 35 on next page). The converter is then rotated until it is in a proper position to receive the charge of melted basic pig iron which is poured into it from a side-tipping ladle, as shown in fig. 35. The alarm is sounded and the air-blast is turned on. The vessel is rotated until in a nearly upright position and the blowing is continued *until the flame drops and* *for a further period*, the length of which is decided by the "**blower**" who is in charge. There is therefore in the basic Bessemer process the period of the **blow**—till the flame "drops"—and a further period called the "**after-blow.**" *It is during the after-blow that nearly all the phosphorus is eliminated,* and the length of that period is a matter for cool judgment.

When the blower thinks the after-blow has continued long enough he has the vessel turned down and the blast stopped. As soon as the "metal" and the slag have separated from each other—and as they are both very fluid and the difference in density is great, separation is soon effected—a sample is withdrawn by means of a long-handled ladle and the "metal" sample is poured into an open mould where it quickly solidifies. The sample is flattened under a steam hammer, water-cooled, and broken across. The blower examines the fracture and judges by the size of the crystals on the fractured parts whether or not the process of dephosphorisation has proceeded far enough. If not, he signals for the continuance of the blow. Another sample is taken and similarly tested. If, in the judgment of the blower, this is still unsatisfactory

Fig. 35.—Charging Lime into a Bessemer Converter.

the blowing is resumed—perhaps for some seconds. When he concludes that the metal is right (due allowance being made for the slight rephosphorising which occurs on the addition of ferro-manganese or spiegel-eisen) some of the slag may be run off. The necessary amount of ferro-manganese or spiegel-eisen is then charged, and, when it has had time to mix well with the metal, the steel is poured into the hot, mounted ladle and duly teemed into the moulds which have been carefully set in the casting pit. The treatment of steel ingots is dealt with in Chapter xiii.

Additions of lime, of scrap, or of iron oxide may be made at a certain stage or stages of the blow.

The Chemical Changes which occur during the basic Bessemer blow may be gathered from the following table:—

Constituents.	Chemical Symbols.	Composition of			
		Pig Iron Charged.	Metal at End of Blow.	Metal at End of After-blow	Finished Steel.
Graphitic carbon,	C	0·82	...	...	...
Combined carbon,	C	2·83	0·05	Trace.	0·14*
Silicon,	Si	0·63	0·03	0·005	0 01
Phosphorus,	P	2·75	2·38	0·04	0·04
Sulphur,	S	0·07	0·07	0·05	0·05
Manganese,	Mn	1·75	0·13	0·10	0·45
Iron,	Fe	Δ	Δ	Δ	Δ
		100·00	100·00	100·00	100·00

Chemical Considerations.—The elements which are required to be removed from the pig iron are oxidised by the oxygen of the air which is forced in such large volume through the pig iron in the converter. Silicon and carbon are vigorously attacked, manganese is freely acted on, and when these are nearly all removed iron begins to be burned, and, lastly, the phosphorus is oxidised. Where abundance of hot lime is present a steady diminution of the amount of sulphur in the

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* The percentage of carbon is varied according to requirements.
Δ By difference.

metal takes place. Prolonging the blow, which is not generally advisable, may lead to a further diminution of sulphur. If the pig iron charged contained much sulphur, part of it may be easily "gasified" or volatilised and carried off in the escaping gases. Hot blows tend to lead to sulphur elimination. Where only a moderate amount of sulphur is present it appears that that which is removed during the after-blow all goes into the slag. In one British Bessemer work about 33 per cent. of sulphur is regularly eliminated during blowing.

The Chemical Reactions may be indicated by the following equations:—

$$Si + O_2 = SiO_2$$

Silicon and oxygen yield silica,

which combines with bases in the slag.

Carbon is oxidised, forming carbon monoxide (CO) and carbon dioxide (CO_2), thus—

$$2C + O_2 = 2CO$$

Carbon and oxygen yield carbon monoxide.

$$C + O_2 = CO_2$$

Carbon and oxygen yield carbon dioxide.

These oxides being gaseous escape by the open mouth of the converter.

$$S + O_2 = SO_2$$

Sulphur and oxygen yield sulphur dioxide.

The sulphur dioxide escapes with the other gases.

Sulphur trioxide (SO_3) may be formed by the action of ferric oxide—

$$9Fe_2O_3 + S = 6Fe_3O_4 + SO_3$$

Ferric oxide and sulphur yield magnetic oxide and sulphur trioxide.

The sulphur trioxide combines with lime in the slag.

$$SO_3 + CaO = CaSO_4$$

Sulphur trioxide and lime form calcic sulphate.

Manganese is oxidised, and the resulting oxide goes into the slag :—

$$\mathrm{Mn} \quad + \quad \mathrm{O} \quad = \quad \mathrm{MnO}$$

Manganese and oxygen yield manganous oxide.

Two oxides of iron are formed, and they constitute part of the slag :—

$$2\mathrm{Fe} \quad + \quad \mathrm{O}_2 \quad = \quad 2\mathrm{FeO}$$

Iron and oxygen yield ferrous oxide.

$$4\mathrm{Fe} \quad + \quad 3\mathrm{O}_2 \quad = \quad 2\mathrm{Fe}_2\mathrm{O}_3$$

Iron and oxygen yield ferric oxide.

Phosphorus when oxidised forms phosphoric acid (more correctly named phosphoric anhydride) :—

$$4\mathrm{P} \quad + \quad 5\mathrm{O}_2 \quad = \quad 2\mathrm{P}_2\mathrm{O}_5$$

Phosphorus and oxygen yield phosphoric acid.

The phosphoric compound unites with lime to form tetra-calcic phosphate :—

$$\mathrm{P}_2\mathrm{O}_5 \quad + \quad 4\mathrm{CaO} \quad = \quad 4\mathrm{CaO}\,.\,\mathrm{P}_2\mathrm{O}_5$$

Phosphoric acid and lime form tetra-calcic phosphate.

Tetra-calcic phosphate was discovered simultaneously by Hilgenstock in Germany, and Stead & Ridsdale in England. So far it has not been found in nature.

The acids in the basic slag are silica (SiO_2) and phosphoric anhydride (P_2O_5). The bases present are lime (CaO), magnesia (MgO), manganous oxide (MnO), and ferrous oxide (FeO). To carry on the process a decided excess of base must be present in the converter.

At the end of the after-blow the "metal" is in a highly oxidised state, and the addition of suitable material containing manganese and carbon is necessary. The finishing material is added as in the acid Bessemer process, and the reactions—detailed on pp. 78, 79, and 80—and effects are similar.

Recarburising.—There is danger of reduction of some phosphorus from the slag during recarburising. To lessen this risk the slag is freely poured off before "finishing." As the bath of metal is highly oxidised it is not unusual to add grey hematite pig iron (which is rich in carbon and silicon) before adding ferro-manganese or spiegel-eisen.

In the basic Bessemer, as in other modern steel-making processes, ferro-manganese is used for mild steels, while spiegel-eisen is employed when higher carbon steels are being made. Carbon is added directly in some instances. The carbon, or molten spiegel-eisen, is added to the metal which had been poured into the ladle with the smallest workable quantity of slag.

Comparison of the composition of the pig iron used for the respective processes :—

Constituents.	Chemical Symbols.	Acid Bessemer.	Basic Bessemer.
		Per cent.	Per cent.
Graphitic carbon,	C	3·42	0·82
Combined carbon,	C	0·46	2·83
Silicon,	Si	2·20	0·63
Phosphorus,	P	0·045	2·75
Sulphur,	S	0·045	0·07
Manganese,	Mn	0·47	1·75
Iron,	Fe	Δ	Δ
		100·00	100·00

It may be noticed at a glance that the basic pig iron is high in combined carbon, in phosphorus, and in manganese. The silicon in it is low, and for a good reason, namely—the result of oxidising silicon is the production of silica, which, being acid, is undesirable in large amount in the slag. The maker of basic pig iron, therefore, keeps the silicon in the pig iron as low as he can. In pig irons which do not contain much silicon, most of the carbon, as a rule, exists in the combined state.

There is considerable amount of manganese in good basic pig iron, because

(*a*) Presence of much manganese tends to keep the percentage of sulphur low.

(*b*) Because the manganese, while undergoing oxidation in the converter, makes good, as far as possible, the heat which would have been derived from the presence of silicon. Manganese oxide (MnO) being basic, is not so objectionable in the slag.

But the chief feature in the comparison is the large amount of phosphorus in the basic pig iron. The percentage of phosphorus is high, because

(*a*) Puddlers tap (tap cinder), from which it is largely made, is comparatively cheap, and contains much phosphorus as well as iron.

(*b*) A large amount of phosphorus is necessary to maintain the needed high temperature in the converter during the continuance of the after-blow, and the heat can be had by the oxidation, or burning, of a comparatively large quantity of phosphorus.

(*c*) The higher the percentage of phosphorus in the pig iron the richer, under ordinary conditions, will the slag be in phosphoric acid, and the higher will be the price obtainable for the slag. With each increase in percentage of phosphoric acid there is a very considerable increase in market value. The basic pig iron is purposely enriched in phosphorus by using mineral phosphate in its production. Under certain circumstances, such as a very hot blow, a little of the phosphorus may escape in the outgoing gases.

APPROXIMATE COMPOSITION OF GOOD QUALITY BASIC BESSEMER SLAG.

Constituents.	Chemical Formulæ.	Percentage.
Phosphoric acid, . . .	P_2O_5	20
Silica, ...	SiO_2	6
Lime, ...	CaO	46
Magnesia, ...	MgO	6
Ferrous oxide, . . .	FeO	13
Ferric oxide, ...	Fe_2O_3	2
Manganous oxide, . . .	MnO	5
Alumina, &c., . . .	Al_2O_3, &c.	2
		100

When the slag has cooled down it is broken up, ground to a very fine powder, placed in bags, and sold as a fertiliser. Reduction to powder may be effected by grinding, or by the action of superheated steam. The lime, and especially the phosphoric acid, in the slag, make it highly valuable for certain soils and crops.

The greater the percentage of *easily soluble* phosphoric acid in the slag the higher is the price it will fetch. And justly so, because such soluble slags will yield a quicker and a greater return to the farmer: a quicker return, because the plants grown in the field which is enriched with this fertiliser will more easily assimilate it, and be thereby helped in healthy growth; and a greater return, because there will be less of the precious phosphoric acid left in the ground, with the possibility of much of it being washed by the winter's rain so deeply into the soil as to get beyond the reach of the roots of the next year's crop.

CHAPTER X.

PLANT AND APPLIANCES FOR THE SIEMENS-MARTIN OR OPEN-HEARTH PROCESS.

MILD or medium steels are regularly made in charges of 5 tons and upwards. The smaller furnaces are for making steel castings. 30-, 40-, and 50-ton charges are now common, and furnaces for 160 tons, and even for 200 tons, are built and at work.

The fuel used in this process is either producer gas, which is specially made in gas producers, or natural gas as found in certain territories in the United States. The regenerative system—a system suggested and practically applied to an engine by the Rev. Dr. STIRLING—is adopted, so as to utilise in the furnace as much as possible of the heat generated.

Gas Producers.—A gas producer is designed to burn solid fuel in such a manner as to convert as much as practicable of it into combustible gases,* which can be collected, conveyed, and used where required.

When coal slack or other suitable fuel is charged into a producer which has been made hot and is in working order, the fixed carbon (C) which it contains is converted into carbon dioxide (CO_2), and the dioxide is reduced to carbon monoxide (CO) if a *moderate* supply of air has access to plenty of glowing fuel. Hydrocarbons, such as methane or marsh gas (CH_4), are liberated from the solid fuel, and hydrogen (mostly from the decomposition in the producer of the steam which is used to impel the air blast) is also found in the producer gas (see analysis on p. 246).

These three components (carbon monoxide, methane, and hydrogen) are all combustible, and the value of the producer gas will depend on the quantity of these in its composition.

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* Gases which can be burned.

The Siemens Gas Producer consists of a rectangular compartment built of brick walls, with fire-bars. Four compartments make up a block and several blocks may be built together. Over each compartment is a hopper by which the coal slack, or other fuel which is to be gasified, is charged into the producer. Air may be admitted between the fire-bars, but the general practice is to close the opening in front of the ashpit and inject air by the force of one or two steam jets. A water trough is provided for the ashes. The gas which is produced is collected and conveyed by an overhead main pipe or by culverts (underground passages) to the furnaces.

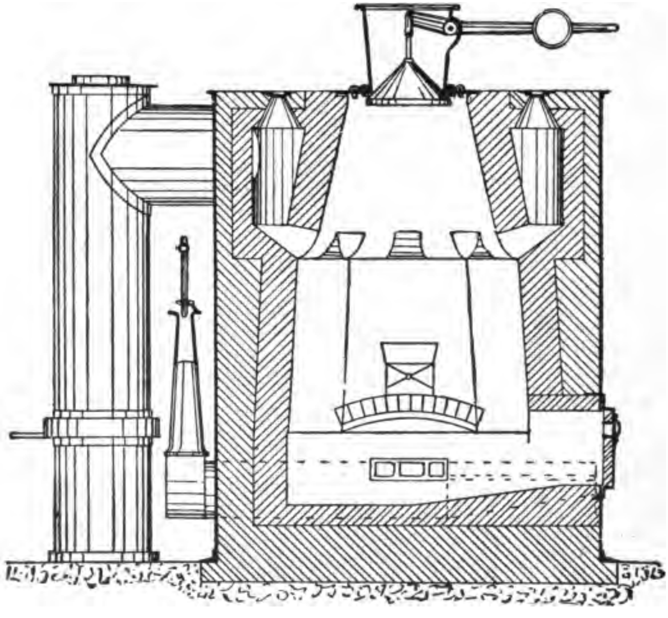

Fig. 36.—Wilson Gas Producer—Section.

The Wilson Gas Producer is an upright cylindrical structure of mild steel plates lined with fireclay bricks or blocks. It is shown in section in fig. 36. The solid fuel, from which the gas is to be made, is charged in by a hopper—a hollow tapered iron casting which is bolted to the top of the producer. A cone closes the passage from the hopper to

Fig. 37.—Wilson Gas Producer with Water Bottom.

the producer, and a lid covers the hopper. The hopper is filled with fuel, and, when it is intended to discharge it, the lid is shut down and the cone is allowed to descend. The fuel is thus admitted to the producer, the cone causing an equal distribution of the slack or other fuel used. As the fuel burns* the charge is in due course decomposed, and every part of it except the ash is converted into gas. The gas is drawn off by suitable ports or openings to the downtake, from whence it is conveyed by culverts or pipes. Air is forced in by means of an injector consisting of a steam jet and a pipe with an enlarged entrance. The amount of air and steam can easily be regulated. They are forced through the pipe into a horizontal brick passage—the distributor—above the flooring of the producer and distributed through openings for that purpose in the brick passage.

The producer has a solid bottom, and, when it is necessary to clear out ashes, iron bars are inserted at a certain height so as to keep the unconsumed fuel up while the ashes are withdrawn through the cleaning door.

"Solid bottom producers are cleaned out at intervals varying from 12 to 48 hours apart, according to the quality of the coal and the amount of work they are doing. This does not by any means involve emptying the producer of fuel. The bottom doors are opened after stopping the blast, &c., and the ash and refuse at the bottom are raked out. The doors are then closed and gas-making resumed."†

In a later design the producer is set on a long **water trough**, as shown in fig. 37. Near the bottom of the producer the inner space is contracted so that the unconsumed fuel is held up, but as it burns away the ash drops into the water in the trough below. A plate suited to the curvature dips from the contracted part into the water lute and prevents the escape of gas. Water-bottom producers are worked continuously, the clinker and ashes being withdrawn from the trough from time to time. To make sure that sufficient is being withdrawn to keep the producer clean and in the best working order, it is necessary in this arrangement to go on shovelling ash out until more or less unburnt fuel comes down.

* A fire must be kindled in the producer on starting it to work.
† *Power Gas Plant*, by Alfred Wilson, p. 25.

The Wilson water-bottom producer with constant ash-removing gear is shown in section in fig. 38. As in the solid-hearth producer, there are no fire-bars. The solid matter sinks down through water inside the lower part of the producer and is forced out by an Archimedian screw arrangement and up an inclined plane to the outside, no gas being able to escape. The screw is caused to constantly revolve very slowly, being driven by suitable gearing from a shaft.

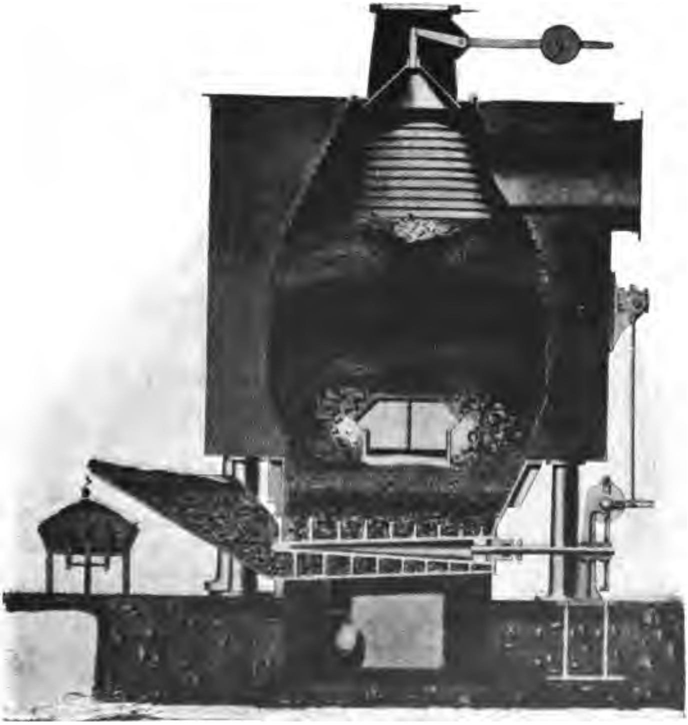

Fig. 38.—Wilson Gas Producer with Archimedian Screw for removing ashes.

The screws or worms are made tapering, the largest diameter being at the outlet end; their blades are also of increasing pitch towards the same end, and by this arrangement nothing can stick in the screw. There is a considerable evaporation from the water at the bottom as the hot ashes gradually descend into it. The steam is, however, decomposed higher up, and serves to increase the percentage of hydrogen in the resulting gas. Owing to the constant agitation of the fuel by the revolving worm the production of gas is uniform, and good working is secured.

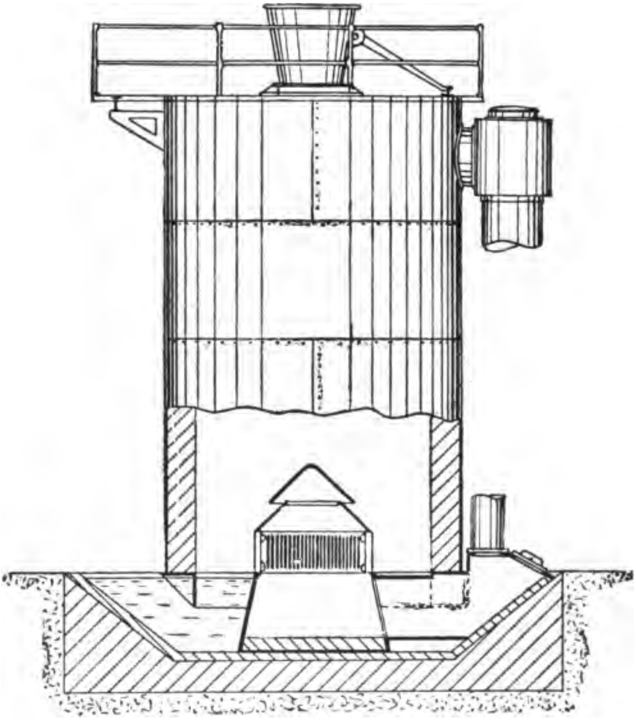

Fig. 39.—A. B. Duff Gas Producer.

The A. B. Duff Producer, which is so much in favour at home, on the Continent, and in America, has a thick lining of fireclay blocks encased in a sheathing of malleable plates. It is of the upright cylinder type, and is surmounted by a hopper through which the fuel is fed in to work its way steadily downwards. The whole structure is set on a water bottom. A sketch, partly in section, is shown in fig. 39.

The necessary air, which is often preheated, is injected by steam, and enters the producer by a circular central tower having slotted cast-iron plates for its sides and a roof arranged to permit the passage of air between its upper and lower parts. An efficient distribution of air is thus ensured. The central tower contracts the space and thus causes the fuel (already somewhat swollen and caked together by heat) to be held up until the combustible components are converted into gases by the action of the injected air. The gases thereby produced ascend and are conveyed by the downtake to a culvert. The ash drops into the water bottom, from whence it is raked out without deranging or stopping the gas-making.

The Gas Valves are of two kinds: **mushroom** valves for regulating the amount of gas, and **butterfly** valves for determining the direction of the air and the gas. Many patent gas valves are in use.

Open-hearth furnaces are either stationary or movable, the latter being known as rolling or tilting furnaces (see p. 255).

The Stationary Open-hearth Furnace is a huge oblong structure built of silica bricks cemented with suitable mortar and braced with buckstaves and tie-rods and set over five arches. Of these arches the central one is left blank, the two arches next to the central one are for **air regenerators**, and the outer two are for **gas regenerators.** But the inner ones may be arranged for gas and the outer ones for air. These **regenerative chambers** contain firebricks, which are packed checkerwise in such a manner as to expose as much surface of brick as possible while allowing free passage for gas or for air. The bricks absorb heat


J. S. TULLEY & Co

from the outgoing (hot) gases and impart heat to the ingoing (cold) air and gas.

Fig. 40 shows the front view of furnaces at the Norfolk Works of Messrs. Thomas Firth & Son, Sheffield.

The chambers communicate with passages both at top and bottom; the top passage of each ascending from its regenerator to port, or ports, at its own end of the furnace. Each end of the furnace includes an outer and an inner wall. The latter may be straight across or be built with a slight curvature. The upright passages leading from the regenerators are built between the two end walls, like an ordinary domestic chimney, but in this case terminating at the top of the ports. The ports are openings (constructed with a slight slant) in the inner wall; they lead from the upward passages to the inside of the furnace. There may be one gas and one (larger) air port at each end, or there may be three air ports and two gas ports, or two gas ports and one wide air port. The air ports are at a higher level than the gas ports. At each end of the furnace the ports and passages correspond in arrangement, number, and size with those at the other end.

When the furnace is at work, producer gas is conveyed through one of the gas regenerators * to its port or ports, and air is conveyed through the neighbouring air regenerator to its port or ports. Where the gas and air meet in the hot furnace, ignition immediately takes place—just as when gas is lit at an ordinary gas burner—and a long sheet of flame sweeps along and heats the furnace, much heat being, in time, deflected from the roof. The hot, spent gases (the products of combustion) pass out at the opposite ports, and, proceeding by proper channels to the top of the regenerators at what is then the outgoing end, impart much heat to the checkered packing of bricks in the regenerators, and are drawn off by passages left under the checker work of the regenerators, and under the valve pit, to the chimney. **The chimney** is usually a cylindrical brick structure, about 50 feet or so in height, encased in rivetted plates. It is set on a firm base and is stayed by stout wire cables. In the base, arrangements are

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* Natural gas, being rich in combustible components, does not require to be passed through a regenerative chamber.

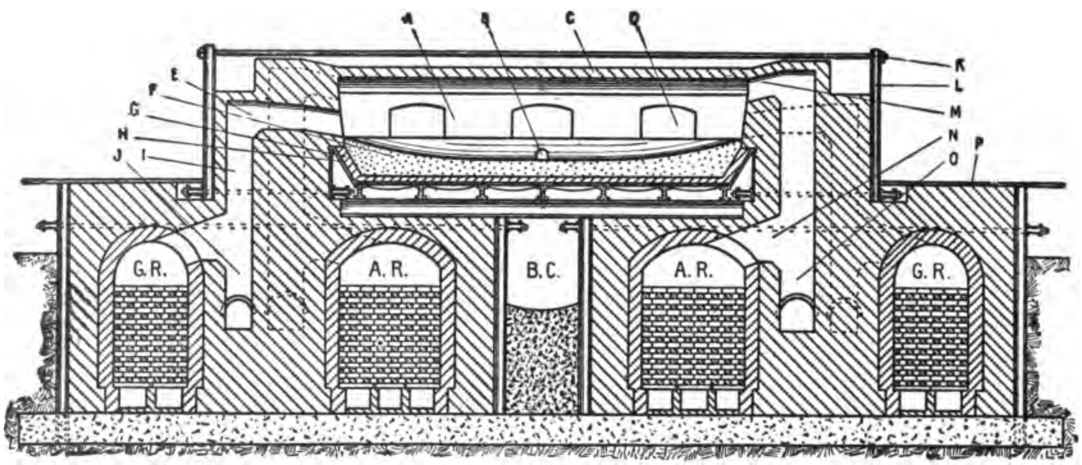

Fig. 41.—Siemens Furnace—Vertical Longitudinal Section.

A, Wall.
B, Taphole.
C, Roof.
D, Charging door.
E, Gas port.
F, Working bottom.
G, Brick lining.
H, Iron plates for supporting lining.
I, Gas uptake.
J, Slag pocket.
K, Nut at end of tie-rod.
L, Buckstave.
M, Air port.
N, Passage to air port.
O, Slag pocket.
P, Plates of charging floor.

A.R., Air regenerators.
G.R., Gas regenerators.
B.C., Blank chamber.

made for kindling a fire to create a "draught" sufficient to "pull" the products of combustion through the furnace and regenerators when lighting, drying, and starting the furnace when new or after repairs. The "draught" is moderated, when required, by the use of a damper.

Beside each of the four checkered chambers is a receptacle known as a **slag pocket or dust catcher.** The slag pocket is intended to retain fine particles of dust—iron ore dust, lime dust, &c.—and an occasional overflow of slag. The dust is liable to be carried over in the current from the furnace and would flux and clog the "checkers" and interfere with the storing up of heat, causing thereby inconvenience and expense.

To return to the consideration of the **regenerative system:** When the flame has continued to travel in one direction for about 20 or 30 minutes, the valves are reversed and the gas and air are caused to pass upwards through the regenerators which have been heated by the outgoing gases.

The ingoing gas and air are thus preheated and yield a hotter flame. The outgoing spent gases pass out at the ports which were formerly inlet ports and descend between the checkered brickwork in the corresponding regenerators which are thus heated highly. Again, in due course, the valves are reversed, and with each reversal the furnace becomes more highly heated, until a temperature which can melt steel is attained. Such, in brief outline, is the regenerative system.

The sides of the furnace are strengthened by iron plates and castings. **Buckstaves**—which are often made of old rails—are set upright at intervals and "tied" by **tie-rods,** which are screwed at the ends to suit large nuts, to the buckstaves opposite. These tie-rods extend, above the roof, from end to end and from side to side. Two tie-rods also reach, in diagonal directions, from strong supports at the corners, thus adding strength to the structure.

As the **roof of the furnace** is built of bricks it would be impossible in practice to keep it from falling in if it were built flat. It is, therefore, arched across. And as the bricks expand very much on being heated, and contract considerably on cooling, the nuts at the ends of the tie-rods are gradually loosened when the furnace is being heated up for a campaign and tightened as the furnace cools down at the close. The general rise and fall of temperature during ordinary working causes expansion and contraction, and the arching of the roof allows a slight but sufficient rising or depressing along the centre and at other parts of the roof as required.

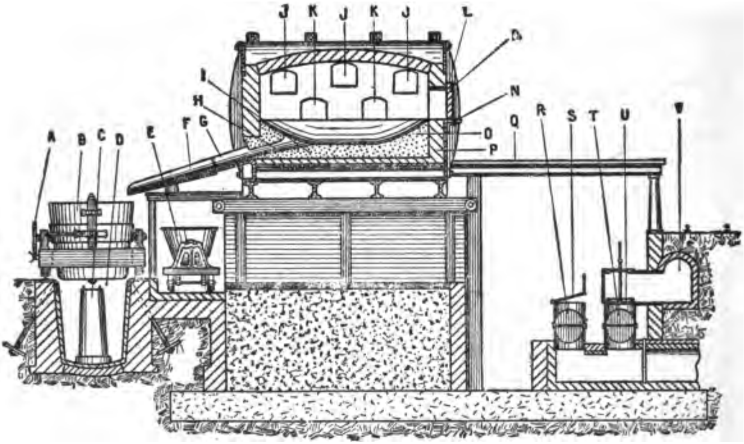

Fig. 42.—Siemens Furnace—Cross Section.

A, Wheel for rotating casting ladle.
B, Ladle.
C, Ingot mould.
D, Casting pit.
E, Slag ladle.
F, Launder.
G, Tapping spout.
H, Taphole.
I, Wall.
J, Air port.
K, Gas port.
L, Buckstave.

M, Charging door.
N, Foreplate or sill.
O, Working lining.
P, Firebricks.
Q, Charging platform of iron plates.
R, Butterfly valve for air.
S, Flap for regulating amount of air.
T, Butterfly valve for gas.
U, Valve for regulating amount of gas.
V, Culvert for gas from producers.

The bottom of the furnace consists of iron plates or castings which are carried on strong steel girders supported on brick-

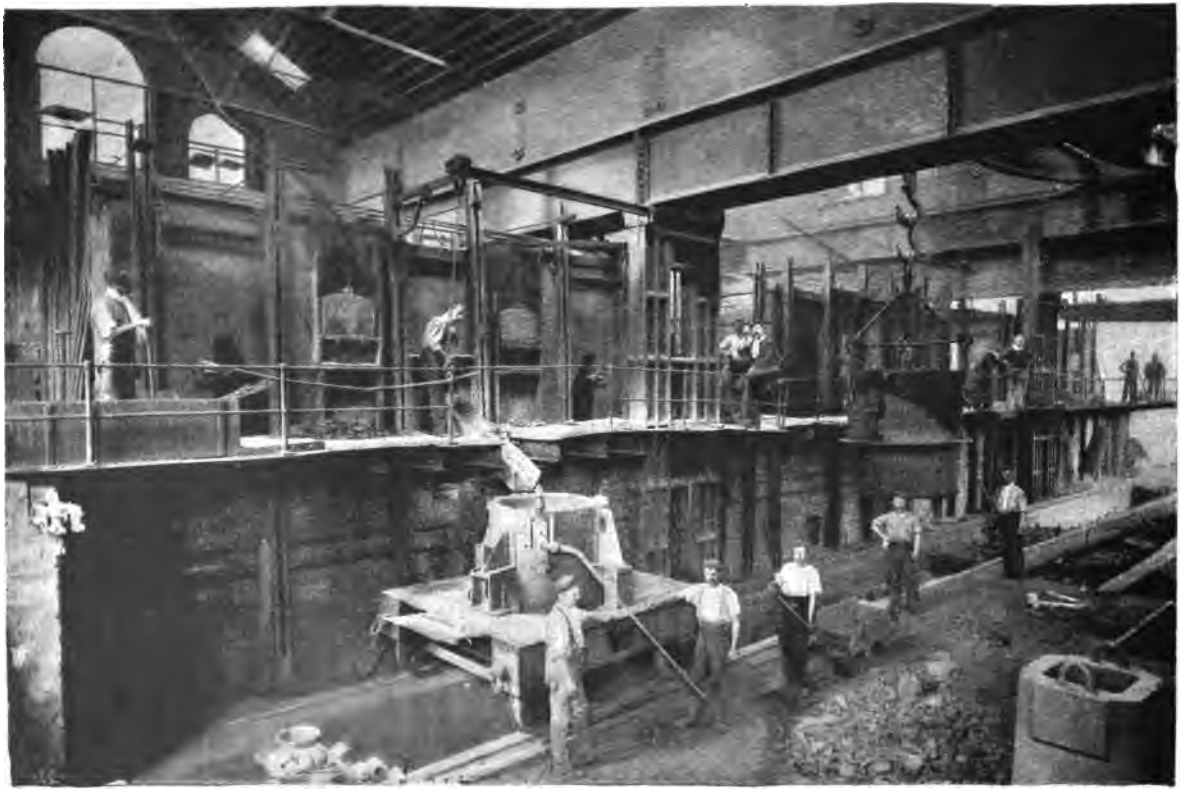

Fig. 43.—View of Back or "Tapping Side" of Siemens Furnace.

work, or, better still, on columns. Cast-iron plates make up a long deep tray with sloping sides. On the tray good bricks are set so as to form an outline somewhat resembling an oval basin. Over the bricks the **working lining** of sand coated with slag is laid in the manner described on p. 114.

On the front or charging side there are generally three openings, and on the tapping side two openings. These can be closed by **doors**, which consist of silica bricks set in strong iron frames. The iron frames are made larger than the openings so that they are not directly exposed to the high temperature of the furnace. The doors may be raised or lowered mechanically or by hand. If by the latter they are suspended from the shorter portion of a lever, on the longer portion of which is a counterpoise which nearly balances the weight of the door. In the centre of some doors there is a peep-hole through which the progress of the process can be observed. A disc or plate covers the peep-hole between observations. Through the three doors on the front side the solid materials are usually charged, and the charge is rabbled when required. Samples are withdrawn through the central front door. All doors admit repairing-material and tools. At the bottom of each door is a thick projecting **sill** or **foreplate** of cast iron.

The Shoot or Launder, along which the steel and slag are conveyed from the taphole to the ladle, is a half-round gutter made of steel plates. It is often in two parts—a short one which slopes sharply, and a longer one which is set with a slope which is not so steep. The short one is fixed to the furnace, the long one rests on trunnions. They are well lined with a thick coating of ganister; the joining of the two is carefully made, and the whole is thoroughly dried and warm when the furnace is tapped. Fig. 43 shows a view of the back or "tapping side" of one of the Siemens furnaces at the Rutland Works of Messrs. Samuel Osborn & Son, Sheffield.

Movable (rolling or tilting) furnaces are described in the appendix.—See page 255.

The Casting Pit for the Siemens-Martin process is generally in a straight line behind the row of open-hearth furnaces. Rails are laid on the tops of the two long walls of the casting pit (fig. 44), and on these rails a four-wheeled bogey, carrying the casting ladle, travels when pushed or pulled by a

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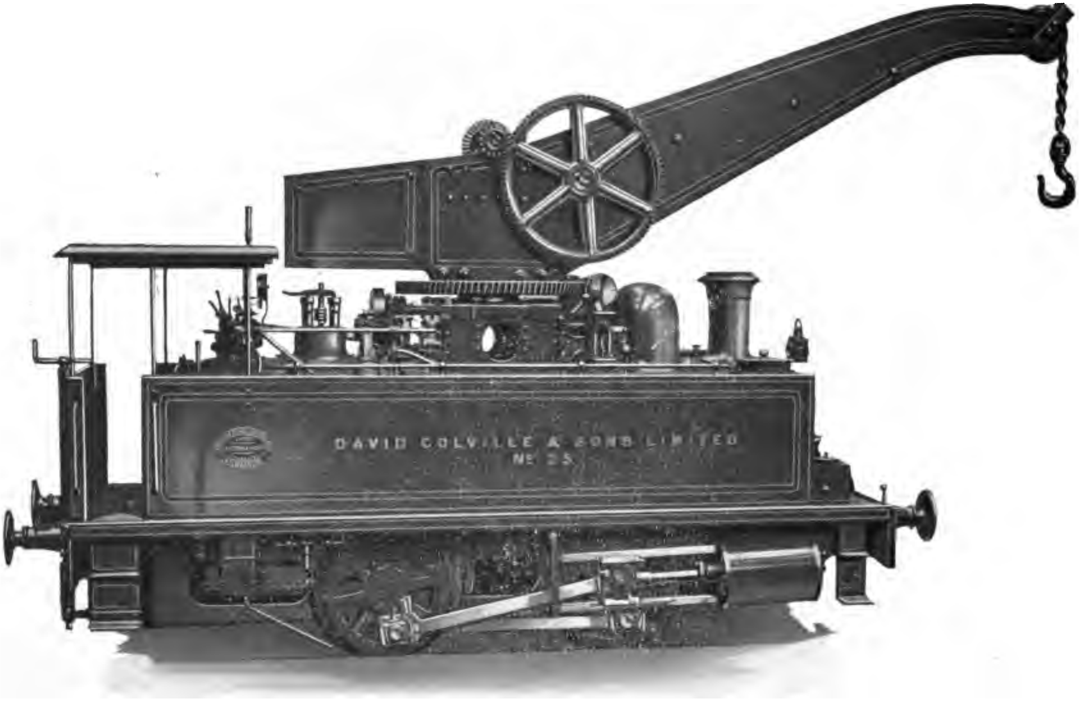

Crane Locomotive (14-inch Cylinders, to lift 5 Tons at 16 Feet Radius).

travelling engine running on rails which are parallel to the pit. The **Travelling Engine** or **Crane Locomotive** of the kind made by Messrs. Andrew Barclay, Sons & Co., Kilmarnock, and illustrated on opposite page, is employed for setting the ingot moulds, stripping and removing the ingots, &c.

The Ladle is of the Bessemer type, is brick-lined, and has rod, stopper, and nozzle.* It is mounted on a four-wheel bogey, which can be caused to travel on the rails at the casting pit. The large ladle, as made by the Lilleshall Company, shown in fig. 45, has double stopper arrangements, so that, when teeming, two ingots may be run at the same time.

Fig. 44.—Siemens Casting Pit, with Ladle in the distance.

Preparing the Furnace.—When a furnace has been built or repaired, a lining of firebricks is placed on the bottom plates, and additional bricks are laid so as to form an oval hollow. The furnace is then carefully dried, the gas introduced with caution, the working lining patiently put in, and the taphole made up.

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* See description of Bessemer ladle on p. 68.

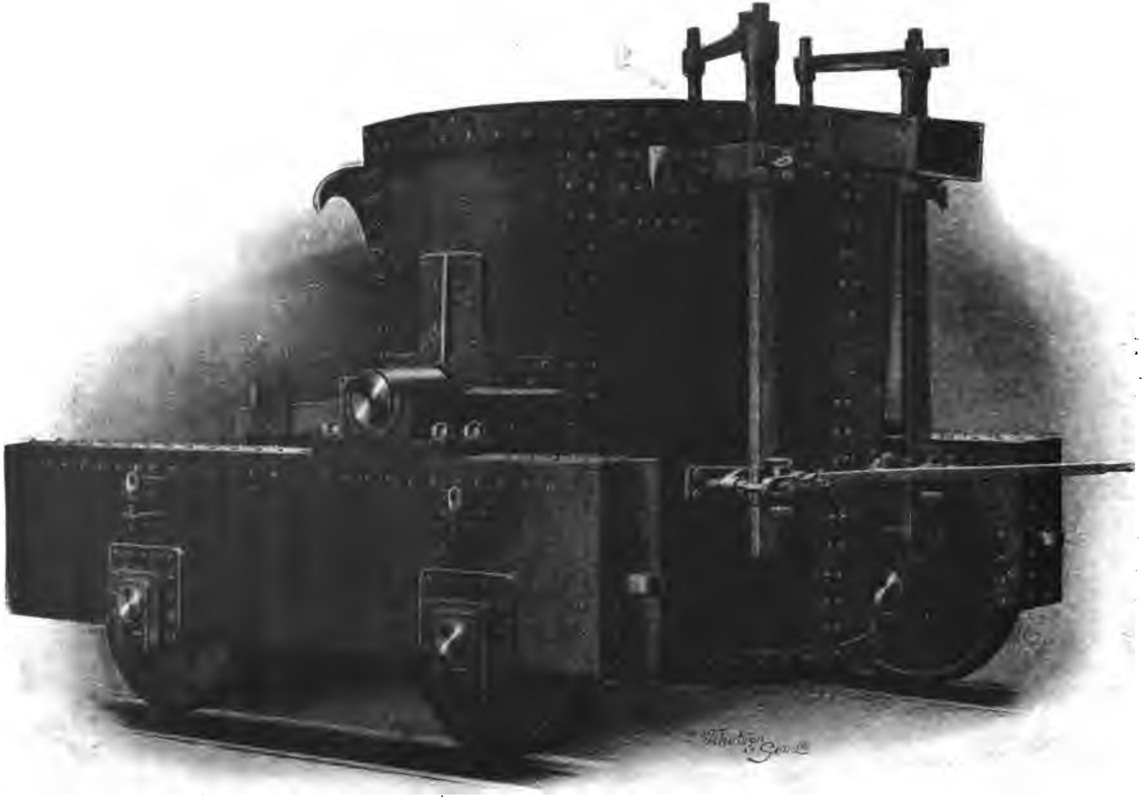

Fig. 45.—Large Steel Ladle with Double Teeming Arrangement.

To dry the furnace, a fire is kindled in the temporary fireplace in the chimney, and fires are also kindled in the regenerative chambers. In about two days the chimney and chambers may be partially dried; the fires are then withdrawn from the chambers. Long fireclay bricks are then built (without mortar or other setting) to form supports on which bricks are piled in open order to make up the checker work in the regenerators. A fire is then kindled in the furnace, air being admitted through the doors, and the hot products of combustion drawn downwards through the four air and gas regenerators to the passages leading to the chimney. When the furnace is ready, gas from the producers is allowed to blow through the culvert as far as the outlet nearest to the furnace, in order to clear the air out of the culvert. Quick-burning materials, such as shavings, splinters of dry wood, &c., are heaped in the furnace so as to fill it with flame and pass much carbon dioxide into the regenerators at the outgoing end. The doors are all closed, and gas from the producers is cautiously admitted; and, under these conditions, it should ignite gently. Carelessness or laziness in preparing to admit gas is unpardonable. For want of ordinary prudence the furnace and checker work may be shaken, and the whole campaign carried on under adverse conditions on account of an easily-preventable explosion.

When the gas has become ignited, more air is admitted to the furnace by opening the doors a little, and, afterwards, a regulated quantity is supplied through the air regenerator. After about seven hours the current may be reversed, the gas being followed a few minutes after by a gentle passage of air through the neighbouring regenerator. The gas and air valves are subsequently reversed from time to time at lessening intervals.

As the temperature of the furnace rises the bricks expand, and the nuts at the end of the tie-bolts must be turned so as to allow the buckstaves to give way a little. Otherwise the roof would become dangerously distorted, and the stability of the furnace would be impaired.

When the heat in the furnace is sufficient to frit* sand, the first sprinkling of the working lining is put in. The working

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* Frit, from a Latin word signifying *to roast*, means in metallurgy to soften by heat, so that the particles stick together.

lining consists of white Belgian sand with an admixture of less pure sand, or of loam, as a binding material.

To make up the required thickness of sand lining a thin layer of the mixture is spread over the bricks, and, when the heat of the furnace has caused the sand particles to firmly stick to each other, another sprinkling of sand is thrown in which "frits" or melts just enough to cause the sticking of the grains to each other and to the layer beneath. In that way, by "shifts" working day and night for about a week, the working bottom (bed and banks) is built up little by little. When the bricks are covered with a thick enough lining—which is continued until it rests also on the silica bricks of which the furnace walls are composed—pieces of Siemens (acid) slag are scattered over the surface. The slag melts and sinks a little into the sand lining, forming a glaze over the surface.

Fig. 46.—Tapping a Siemens Furnace.

The working lining of the furnace is shaped so as to slope towards the taphole, at the centre of the tapping side—that is, the side at which the metal is tapped, or discharged, when ready. Before charging the furnace the taphole is well rammed with a mixture of crushed anthracite and sand, firmly enough to prevent a breaking out of the melted charge, yet not jammed so tightly as to cause a "hard tap." A hard tap occasions undue delay when the metal is ready for the ladle. When required, the taphole is opened by means of a pointed rod and a sledge hammer. The rod is driven in from the outside, a ring is slipped on, and a wedge inserted between the rod and the ring with its thin end towards the ladle. On hammering the wedge the rod is forced out, and the opening made is widened by means of a rod worked through from the charging side of the furnace.

After the metal and slag have been tapped out, the sand bottom is repaired by fritting sand where hollows have formed. All slag is carefully cleared away from about the taphole.

To make up the taphole for the next charge an iron tool, consisting of a long rod with a plate or an enlargement at one end, is used. The larger end of the rod is pressed against the inner end of the taphole, which is then firmly rammed with the usual mixture of sand and crushed anthracite.

A Siemens furnace is not usually hurried in the working of its earlier charges: it generally does its best work in the second week of its campaign, which, as a rule, lasts about ten weeks before the furnace requires partial repair.

Parts which wear away quickly are patched up where they can be got at. Should a part of the roof give way, a "crab" —that is, a flat iron clamp, or clamps, embracing a number of silica bricks—is placed over the worn part.

For charging the furnaces machinery has been installed in several leading works. Indeed, since the decided increase in the capacity of open-hearth furnaces, machine charging has become imperative. Large furnaces, mounted on circled supports, and which can be tilted either to receive a charge or to be tapped, are in successful operation. Plant has also been installed for teeming from the ladle to the ingot moulds in a separate part of the work. Overhead cranes form an important part of that and some other arrangements.

Modern charging machines are described on page 256.

CHAPTER XI.

THE ACID OPEN-HEARTH PROCESS.

As already indicated, Siemens, or Siemens-Martin, steel is made in large reverberatory furnaces with regenerators, and gas is supplied for fuel.

Working an Acid Open-hearth Charge.*—The furnace being in good working condition and the taphole having been made up, the charge of pig iron and scrap is put in either by hand or by machinery.

To charge by hand a piece of old rail is laid on the sill or foreplate at one of the charging doors, and the flat part of a mild steel peel (fig. 47) is set on it. A piece† of hematite pig iron is placed on the peel, the door is raised, the peel is pushed into the furnace and turned over or jerked so as to drop the pig iron into the furnace. The peel is quickly withdrawn, another piece of pig iron is placed on it (fig. 48), and is quickly charged in like manner. The parts of the working

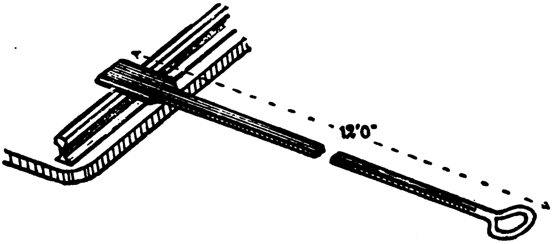

Fig. 47.—Peel, Rail, and Foreplate.

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* The first charge in a new furnace, or a furnace which has been "off" for repairs, does not carry as heavy a tonnage as following charges. The second and third charges are heavier, and at the fourth the full amount may be charged and worked.

† For convenience of charging, the "pigs" of iron are broken across into two parts.

bed of the furnace furthest from the doors being thus charged, and the pig iron well placed at the sides and back of the working bed, the remainder of the pig iron is thrown in. Steel scrap is similarly charged over the top of the pig iron.*

When charging is completed the doors are closed (they are kept closed as much as possible during charging), the valves are reversed from time to time, and the charge in the furnace melts.

Fig. 48.—Men Charging Steel Furnace.

Oxidation steadily proceeds. In the first two stages the oxidation is effected by the excess air which enters the furnace along with the producer gas. To bring on the "boil," ore is charged towards the end. The oxidised products—silica (SiO_2), oxide of manganese (MnO), and some oxides of iron (FeO and Fe_2O_3)—go into the slag. In the third stage oxidation is largely due to the oxygen in the ore which is fed in. When the charge has become sufficiently decarburised, and the bath of metal is in good position for tapping, the taphole is

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* Instead of charging cold pig iron into the furnace, much fluid metal is now used in some works.

opened—as described on p. 115—and the metal flows from the furnace along the spout and launder into the hot ladle (fig. 49) which is ready to receive it.

On tapping the furnace the "metal" comes first, then metal and slag, then mostly slag. When nearly all the steel has gone into the ladle, the launder (see fig. 42) is struck a heavy blow with a sledge hammer, thus separating the two parts. The slag, with a little of the metal, is thereby diverted to the slag tub beneath. When the ball of slag has solidified it is emptied out of its tub, and any metal which may have been with it is collected.

Fig. 49.—Steel and Slag being Tapped from Furnace.

In some works all the slag is run into the ladle, some of the slag being allowed to overflow into the adjoining slag tub. In such cases practically the whole of the steel goes into the ingot moulds. It is a good plan; more ingot steel is made, and less scrap steel; besides, the slag left on the top keeps the steel warm while casting is going on. But this plan involves the use of very large ladles.

When about one-third of the metal has entered the ladle a weighed quantity of hot ferro-manganese, in small pieces, is shovelled into the ladle to act as a deoxidiser and to provide a small percentage of manganese, which acts beneficially in the steel. The "addition" is generally completed when the second-third has run into the ladle. It soon melts, and the churning up, due to the fall of the remainder of the metal into the ladle, causes the ferro-manganese to become so diffused that a fairly homogeneous steel, containing a definite percentage of carbon and manganese, is produced.

Fig. 50.—Teeming Steel into Ingot Moulds.

If, instead of mild steel, a medium steel (say a steel with 0·5 per cent. of carbon) is required, a weighed quantity of hot spiegel-eisen is added, and allowed to melt and mix through the bath of metal before tapping the furnace. Ferro-manganese is also added in the ladle. Spiegel-eisen is not used in the manufacture of mild steel.

The steel in the ladle is discharged through the nozzle into the moulds in the manner described in connection with the Bessemer process, and shown in fig. 50. When the ingot has set, the mould is stripped off (see fig. 51), and the ingot is removed for reheating or to be stocked. The peculiarities of a steel ingot and the further treatment to which it is subjected are dealt with in Chapter xiii.

Fig. 51.—Stripping Steel Ingot.

On the completion of the teeming, the ladle is wheeled to a convenient part of the casting pit, turned over to get rid of the remaining slag (fig. 52), and the nozzle is knocked out to be ready for the fitting in of a new one.

Composition of the Materials used in the Open-hearth Process.—The pig iron is of the kind known in the trade as

Bessemer pig iron, or hematite pig iron, the composition of which is noted below. The steel scrap charged has, of course, the composition of the finished steel, which is also noted below:—

Fig. 52.—Empty Steel Ladle.

Constituents.	Chemical Symbols.	Hematite Pig Iron.	Steel Scrap.
Carbon (graphitic), . .	C	3·500	None.
Carbon (combined), . .	C	0·250	0·170
Silicon, ...	Si	2·200	0·025
Sulphur, ...	S	0·047	0·049
Phosphorus, . . .	P	0·047	0·050
Manganese, . . .	Mn	0·500	0·500
Iron (by difference), . .	Fe	93·464	99·215
		100·000	100·000

The finishing materials (ferro-manganese and spiegel-eisen) are similar to those used for the Bessemer process. Their composition is noted on p. 237.

Good Campanil Ore, a favourite brown hematite for the process, approximates in composition to the following:—

Constituents.	Chemical Formulæ.	Percentage.
Ferric oxide, ...	Fe_2O_3	75·0
Manganic oxide, ...	Mn_3O_4	1·0
Silica, ...	SiO_2	6·0
Lime, ...	CaO	4·50
Magnesia, ...	MgO	1·50
Phosphoric acid, ...	P_2O_5	0·03
Carbon dioxide, ...	CO_2	4·8
Water (combined), ...	H_2O	4·0
Moisture, ...	H_2O	3·0
		99·83
Metallic iron, ...	Fe	52·5

The carbon dioxide and combined water are soon driven off at the temperature of the furnace. The ore thus becomes porous—a good condition for being rapidly reduced.

Chemical Considerations.

During the first stage of the process—**the melting down stage**—about one-half of the silicon and about one-third of the manganese in the charge are oxidised. The oxides, uniting with oxidised iron, form slag. A little of the carbon may be oxidised and escape in the outgoing gases.

During the second stage—**going on the boil**—the remainder of the silicon and manganese are eliminated, and there is a noticeable diminution in the amount of carbon left in the charge.

During the third, or **boiling stage**, more carbon is oxidised, and, as the carbon-with-oxygen compounds (carbon monoxide and carbon dioxide) are gaseous, they cause a commotion, with appearance of boiling, as they come off. When this stage is reached good, pure, lumpy hematite ore (preferably Campanil ore) is cautiously fed into the furnace. The chief constituent of the ore is ferric oxide (Fe_2O_3), which, in the furnace, is decomposed; its oxygen hastens the burning out of the carbon, and the iron which is reduced increases the weight of ingots produced. A double duty is thus done—the carbon of the pig iron is oxidised and eliminated, and iron is produced direct from the ore.

If too much ore is fed in, or if it is fed too quickly, the steel is apt to be "wild," unmanageable, and unsound.

The **chemical reactions** are the same as in the acid Bessemer process, as detailed on pp. 78 and 79, but in the open-hearth process the oxidation of the carbon is chiefly effected by oxygen from ferric oxide (in the ore used), as indicated by the equation—

$$\begin{array}{ccccccc} 3C & + & Fe_2O_3 & = & 2Fe & + & 3CO \\ \textit{Carbon} & \textit{and} & \textit{ferric oxide} & \textit{yield} & \textit{iron} & \textit{and} & \textit{carbon monoxide.} \end{array}$$

Carbon dioxide (CO_2) is also produced.

The gases, carbon monoxide or carbon dioxide, as the case may be, escape with the outgoing gases from the furnace. The other oxidised materials go into the slag.

Action of the Ferro-Manganese or Spiegel-eisen.—The deoxidising action of the manganese is the same as in the Bessemer process (see p. 79); but in the Bessemer process the metal is completely decarburised before the spiegel-eisen or ferro-manganese are added. In the open-hearth process the "metal" which is ready for tapping contains carbon. In deciding on the material necessary for deoxidising open-hearth steel, allowance must be made for the carbon contained in the ferro-manganese or spiegel-eisen. In deoxidising Bessemer metal, carbon must be added to carbonise the metal: in finishing open-hearth steel, the carbon which is unavoidably present in the deoxidising materials must be allowed for, and the open-hearth metal decarburised to the proper percentage before being tapped. Thus, for a charge of finished steel to contain a half per cent. (·50) of carbon, the bath of metal in a furnace will be held to be sufficiently decarburised when ·37 per cent.* of carbon is present. If at this stage the other indications give assurance that the metal is ready for finishing and tapping, the right quantity of hot spiegel-eisen will be thrown in. There are unmistakable signs known to good steel

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* The steel melters would call this 37 points.

smelters. If, for instance, the slag which clings to the handle of a sample spoon or other tool breaks off in a clean, crisp manner when thrown down, the "first hand"—taking into account, of course, other considerations—will correctly conclude that the charge is in good condition for tapping. The fracture of the small test button—which is obtained by taking out a sample, partly cooling it, hammering it flat, breaking it across, and examining the appearance of the fracture—its soundness and malleability (or the absence of these qualities) afford valuable guidance.

Before finishing a charge it is generally good practice to "**pig back**"—that is, to place a few half pigs of good rich grey hematite iron (hematite pig iron containing much carbon and silicon) just inside the doors of the furnace, and, when the pig iron is red-hot, to push the pieces into the bath and rabble vigorously. The result of this is most beneficial, as the silicon "kills" some of the active oxides which may remain. A quiet metal may thus be ensured. The unfinished steel may then receive the addition of spiegel-eisen, if a medium steel is required, or be tapped and treated with ferro-manganese in the ladle if mild steel is wanted.

Before tapping, it is essential to success that the metal and the slag should both be in good condition. The metal should be hot enough to undergo the natural cooling in the ladle before and during pouring into the several moulds—with, of course, a margin of safety. But it is well that the steel should not be too hot when teemed.

The proportion of pig iron and scrap steel in a charge will depend on circumstances. As steel cannot be worked without the production of scrap it is necessary to have a process in which it can be utilised. Where scrap is plentiful, as much as 80 per cent. may be charged, and with such a proportion the charge can be worked through quickly. On the other hand, charges containing 75 per cent. of pig iron are regularly worked. Scrap steel is not necessary for the process. Sometimes it is convenient to work with about equal quantities of pig iron and scrap steel, and such a charge might be made up of the following for each 10 tons:—

6 tons of hematite pig iron (of various brands*),
4 tons of scrap steel.

1½ tons of brown hematite ore will be used for feeding, and about

2 cwts. of ferro-manganese may be required for deoxidising, and yielding the required manganese.

The progress of the process may be traced from the following figures:—

	Composition of the Pig Iron and Scrap Steel as Charged.	Composition when Melted.	Composition at the Beginning of the Boil.	Composition when ready for the Ferro or Spiegel.	Composition of the Finished Mild Steel.
Carbon, . .	2·85	2·63	2·50	0·13	0·18†
Silicon, . .	1·41	0·84	0·36	0·02	0·02
Phosphorus, . .	0·048	0·048	0·049	0·049	0·05
Sulphur, . .	0·048	0·048	0·049	0·050	0·05
Manganese, . .	0·75	0·56	0·11	Trace.	0·54
Iron, . . .	Δ	Δ	Δ	Δ	Δ
	100·000	100·000	100·000	100·000	100·000

The increase in the percentage of phosphorus is due to its being concentrated in less weight of "metal" up to the time of boiling, for, in addition to the elimination of carbon, silicon, and manganese, some iron will have become oxidised, and, as oxide, removed to the slag. As the ore which is fed in becomes reduced the weight of "metal" increases, but as the ore contains phosphoric acid (P_2O_5), which is reduced to phosphorus, the percentage in the metal is not diminished thereby. A slight increase in the percentage takes place on the addition of ferro-manganese, which is due to phosphorus in that material.

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* Where pig iron is purchased, a variety of brands—each with the distinctive mark of the maker—is prepared for each charge. Steelmakers who produce pig iron use their own make.

† The carbon is purposely varied to suit requirements, the other elements are fairly constant in percentage.

Δ By difference.

The same remarks apply, in some measure, to the increase in the percentage of sulphur. And the melted metal sometimes takes up sulphur from the producer gas which is burnt in the furnace. By careful boiling of the charge it is possible to diminish the amount of absorbed sulphur.

The Slag produced may be composed of the following, in proportions near to the figures given :—

Constituents.	Chemical Formulæ.	Approximate Percentage.
Silica, ...	SiO_2	56
Alumina, ...	Al_2O_3	1
Ferrous oxide, ...	FeO	27
Manganous oxide, ...	MnO	10
Lime, ...	CaO	5
Magnesia, &c., ...	MgO, &c.	1
		100

Although such slag contains 21 per cent. of iron and 7·75 per cent. of manganese, no process is at work for utilising more than a very small amount of the enormous quantity which is regularly produced.

CHAPTER XII.

THE BASIC OPEN-HEARTH PROCESS.

THE production of trustworthy steel from materials which contain phosphorus in medium amount has been forced on the trade. The process has assumed large proportions and is growing in importance. The elimination of phosphorus from melted pig iron having been successfully carried on in a basic-lined Bessemer converter, attempts to dephosphorise in an open-hearth furnace became inevitable. Open-hearth steel is popular with many purchasers.

The advantages of working in a reverberatory furnace have already been stated, see p. 14. To the advantages previously mentioned may be added this important one, namely:—That as the temperature is maintained by burning the gas supplied for heat raising, it is not necessary, as in the basic Bessemer process, to have a large percentage of phosphorus to keep up the heat by its oxidation.

Many ores yield pig iron containing a medium quantity of phosphorus—too high to be dealt with in an acid-lined furnace, or acid-lined converter, and not high enough to yield heat sufficient for Bessemerising. And even from pig iron obtained from good ores comparatively low in phosphorus, some of that deleterious element can be eliminated and a superior quality of soft steel obtained.

Until the advent of the basic open-hearth process such ores were almost valueless for steel-making. A famous American iron-master bought extensive mines of medium phosphoric ore for a modest sum. By the successful working of the basic open-hearth process these ores attained a high commercial value.

The furnace requires a basic lining, for reasons stated on p. 84, and the basic lining is the only matter in which the plant differs from the original open-hearth, or, as it is now called, the acid Siemens process; except that, as a greater quantity of slag is produced in the basic than in the acid process, smaller charges of basic steel must be worked in furnaces of given capacity.

The same style of valves, cranes, ladles, moulds, &c., are used as for the acid open-hearth process.

The furnace bottom is of cast-iron plates carried on steel bearers. Bricks, preferably of a neutral nature, are laid over the cast-iron plates and the bricks are covered with a thick basic lining of burnt magnesite or burnt dolomite and hot, boiled, anhydrous tar. The basic lining may be put in in one of three ways:—

(*a*) It may be spread and pressed with hot rammers, in the manner described when dealing with the lining of a basic converter.

(*b*) It may be made up of pressed bricks cemented together and covered over with rammed basic material.

(*c*) It may be spread and heated so that the materials fuse together, one thin layer being run on the top of another in the same manner as a sand lining is put in an open-hearth furnace.

A good method of lining a basic open-hearth furnace is to set a course of firebricks on the iron plates and a layer of magnesia bricks thereon, then "burn in" a coating of burnt dolomite mixed with 5 per cent. of finely-ground basic slag, each layer being firmly bound together by heat. When the "burning in" is finished, ground basic slag is thrown on the banks, where it melts and is absorbed. This is continued till a pool of melted slag is found on the bottom.

It is a safe plan to finish the bottom by ramming, and then heat the furnace with gas for at least a week before commencing to charge.

A magnesia lining formed of thoroughly calcined magnesite, cemented with magnesium chloride, is highly recommended.

As chemical action would take place between the acid bricks, of which the furnace walls are built up, and the basic lining, it is usual to form a neutral course where the thin part of the lining rests on the brickwork as shown in fig. 53. The neutral course may consist of a mixture of crushed chrome iron ore and tar rammed in position, or of neutral bricks (made of chrome iron ore mixed with tar, pressed and kiln-fired) carefully built in the course. It is not unusual to have magnesia brick walls below the line of the neutral rib.

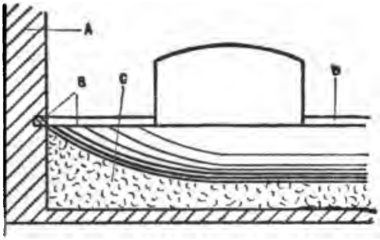

Fig. 53.—Neutral Rib, B, dividing Silica Bricks, A, from Dolomite Lining, C.

The mixture used for ramming the taphole is calcined dolomite, with tar and anthracite.

The Materials used in the Process are pig iron, broken iron castings, scrap steel, scrap wrought iron, iron cinders which do not contain too much silica, calcined pottery mine, purple ore, impure hematite ore, and limestone—both raw and calcined. The charge is finished with ferro-manganese in the usual way.

The Composition of the Pig Iron used varies considerably, the process being capable of utilising pig irons, &c., having a wide range of composition. Suitable pig iron is low in silicon and in sulphur. The content of phosphorus is not of so much consequence as in the Bessemer process; if high, a richer slag is produced, which sells at a higher price, but the risks in working are greater, and more time is occupied in working a charge.

The following may be taken as fairly representative of average pig iron for use in the process:—

Constituent.	Symbol.	Percentage.
Carbon, ...	C	About 3·50
Silicon, ...	Si	,, 1·00
Phosphorus, ...	P	,, 2·00
Sulphur, ...	S	,, 0·06
Manganese, ...	Mn	,, 1·50
Iron, ...	Fe	Δ
		100·00

Pig irons containing over 3 per cent. of phosphorus are regularly worked.

Working a Basic Open-hearth Charge.—When the furnace has been brought into good working condition, the scrap is charged, then lime, and perhaps some ore, and, lastly, the pig iron. In due course the charge melts, and calcined pottery mine or good cinder is fed into the furnace to hasten oxidation, and lime and limestone are also added to keep the slag in good basic condition. Elimination of silicon, phosphorus, sulphur, and carbon proceeds steadily. From time to time samples of the "metal" are taken, and quickly tested. When it is found to be pure enough, it is tapped out, received in a hot Bessemer ladle, deoxidised with ferro-manganese, and discharged into the ingot moulds.

Fig. 54.—Shovelling Lime into a Steel-Melting Furnace.

If the pig iron is high in sulphur, 3½ cwts. of limestone and 1½ cwts. of cinder rich in iron oxide are charged per ton of metal. This yields a very thick slag, which is opened out with 3 or 4 cwts. of calcium chloride or fluorspar and 5 or 6 cwts. of mill scale containing not more than 8 per cent. of silica. If the slag is kept in proper condition, so as not to eliminate the carbon too quickly, the sulphur may be diminished in quantity and brought down to a low percentage.

The working of Cleveland pig iron into good steel in basic open-hearth furnaces was ably pioneered by Mr. E. H. Saniter.

Mr. G. A. Wilson gives details* of a charge containing 1 per cent. of silicon, 0·2 per cent. of sulphur, and 1·5 per cent. of phosphorus being so worked as to produce a finished steel containing carbon 0·16, silicon 0·004, manganese 0·44, sulphur 0·042, and phosphorus 0·019 per cent.

Chemical Considerations.—The rate at which the elements are eliminated depends on the composition of the "metal" and slag and the conditions of working. Speaking generally, silicon is removed early, and manganese is also rapidly removed. This is fortunate, as the excess oxide of manganese formed neutralises the acid nature of the silica which is formed by the oxidation of the silicon. The carbon and the phosphorus are both steadily oxidised and removed throughout the process. It is important that all the carbon should not be removed before the phosphorus, as the commotion caused by the elimination of carbon (as gas) aids in quickly bringing the metal into more intimate contact with the slag from which, especially towards the finish, the oxidation is derived, and the lime of which takes up the phosphoric acid.

A slag which is too rich in iron oxides or is not of the right consistency may give rise to trouble in working the charge. Insufficiency of lime in the slag may cause a charge to go "off the boil" before enough phosphorus has been eliminated. In such a case, more lime is added and hot pig iron is charged in order to renew the "boiling," so that a steel containing only a small quantity of phosphorus may be produced.

The composition of the finished steel is much the same as that of acid open-hearth steel. Basic steel is, however, frequently lower in phosphorus. The percentage of carbon is varied as required.

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* *West of Scotland Iron and Steel Institute Journal*, Nov. 1903.

The (basic) slag—which contains much phosphoric acid when a highly phosphoric pig iron is used—is collected, and, if rich enough in phosphoric acid, is ground to fine powder, and sold for manure. If poor, it is tipped on the slag heap.

The slag produced when fluorspar is used is not as soluble as ordinary basic slag; it therefore has a lower agricultural value, and does not command such a high price.

The chief points of difference between the acid and the basic open-hearth processes are:—

Acid.	Basic.
Furnace lined with siliceous material.	Furnace lined with basic material.
Taphole rammed with anthracite and sand.	Taphole rammed with calcined dolomite and tar, and some anthracite.
Hematite pig iron used.	Phosphoric pig iron used.
Pure scrap used.	Phosphoric scrap may be used.
Pure quality brown hematite ore used for feeding.	Iron ores or cinders containing phosphorus used for feeding. Lime freely used.
No elimination of phosphorus.	Phosphorus eliminated.
Valueless slag produced.	Fertilising slag produced and sold.

COMPOSITION OF BESSEMER AND OPEN-HEARTH STEELS.

Steel for	Percentage of					
	Carbon.	Phosphorus.	Sulphur.	Manganese.	Silicon.	Iron.
Electrical purposes, . . .	·04	·03	·03	·05	Trace.	By difference.
Tinned plates, ...	·10	·06	·09	·50	·01	
Ship plates, ...	·15 to ·20	·05	·05	·50	·02	
Bridge work, ...	·19	·05	·05	·50	·02	
,, ,, ...	·23	·05	·05	·50	·02	
Pens, ...	·30	·04	·04	·20	·02	
Rails, ...	·40 to ·50	·05	·05	·60	10	
Guns (cannons), . . .	·30 to ·50	·04	·05	·50	·02	
Tyres for railways, . . .	·60	·05	·05	·60	·20	
Projectiles, ...	·80 to ·90	·04	·05	·50	·12	
Dies, ...	·80 to 1·0	·04	·04	·50	·01	

For composition of tool steels, see p. 50.

CHAPTER XIII.

BESSEMER AND SIEMENS STEEL INGOTS.

As stated in preceding chapters, ingot moulds are suitably set and fluid steel is poured into them.

If the newly-teemed steel proves to be "fiery" or "wild"—throwing off sparks very actively and frothing or boiling in the moulds—quietness may be induced by throwing little pieces of aluminium into the steel. The effect appears magical and out of all proportion to the small amount of aluminium used. Soundness in the ingot may be promoted by the judicious addition in the furnace of an alloy of iron containing much silicon. Alloys such as silico-ferro and silico-spiegel (see analysis on p. 238) may be used in small amount.

A common practice for promoting soundness is that of stoppering the ingot. The practice is this:—The mould is not quite filled with steel, and sand is thrown into the unoccupied space; on the top of the sand a rigid metal plate is placed, a bar is thrust through the two lugs of the mould and a wedge is firmly driven in between the plate and the bar. Ingots stoppered down in this way are shown in fig. 50, p. 119.

When the ingots have sufficiently solidified, on the outside, so that the crust can safely contain the still fluid interior portion, the moulds may be stripped off (see fig. 51, p. 120), the covering (if any) of plate and sand having been previously removed. If an ingot is stripped too soon a portion of the crust or shell may give way and steel may ooze or flow out—a condition known in works as "bleeding." Such ingots are objectionable. Serious accidents have arisen through premature stripping of ingots. The shrinking of the ingot during cooling facilitates stripping.

To remove ingots they are gripped by "dogs" at the end of a crane chain (see fig. 32, p. 77) and conveyed to be brought into condition for rolling, or to be stocked till required.

The moulds are cooled either by natural exposure to air, or, more quickly, in a vat or by a spray of water. The latter method is not economical. They are re-set as required for further use.

An ingot of steel, while cooling, becomes, naturally, solid on the outside before the inside. Impurities are concentrated in the portion which remains longest in the fluid state, and the more slowly an ingot cools the more marked will be the concentration, or **segregation** as it is called, of impurities in the centre.

On subjecting drillings from the longitudinal centre of an ingot to chemical analysis it is found that there is a perceptibly higher percentage of carbon, phosphorus, and sulphur than in drilling from parts nearer the sides of the ingot. This is fortunate, for on rolling out the ingot into plates, bars, &c., the least pure portion is, and remains, furthest from the surface. There are thus malleable surfaces and a harder backbone in cast and rolled steel.

Fig. 55. — Sketch representing Vertical Section of Partly-cooled Ingot.

In steel works practice the top part of an ingot is cut off and treated as scrap, because it is unsound. Why so? There are two good reasons.

As the steel ingot cools it contracts, and contraction goes on smoothly until the mass has become partly solid. So long as the steel is even feebly fluid the topmost portion settles down comfortably on the lower parts (fig. 55). But, in course of cooling, the outside portion of the upper part—the top, and the parts next the ingot mould—solidifies, while the still liquid centre portion flows downwards and continues to make good the void arising from the gradual cooling and contraction of the mid and bottom parts. A hollow, or **pipe**, is thus formed in the centre of the top part, as indicated in fig. 55. This **piping** is well marked in good crucible steel ingots.

And there is another serious imperfection in the top part. This arises from the comparatively slow expulsion of gases from the cooling ingot. The retaining of gases in fluid, and even solid, steel is remarkable. We speak of **occluded gases** and of **occlusion**—that is, of gases which are naturally retained in liquid metals, and sometimes for a considerable time in solid metals. As a steel ingot cools down, and becomes more solid and dense, some of the gases are, as it were, squeezed out, and ascend through the still liquid upper parts of the mass. But the topmost part solidifies before the whole of the middle and lower parts, and thus a crust is formed which the ascending gases are unable to get through. The gases which are thus trapped often gather into globules, and exert such a pressure as to force a part of the solidified top slightly upwards. The cavities so formed in the steel are known as **blowholes.*** These blowholes naturally accumulate near the top, and render that portion unreliable (see fig. 55). Hence the trade practice of cutting off the top part and treating it as scrap.

The advantages of pressing a newly-teemed ingot with a layer of sand and firmly covering with a wedged-down steel plate should be plainly apparent. The top part does not then solidify as quickly as when exposed to the air; the ascending gases are thus allowed more time to escape through the fluid steel at the top. Without difficulty the gases which rise clear of the steel find an exit between the sand granules and past the edges of the plate. Later, the top part cannot be so easily raised by the gases, and so the ingot is left in a more solid condition.

A sample of Bessemer steel was found to have occluded seventy times its own bulk of gases. On withdrawing the

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* The escape, or non-escape, of the gases from a cooling ingot have some resemblance to the "working" of a piece of dough. Sometimes a bubble bursts through the dough, but the dough being in the plastic condition, the opening is soon closed. Much of the gas, however, cannot escape, hence the open structure of bread.

gases the steel was to all appearance quite solid. Occluded gases are slowly given off from cold steel.

The composition of the gaseous mixture occluded in solid steel must vary very much. The following may be accepted as approximately representing average composition :—

Carbon dioxide, . . .	2 per cent.
Carbon monoxide, . . .	55 ,,
Hydrogen, &c., . . .	43 ,,

The large percentage (98) of *reducing gases* is important.

Treatment of Ingots before Rolling.—The ingots produced by either of the Bessemer or Siemens processes require to be reheated, or have their heat equalised, before being rolled into useful forms. An ingot, as previously stated, naturally cools more quickly on its outside than in its interior. As soon as the outside has solidified sufficiently, or as soon as a thick enough crust or shell has formed, the mould is stripped off the ingot and is laid aside. The ingot (which is then red hot on the outside and white hot and quite fluid within) is conveyed

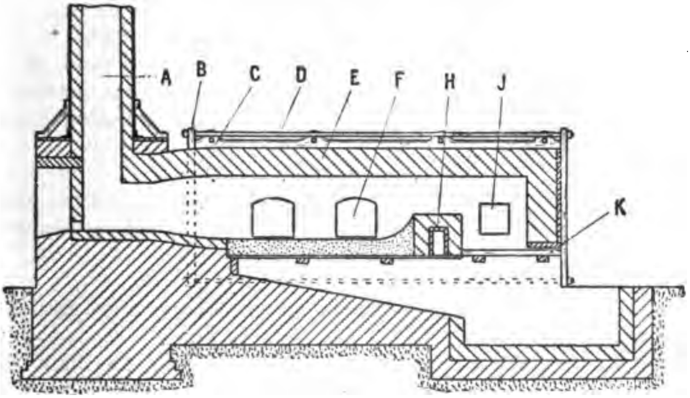

Fig. 56.—Reheating Furnace—Longitudinal Section.

A, Stack.	D, Tie-rod.	H, Fire-bridge.
B, Buckstave.	E, Roof (brickwork).	J, Coal-firing door.
C, Plates.	F, Door.	K, Iron bearers.

to a reheating furnace,* or to a soaking pit, or a vertical reheating furnace, to be heated uniformly before being rolled or hammered.

An ordinary **reheating furnace** is of the reverberatory type. It is built of refractory fireclay bricks, has suspended doors, and is very much like a puddling furnace. The chief differences are that the reheating furnace has no flue-bridge, and that the neck, or flue, between the furnace and the chimney is arranged so as to form a slag run for the flue cinder (fig. 56).

Reheating furnaces are worked by gas or by a coal fire. One district favours one system, while another district adopts and retains the other. Doubtless each has found out the one best adapted to its requirements and suited to its fuel.

The **working bottom** of the furnace may be of sand, or of iron ore, or of selected basic slag. The latter was patented by Messrs. Harbord & Tucker, and has given much satisfaction in steel works.

The ingots are charged horizontally into a furnace, and are allowed to remain there until each has attained throughout its mass a suitable temperature for rolling.

A distinct advance in steel-working was made by the late Mr. John Gjers' invention of the soaking pit.

Soaking Pits are arranged in sets. They are built in a mass of brickwork on a concrete foundation. Each pit has a carefully mitred lining of fireclay lumps 6 inches thick on its four sides. A good hard working bottom is made of broken bricks and silver sand. At the top, on the floor level, is a frame of cast iron, and the working doors or covers consist of iron frames enclosing firebrick slabs These covers are lifted and replaced, when required, by cranes, or are moved by other contrivances. Each pit is about 6 inches deeper and 3 inches wider than the ingots intended to be dealt with. Soaking pits are worked by the heat remaining in the hot ingots which are charged into them.

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* Occasionally the ingots are allowed to cool down completely, and are afterwards reheated and rolled.

To begin with, each pit is warmed by a succession of hot ingots which impart heat to the brickwork: on being taken out these ingots are reheated in a furnace. The pits, having been thus heated, are ready for regular working, and are charged with semi-cooled ingots. The heat of the steel tends to become equalised through the whole ingot. Little heat escapes from the pit, and much is absorbed and afterwards reflected from the brickwork on to the ingot. If a constant succession of hot ingots is kept up, the initial heat is sufficient, by equalising, to bring the whole mass of the metal into a fit state for rolling.

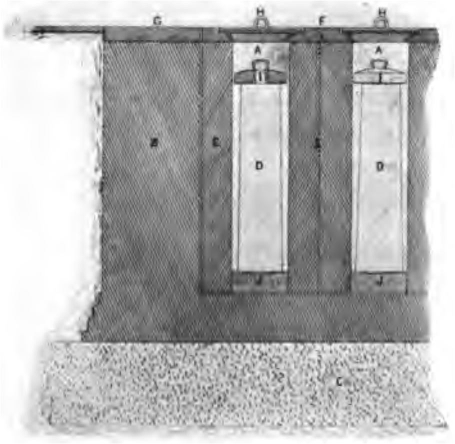

Fig. 57.—Gjers' Soaking Pit.

A, Fireclay cap or cover.
B, Brickwork.
C, Concrete foundation.
D, Ingot.
E, Firebrick lining.
F, Cast-iron plates.
G, Cast-iron plates enclosing F.
H, Cast-iron brick-lined cover.
J, Working bottom.

The advantages of the soaking pit are:—

(*a*) Saving of fuel,
(*b*) The ingots are handled and kept in a vertical position,
(*c*) The four sides of the ingots are heated equally, and
(*d*) The waste of iron is lessened.

The chief drawbacks are the awkwardness of the preliminary heating and the uncertainty of maintaining a constant supply of hot ingots from the casting pits.

It is now usual to have soaking pits coal-fired, or in conjunction with producers which supply the gas for heating the pits before starting and when empty. They are therefore now known by such names as "soaking furnaces," "vertical furnaces," &c. Fig. 58 represents half of a series of soaking furnaces which are gas-fired.

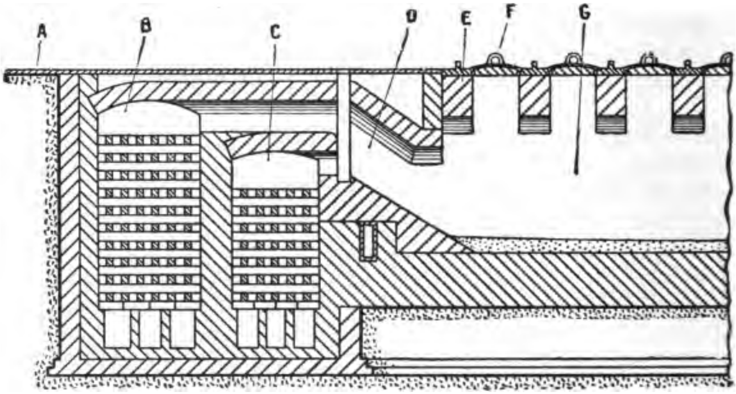

Fig. 58.—Gas-fired Soaking Furnace—Longitudinal Vertical Section.

A, Floor of mild-steel plates.
B, Air regenerator.
C, Gas regenerator.
D, Port.
E, Brick arch.
F, Cover of soaking chamber.
G, One of the soaking chambers.

A set of gas-fired soaking furnaces consists of a series of firebrick-lined cells below the level of the works floor. Deep archways of firebrick support the covers, and from these a large amount of heat is reflected. This keeps the top part of the ingot particularly hot and thus prolongs the fluid and plastic conditions where most beneficial. A working bottom is made up as in the original soaking pits, and the ingots are set and kept in the vertical position while soaking. At the lowest point a taphole is provided through which slag is run off.

Producer gas is provided and its combustion supplements the heat in the recently-stripped ingots. At each end of the series of pits are regenerators for gas and for air. The pits are worked on the regenerative system,* and the flame, in passing from one end to the other (alternately from each end), heats the ingot with fair uniformity.

From a furnace which is sunk in the ground there is not much loss of heat, and, as the current passing through soaking furnaces is not strong, the reducing gases from the ingots are not rapidly carried off. The "atmosphere" in the soaking furnace is therefore not so strongly oxidising as that of the ordinary reverberatory reheating furnace,† and hence the waste of steel is not so great. The vertical position in which the ingot is set for soaking is preferable to the horizontal position. The ingot settles more solidly and all sides are heated alike.

In daily works practice, the ingots are, as soon as permissible (with, of course, a working margin of safety), conveyed to the hot cells of the furnace and allowed to "soak" in the heat thereof. When taken out, an ingot is externally hotter than when charged—its heat has been equalised throughout its mass.

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* See pp. 105 and 107 for an explanation of this system.

† It should be remembered that an ordinary reverberatory furnace must be worked with an excess of air if a high temperature is to be maintained.

CHAPTER XIV.

MECHANICAL TESTING OF STEEL AND IRON.

THE fitness of finished steel and iron for certain purposes is mechanically tested by subjecting prepared test-pieces to a gradually increasing pull or stress in a testing machine, noting the tonnage at which it breaks, and measuring the extent to which it has stretched and the reduction in area of the fractured surfaces. The capacity of the material to withstand cracking or rupture on being bent or flanged is sometimes ascertained, and its welding quality is tried on certain occasions. Resistance to impact from a falling weight and other tests are also applied.

Preparation of Test-Pieces.—A selection is made from the plates, bars, or other products to be inspected, and, from portions systematically selected, test-pieces are shaped and marked.

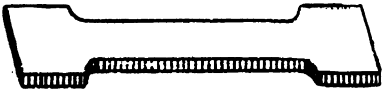

Fig. 59*a*.—Flat Test-piece, before Testing.

Fig. 59*b*.—Flat Test-piece, after Testing.

Strips from plates, &c., are cut in batches to the shape shown in fig. 59*a*, and marks are punched at certain distances—say 6, 8, or 10 inches apart. If from plates ½ inch thick, the strips may be machined so that the narrowest part is 2 inches broad, thus giving a cross area of 1 inch. In all cases the rolled surfaces are left untouched, the machine cutting being done on the edges to the extent necessary to bring the breaking stress within the capacity of the testing machine.

From massive pieces, such as axles, tyres, &c., portions are cut out and turned to the shape shown in fig. 60*a*. These when finished in the lathe often have a diameter of ·798 inch on the narrow part: this gives a cross area of ·500224, or a mere trifle over half an inch. Wrought-iron pieces are often turned to a diameter equal to 1 square inch. Marks are punched at certain distances apart. In preparing test-pieces the ends are left broader than the centre portion: this ensures a good grip when in the testing machine.

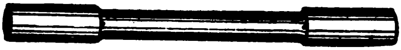

Fig. 60*a*.—Cylindrical Test-piece, before Testing.

Fig. 60*b*.—Cylindrical Test-piece, after Testing.

Testing the Tensile* Strength of a Test-Piece.—The prepared piece having been securely fixed in the jaws of the testing machine, power (generally hydraulic) is applied to pull the piece till the stress fractures it. The amount of stress is indicated by the position of a jockey weight which is caused to travel along a graduated scale on a beam. If the cross area of a test-piece, before being fixed in the machine, is exactly 1 square inch (1 □″) the indicated tonnage at which the piece was ruptured shows directly the tensile strength of the metal. When pieces which were turned to a diameter equal to ½ a square inch are ruptured the indicated tonnage is, of course, doubled so that the tensile strength is reported in terms of tons per square inch.

In works practice a gauge is used to see if the turned test-pieces are of the correct diameter. Special scales, slide rules, and tables are also used to facilitate calculations, for all test-pieces are not cut or turned to set sizes. But as a student

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* Tensile strength means the strength or power to hold together while subjected to a force tending to stretch or sunder by pulling.

should be able to calculate areas, &c., without such aids the following explanations and examples may prove useful. The decimal system is in use in test houses. The cross area of a flat test-piece is ascertained by measuring the breadth and the thickness, converting any vulgar fractions into decimal equivalents, and multiplying one dimension by the other.

To Ascertain the Cross Area of a Cylindrical Piece.—*Square the diameter and multiply the result by ·7854.*

Example.—What is the cross area of a test-piece which has been turned to ·797 inch diameter?

$$\cdot797 \times \cdot797 \times \cdot7854 = \cdot635209 \times \cdot7854$$

$$\cdot635209 \times \cdot7854 = \cdot49889$$

and

$$\cdot49889 = \text{cross area.}$$

To Compute the Tensile Strength of a Test-piece.—*Divide the indicated tonnage by its original cross area.*

Example.—A test-piece ·8 inch diameter broke under a maximum stress of 16·8 tons. What was its tensile strength?

$$\cdot8 \times \cdot8 \times \cdot7854 = \cdot50265,$$

$$\frac{16\cdot8}{\cdot50262} = 33\cdot42,$$

and

$$33\cdot42 = \text{tensile strength per square inch.}$$

To Compute the Percentage Elongation of a Test-piece.—*Find the difference in the distance between the punch marks on the piece before and after rupture. Divide the difference by the original distance, and, in order to find the percentage elongation, multiply the result by 100.*

Example.—Distance between the marks when the test-piece broke = 9·82 inches.

Distance between the marks on the test-piece before fixing it in the testing machine = 8·00 „

Difference = 1·82 „

Then,

$$\frac{1\cdot82 \times 100}{8} = 22\cdot75,$$

and

$$22\cdot75 = \text{elongation per cent.}$$

To Compute the Percentage Contraction of Area of a Test-piece.—*Find the difference between its cross area before and after testing. Divide that difference by the original cross area, and, in order to find percentage, multiply the result by 100.*

Example.—Diameter of the piece before testing = ·800 inch.
Diameter of the test-piece when broken = ·521 „

Then,
$$\cdot 8 \times \cdot 8 \times \cdot 7854 = \cdot 50265 \text{ inch.}$$
$$\cdot 521 \times \cdot 521 \times \cdot 7854 = \cdot 21319 \text{ „}$$
$$\text{Difference} = \cdot 28946 \text{ „}$$

And
$$\frac{\cdot 28946 \times 100}{\cdot 50265} = 57 \cdot 58.$$

57·58 = percentage contraction of area.

The quality of a certain make of steel will depend chiefly on (*a*) its composition, (*b*) the working of the steel in the furnace or converter, and (*c*) the treatment to which it was subjected after being poured into the ladle.

The percentage of carbon will, to a large extent, influence its tensile strength and its elongation. Within limits, the higher the percentage of carbon present the greater will be its tensile strength and the less its capacity for elongation before breaking. The other elements present will have a marked effect on its mechanical properties. Malleable metals are improved by judicious manipulation, such as rolling at proper temperature.

Mild steels generally have composition near to the following:—

Carbon,	·17*
Phosphorus,	·05
Sulphur,	·05
Silicon,	·02
Manganese.	·50
Iron (by difference),	Δ
	100·00

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* The percentage of carbon is purposely varied to suit the purpose for which the steel is intended.

The tensile strength of such steel is generally equal to from 27 to 32 tons per square inch, with an elongation of from 16 to 22 per cent. on 8 inches.

SPECIFICATIONS FOR MILD STEEL.

	Tensile Strength in Tons per Square Inch.	Percentage Elongation.
Ship plates—		
Admiralty, . . .	26 to 30	20 per cent. on 8 ins.
Lloyds, ...	28 ,, 32	16 ,, ,, ,,
Boiler plates—		
Admiralty, . . .	27 ,, 30	20 ,, ,, ,,
Board of Trade, . .	27 ,, 32	18 ,, ,, ,,
Lloyds, ...	27 ,, 32	20 ,, ,, ,,
Boilers (other parts)—		
Admiralty, . . .	24 ,, 27	25 ,, ,, ,,
Board of Trade, . .	26 ,, 30	20 ,, ,, ,,
Lloyds, ...	26 ,, 30	20 ,, ,, ,,
Steel for bridge building, .	27 ,, 31	20 per cent. on 8 or 10 ins.

Pieces which have been rolled into thin sections or drawn into wire yield better results than thicker sections.

Common wrought iron may contain—

Carbon, ...	·05
Phosphorus, ...	·35
Sulphur, ...	·06
Silicon, ...	·23
Slag, ...	about 3·3

Best wrought iron may contain—

Carbon, ...	·06
Phosphorus, ...	·18
Sulphur, ...	·04
Silicon, ...	·20
Manganese, ...	·06
Slag, ...	about 2·8

STRENGTH OF WROUGHT IRON.

	Tensile Strength in Tons per Square Inch.	Percentage Elongation.	Percentage Contraction.
Puddled bar, . . .	18·6	4 to 8	4·5
Common iron, . .	21·0	8 ,, 16	5·3
Treble best, . . .	23·0	12 ,, 25	15 to 35

STRENGTH OF CAST IRON.

For testing the power of iron castings to withstand crushing, test-pieces 3 inches by 1 inch are prepared, and they show a resisting power of 25 to 90 tons, with a probable average of about 45 tons.

For testing the transverse strength of castings, a bar 2 inches deep by 1 inch in breadth is laid on supports 3 feet apart. Under these conditions common iron will carry from 23 to 27 cwts., and better iron will carry from 28 to 31 cwts., with a deflection of ·3 inch.

CHAPTER XV.

FOUNDRY PRACTICE—IRON AND STEEL CASTINGS.

THE object of the iron-founder is to "cast" or form pig iron into shapes required. This he does by pouring melted pig iron into prepared moulds, so that the "castings" will be of the desired size, shape, and strength.

For the production of sound and shapely castings the melted "metal" must be of suitable chemical composition, and must be cast at proper temperature in reliable moulds Increasing attention is now being paid to these points.

The **moulds** must be of material which will withstand, without softening or fusing, the heat of the molten pig iron; the material must have coherency—that quality which binds it together so as to hold against the pressure of the fluid metal—it must be close enough to contain the liquid metal, while, at the same time, open, or porous enough to permit the escape of gases which are liberated from the melted metal during solidification. The chief constituent of the material for the mould is silica * (SiO_2), as shown in the following analyses:—

Constituents.	Chemical Formulæ.	Fire Sand.	Moulding Sand.	Core Sand.
Silica, ...	SiO_2	98·0	86·0	94·3
Alumina, . . .	Al_2O_3	1·5	8·5	2·0
Iron oxide, . . .	Fe_2O_3	0·1	2·0	0·3
Lime, ...	CaO	0·2	0·5	0·0
Carbonate of lime, .	$CaCO_3$	...	0·3	1·6
Magnesia, . . .	MgO	0·1	0·8	0·5
Alkalies, . . .	Na_2O and K_2O	...	0·1	0·1
Combined water, .	H_2O	0·1	1·5	1·0
Organic matter, . .	...	...	0·3	0·2
		100·0	100·0	100·0

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* White sand is a familiar example of silica; a still better example of pure silica is quartz, a hard, glistening substance.

Fire sand is useful for mixing so as to increase the power of withstanding a very high temperature, and especially for steel-casting purposes. It is also useful for correcting a moulding sand which is too apt to bind.

Moulding sand of the composition stated is suitable for medium iron work. For lighter iron work moulding material with 82 per cent. of silica is suitable; for heavy iron work the silica may amount to 88 per cent., or over.

In moulding materials silica is the fire-resisting substance. Alumina is also refractory, but it "bakes together" when heated with silica—it possesses "bond." When too much alumina is present there is danger of the mould being spoiled by excessive shrinkage or by being non-porous. A sand low in alumina and iron will permit of the rapid escape of gases; with high alumina the sand bakes and holds back the gases. "Organic matter gives bond to sand, but the bond or binding property is destroyed the moment it comes in contact with the molten metal, the organic matter being burned out; consequently there is a loss in volume, and this shrinkage causes the sand to fall or crumble."* The other ingredients mentioned in the table tend to cause the material to fuse or melt. Alkalies (potash and soda) are specially bad. Being thus objectionable they can only be tolerated in small amount.

The mechanical condition, the intimacy of intermixture, the pressure to which the substance has been subjected while in its native bed, and the fineness to which the particles have been ground—all these have an important bearing on the quality of moulding material. The proof of its fitness or unfitness may best be found by trial. But chemical analysis may, in a most helpful degree, suggest the proper proportion in which to mix with some other material to produce a good moulding compound.

The moulding material must be of the proper grain; its binding power may be increased by admixture with clay, or with tar, or with cheap gum. Cores have been made of pure sand and thick oil. Porosity may be improved by judicious

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* C. Scott, see paper by J. E. Stead, F.R.S., Cleveland Institute of Engineers, Feb. 1905.

admixture with coal dust. Binding power is sometimes improved at the expense of porosity; improved porosity may mean corresponding diminution in binding power. Chopped straw, cow hair, horse dung, &c., are mixed with sand and loam. They give additional strength, and, as they burn off, leave passages for the escape of gases.

Green-sand is the term applied to moulds made of sand in its natural, raw, or green state. The composition of the sand may be correct for light castings, or an addition of 5 or 6 per cent. of fireclay may be necessary for heavy castings. Green-sand moulds need a facing, about an inch in thickness, of a mixture of sand and coal dust towards the hot metal. The coal dust prevents fusion, and the castings have a cleaner surface. The surface is blacked with graphite (plumbago), or other suitable substances. For **dry-sand castings** the moulds are carefully dried before pouring in the metal. This takes time, and increases the cost. For large castings **loam moulds** are prepared. Loam moulding is the most expensive form of founding, but is practically the only one for certain purposes.

The Melting of "Metal" for Foundry Purposes.—In a few works the "metal," as it comes from the blast furnace, is run directly into ironfounders' moulds. But, as a rule, it is cast into "pigs" (see p. 208), which are allowed to solidify, and are afterwards graded and remelted in the foundry. Metal for special purposes is remelted in reverberatory furnaces, as they are well under control and can discharge at one time a large quantity of fluid metal of uniform composition. When melted metal is required in small quantities only, the pig iron is remelted in crucibles. For general foundry purposes a cupola is employed for remelting. A Bessemer works' cupola has been described on p. 71, and it differs from the foundry cupola chiefly in size. A Bessemer cupola is worked day and night; as a rule, a foundry cupola is not.

Foundry Cupolas.—A foundry cupola is an upright cylindrical structure of firebrick encased in rivetted boiler plates. Internal rings or angle irons are attached at intervals to the plates for supporting the brickwork. An air blast is injected through tuyeres, which may be in one row or more. For

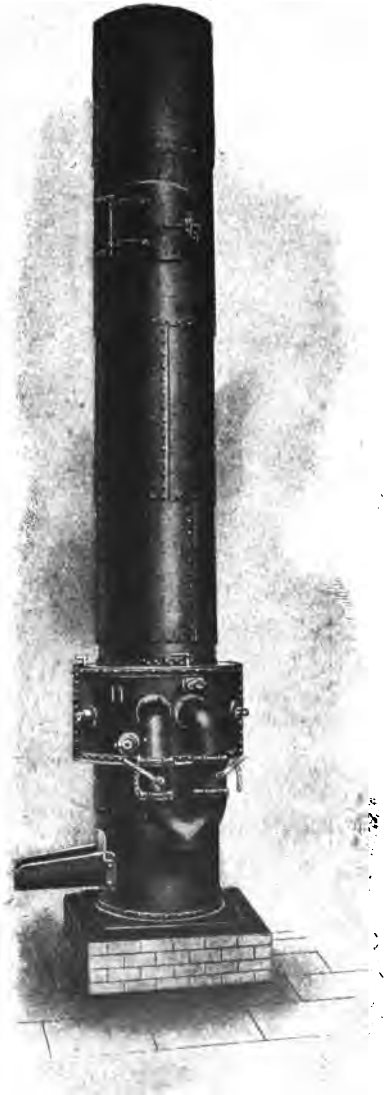

Fig. 61.—Foundry Cupola with Solid Bottom.

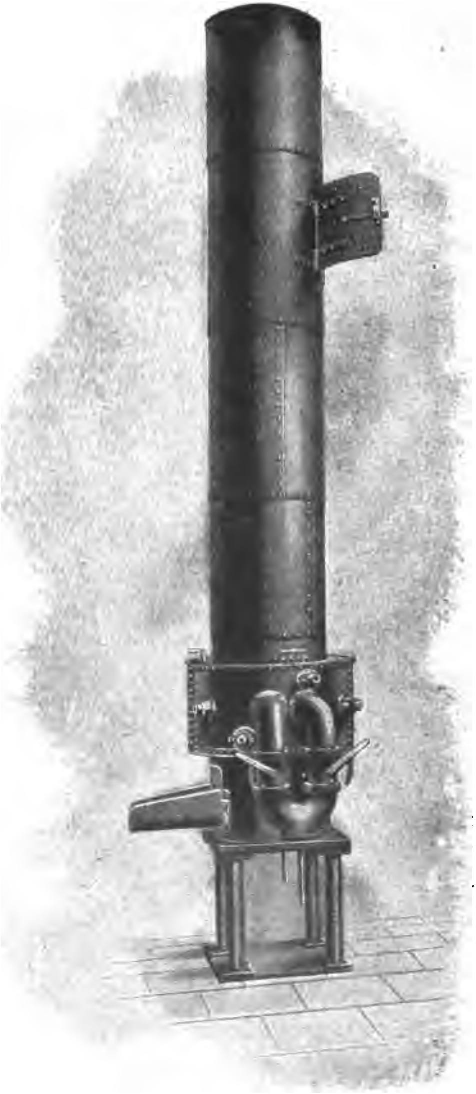

Fig. 62.—Foundry Cupola with Drop Bottom.

heavy foundry work the tuyeres are placed higher than for small foundry work. Pig iron, fuel, and flux are charged into the hot cupola; molten metal is tapped out, when required, and runs from the taphole along a spout or launder into the casting ladle. For small foundry work the spout is placed about 20 inches from the ground; for heavier work it is placed higher. From larger cupolas slag is tapped off from the slaghole as it gathers.

Some cupolas have solid bottoms, as shown in fig. 61; others are constructed with a "drop" iron bottom plate, as shown in figs. 62 and 63.

On an iron foundation plate four massive cast-iron columns are set; these support a substantial base plate which carries the shell of the cupola. When the bottom plate is removed, or unfastened, the materials left in the cupola—those which have not been tapped out—are removed. Fig. 63 shows a section of such a "drop-bottom" cupola erected to the specification of Mr. Robert Buchanan in the Soho Foundry of Messrs. W. & T. Avery, Limited. Its tuyeres are not at one uniform level, but are arranged as points in a spiral. Beneath the lowest tuyere, in the tuyere belt, is a plug composed of an alloy which melts very readily, and in the event of slag or metal rising accidentally to an inconvenient extent, the "fusible plug" melts, and thus an outlet is provided and damage to the tuyere is prevented.

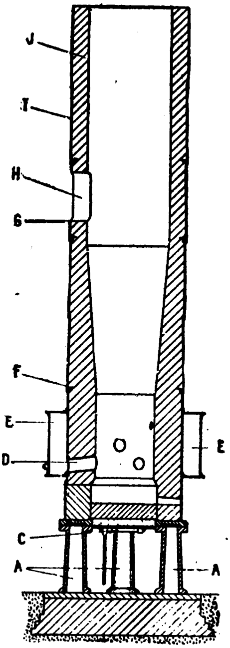

Fig. 63.—Section of Foundry Cupola with Drop Bottom.

A,	Columns.
C,	Drop bottom.
D,	Tuyere.
E,	Air belt.
F,	Iron angle.
G,	Charging platform.
H,	Charging door.
I,	Iron shell.
J,	Brickwork.

Fig. 64 shows a view of one of the improved rapid cupolas erected by Messrs. Thwaites Brothers, Bradford. An important adjunct is the **receiver,** which is lined with firebrick, and connected with the cupola by a brick-lined channel. It has usually about half the hourly melting capacity of the cupola. The hot-air pipe between the receiver and the cupola supplies sufficient hot air from the latter to prevent the chilling of the "metal."

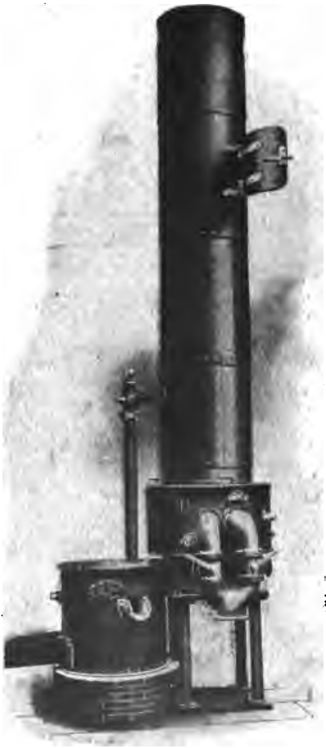

Fig. 64.—Foundry Cupola with Drop Bottom and Receiver.

The blast required for a cupola is usually supplied at a pressure of about 10 ozs. per square inch.* The quantity of air needed is about 650 cubic feet per minute for each ton of

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* Equal to a 21-inch column on a water gauge.

pig iron melted. The amount and pressure vary according to circumstances. An economical and convenient appliance for supplying the required air blast is the **Roots blower**, which is illustrated in figs. 65 and 66. As made by Messrs. Thwaites Brothers, Bradford, Yorks, the blower consists of a carefully-machined cast-iron case which is elliptical in cross section. The end plates are bored by a duplex machine for the journals of the shafts for the revolvers. Each revolver is

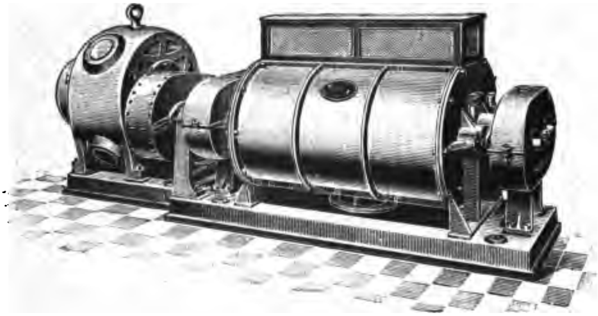

Fig. 65.—Roots' Blower with Electric Motor.

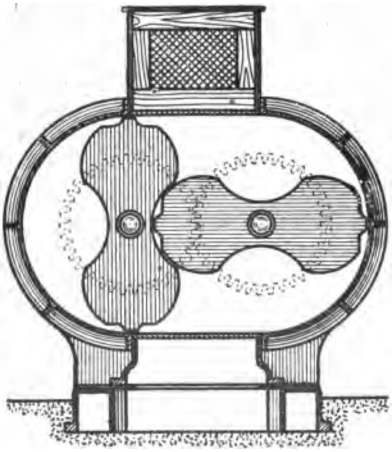

Fig. 66.—Section of Roots' Blower.

cast in one piece, accurately machined all over to gauge, specially centred, and carefully balanced. Conical adjustable bearings are used. Geared wheels are introduced to equalise the power transmitted to the revolvers. Oil baths set for the lower part of each wheel ensure comparatively silent and smooth working. Generally there is a wooden cover with perforated metal panels on the top of the cylinder, but sometimes the air inlet is placed on one side.

The blower is mounted on a bed plate, and may be driven by belt, by steam engine direct, or by a motor. For a cupola melting about 4 tons of pig iron per hour the blower may be worked at 380 revolutions per minute; for cupolas of greater capacity the revolutions will be less, but the driving pulleys will be of greater diameter.

Fans are frequently used for forcing the air required for cupolas.

Working a Foundry Cupola.—When the cupola has been brought into working condition a coal fire is kindled and then covered with a "bed" of coke. When the coke has burned up to the level of the tuyeres, the door near the bottom of the cupola, as described in p. 71, is placed in position, and charging from the charging door is begun.

Mr. Robert Buchanan gives the following particulars[*]:—

Bed of coke = 5 cwts.
Five charges of 10 cwts. of pig iron, alternating with 1½ cwts. of coke.
Alternate charges of 10 cwts. of pig iron with 1 cwt. of coke.
Towards the end of the working day the proportion of coke is further diminished.

The amount of coke consumed varies, 1 lb. of coke sufficing, on an average, to melt 10 lbs. of "metal" for heavy castings, or 8 lbs. of "metal" for light castings.

Limestone is also charged into the cupola to supply lime to combine with the ash of the coke and the sand on the pig iron to form a fusible slag. The amount of limestone used varies between a quarter and a half hundredweight per ton of metal.

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[*] *Proceedings of the Staffordshire Iron and Steel Institute*, Nov. 1901.

Foundry Ladles are of cast iron if small, of wrought iron or mild steel if larger, and have a capacity of from half a hundredweight up to several tons. They are lined with refractory materials and should be heated before using. Figs. 67 and

Fig. 67.—Moulder's Hand Shank Ladle.

Fig. 68.—Moulder's Double Hand Shank Ladle.

68 represent hand ladles used for small castings. In Fig. 69 is shown a large-sized geared crane ladle, as manufactured by

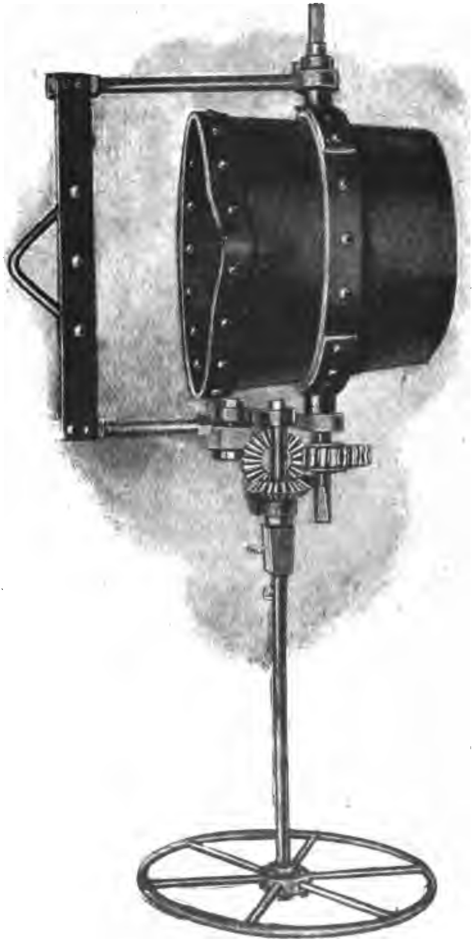

Fig. 69.—Moulder's Geared Crane Ladle.

Messrs. Thwaites Brothers, Bradford. A trolley ladle, which is convenient for conveying and dealing with foundry metal,

Fig. 70.—Moulder's Ladle Mounted on Wheels.

is illustrated in Fig. 70. The latter, made by C. M'Neil, Glasgow, is of stamped steel, without weld or rivets.

The contents of the ladles are generally emptied over a lip or spout, the ladle being tilted as required and the slag held back during pouring when necessary.

Pig Iron for Foundry Use.—The pig iron, or mixture of pig irons, should be of a composition suited to the qualities needed in the castings which are to be produced. A strong, heavy casting is best made from pig iron which is not suited for light ornamental work, and "metal" which is well adapted for light work does not suit for strong castings. It is a costly mistake to attempt to improve certain castings by incorporating high-priced hematite pig iron. The author has frequently, with most satisfactory results, advised the introduction of more cheap pig iron in mixtures. There is in the minds of many foundrymen a notion that in order to make good castings costly pig iron is necessary, and whenever trouble comes and castings are faulty, tests bad, and rejections numerous, recourse is had to hematite as the cure for all ills. It is equally a mistake—although not by any means so common—to seek to improve all mixtures by using cheap, highly-phosphoric pig irons. The purchase and use of a first-class foundry pig iron, of a good old standard brand, is often a profitable investment for the foundryman. Castings which have been proved by long and useful service to be excellent do not vary in composition to any great extent.

By selecting grey and white, or grey and mottled pig, irons in such proportions that the chemical composition will yield "metal" from the cupola of the composition required, one of the first conditions for the production of suitable castings will be complied with. The changes in composition which pig iron undergoes while passing through the cupola—such as oxidation of iron, diminution in percentage of silicon and of manganese, increase in percentage of sulphur, and the slight increase in percentage of phosphorus—must, of course, be allowed for in making up the cupola charge. With well-arranged and well-finished moulds of proper materials, suitable metal, attention to the best temperature at which to pour, and the rate at which the castings are allowed to cool, waste will be reduced to a minimum.

Silicon is the element in pig iron which has a dominant effect, either directly or indirectly, in modifying the character of a casting. It has a marked effect on the condition of the carbon. When the percentage of silicon is high the carbon is mostly in the graphitic state,* and the sulphur is, as a rule, low. Such a pig iron is grey, unless produced under abnormal blast-furnace conditions. A pig iron, or a mixture of pig irons, containing a fair proportion of silicon, is well adapted for casting, because it is very fluid when melted, fills the mould well, and makes a casting which is likely to be free from blowholes. A soft grey pig iron is best suited for castings which are to be tooled.

Professor Turner investigated the relations between chemical composition and mechanical qualities, and found that—

Castings of maximum tensile strength contained 1·8 per cent. of silicon.
,, ,, transverse ,, ,, 1·4 ,, ,,
,, ,, crushing ,, ,, 0·75 ,, ,,

Phosphorus in pig iron increases the fluidity but reduces the strength. Sulphur tends to whiten the iron and may, to a limited extent, add to its strength. Its presence beyond a limited amount is objectionable. In experiments conducted by Mr. Chas. Wood, the presence of 0·16 per cent. of sulphur did not appear to be harmful.

The effects of carbon in castings are most marked. "Combined carbon is mainly the determining factor of the hardness and shrinkage of a casting. . . . For general engineering foundry castings about 0·5 per cent. is a fair amount. . . . The total carbon should not exceed 3·25 per cent. either in hard or soft castings."† When pig iron contains a high percentage of graphitic carbon the plates of graphite are generally large, and, as they distinctly break the metallic continuity of the casting, its strength is lessened. Professor Turner has investigated the influence of size of graphite plates in castings with important results.

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* See p. 12.

† J. E. Stead, paper read before the Cleveland Institution of Engineers, February, 1905.

Approximate Analysis of Grey Foundry Pig Iron.

	Chemical Symbols.	Per cent.
Graphitic carbon,	C	3·25
Combined carbon,	C	0·25
Total carbon,	C	3·50
Silicon,	Si	2·50
Phosphorus,	P	0·80
Sulphur,	S	0·10
Manganese,	Mn	1·30
Iron,	Fe	Δ
		100·00

Composition of Iron-Castings.

	Chemical Symbols.	Heavy, Strong.	Light, but Fairly Strong.	Ornamental.
Carbon,	C	3·5	3·8	4·0
Silicon,	Si	1·9	2·3	2·8
Phosphorus,	P	0·6	0·8	1·0
Sulphur,	S	0·09	0·08	0·09
Manganese,	Mn	0·5	0·5	0·5
Iron,	Fe	Δ	Δ	Δ
		100·00	100·00	100·00

Cast iron can be softened by altering its composition, especially by enriching with silicon, or by allowing to cool slowly. And it can be hardened by remelting, so as to eliminate silicon, or by causing it to cool quickly—as in the making of chilled castings. Materials which are known in foundry practice as **softeners** are regularly produced, and they are useful in "correcting" irons which are too hard, and for promoting soundness in castings. Softeners must, of course, be added "with brains."

For composition of softeners see p. 238.

When melted grey pig iron is allowed to stand for some time in a ladle, **kish**, which consists largely of graphite and contains notable amounts of manganese and sulphur (all of which are eliminated from the iron), collects on the surface.

A ladleful of melted pig iron, especially if covered with ground coke, or any other suitable substance which will retard cooling, will remain in teeming condition for a long time.

Remelting of pig iron is, and repeated remeltings may be, up to a certain point, beneficial. But as some silicon is eliminated during each remelting, it is clear that when the silicon has reached the proper percentage for the purpose in view any further remelting must be a distinct disadvantage. Manganese is also lessened in amount during each remelting, and sulphur (unless precautions are taken) is increased.

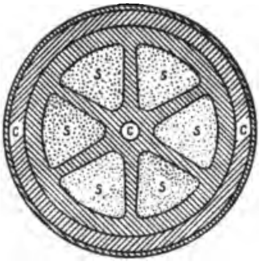

Fig. 71.—Chilled Casting.
S = Sand mould.
C = Iron mould or "chill."

Chilled Castings. — Certain castings have parts of their surfaces purposely hardened by being cast in moulds which are partly of iron. Thus a wheel may be hardened on the wearing surface of the rim, and the centre of the nave may be also hardened. Fig. 71 may convey an idea of how the *superficial* hardening is induced. The chill is not deep, and the comparative pliancy and absence of brittleness of the portions which have not been chilled are advantageous.

The **crystallisation** of cast iron calls for consideration. Iron, like other metals, crystallises at right angles to the surface which is cooled.* If a casting is not designed with a due regard to the formation of crystals its strength may be insufficient. The earlier cylinders employed at the erection of the Menai Bridge had sharp corners, as shown in fig. 72, and they soon broke along the lines of weakness, as represented

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* A piece of common spelter (ingot zinc) shows well the lines of crystallisation in cast metal.

in fig. 73. The form sketched in fig. 74 was an improved design, which, having no pronounced lines of weakness, withstood the heavy pressure. The lines of crystallisation in a circular casting are shown in fig. 75, and figs. 76 and 77 indicate the crystallisation in a square and a long iron casting.

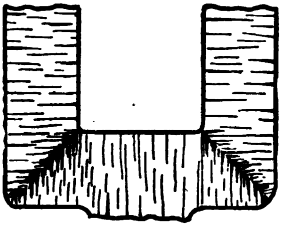

Fig. 72. —Section of Original Cast-iron Cylinder—Sketch Showing Arrangement of Crystals.

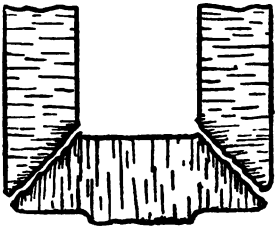

Fig. 73.—Section of Cast-iron Cylinder (broken) — Sketch Showing Arrangement of Crystals.

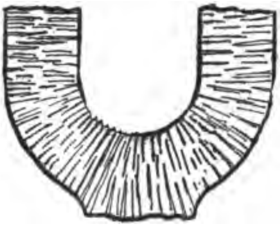

Fig. 74.—Improved Section of Cast-iron Cylinder—Sketch Showing Arrangement of Crystals.

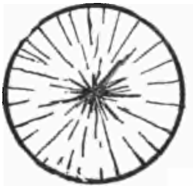

Fig. 75.—Circular Casting.

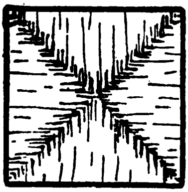

Fig. 76.—Square Casting.

In making castings, the **shrinkage** which occurs must be allowed for; they must be cast larger than the finished products are required to be. The amount of shrinkage varies with the class of pig iron, and also with the size of the casting.

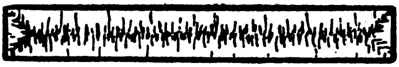

Fig. 77.—Long Casting.

Massive castings do not shrink, relatively, as much as lighter ones do. As a general indication of the trade practice the following figures are useful:—

The allowance for

Massive castings is . .	$\frac{1}{8}$ inch	in 18	inches.
Medium ,, . .	$\frac{1}{8}$,,	15	,,
Light ,, . .	$\frac{1}{8}$,,	12	,,

STEEL CASTINGS.

The chief difficulties in the way of producing good steel castings arise from the high temperature at which it is necessary to produce and teem the metal, the unsatisfactory nature of iron-moulding material for steel castings, the great skrinkage, and the want of soundness and strength in the finished material, due in large measure to the great quantity of gas which steel is apt to **occlude**. By **occluding** is meant that power by which *melted metals can dissolve many times their own bulk of gases and retain them for a time.* Some of the occluded gases become liberated during the cooling of the metal, and, after a crust has formed, they cannot easily escape. In these circumstances gases gather in one or more parts of the casting and form cavities or **blowholes**.

The temperature at which the "metal" for steel castings melts is said to be from 1,450° C. (= 2,642° F.) to 1,500° C. (= 2,732 F.),* and a higher temperature must be employed.

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* The temperatures expressed here were ascertained by a modern pyrometer which indicates much lower (but probably more accurate) degrees for high temperature. The older heat measurements of high temperatures are not reliable.

A satisfactory moulding material, capable of withstanding the great heat, and yet porous enough to allow free escape of the large volume of contained gases, is made by heating quartz, quenching in water, grinding to powder, and mixing with clay in proper proportion. The prepared moulds require to be well faced with graphite. The shrinkage is about double that of iron castings. It is usual to strip the castings as soon as permissible, the cores, &c., being removed early.

The troubles incidental to the introduction of a new branch of manufacture have been overcome, and sound steel castings are now made with fair regularity. Steel for castings is produced in crucibles, in converters, and in open-hearth furnaces. As it is not easy to keep the metal hot during the long time occupied in casting large quantities, small furnaces and converters are in general use for steel founding. Basic steel castings are in some instances preferred to those of acid steel. The procedure for producing steel for castings in open-hearth furnaces is much the same as for the production of ingots. For castings it is essential that the steel should be finished hot, and in practice ferro-silicon (see p. 238) is freely but judiciously used.

Steel castings vary widely in chemical composition, each tap of metal being finished to suit the order in hand. The following are examples:—

	Percentage of				
	Carbon.	Silicon.	Phosphorus.	Sulphur.	Manganese.
Stern frame, .	·17	·50	·055	·048	·56
Railway wheel, .	·30	·27	·065	·039	·63
Railway wheel, .	·44	·38	·051	·043	·51
Crank axle, . .	·34	·15	·041	·042	·56
Bracket, . .	·41	·57	·060	·068	·66

CHAPTER XVI.

MALLEABLE CASTINGS.

NUMEROUS small articles of intricate shape, and fairly strong, are in daily demand—such articles as keys, parts of locks, nozzles, hooks, &c. It would not pay to fashion keys by hammering wrought iron into shape, and cast-iron keys would not be strong enough, unless heavy. Hence the desire for a process by which some of the qualities of wrought iron may be conferred on castings of complicated shape. The castings can be more cheaply worked out by a sand pattern than in the iron itself. By the annealing process to which they are subjected, important changes are effected by which they become malleable.

The manufacture of malleable castings embraces the following stages:—

Making the Pattern.—The moulds are of green or of dry sand.

Melting the Metal.—The metal is melted in graphite crucibles, or, in some cases where the castings are large, in cupolas, and cast in the moulds. A special kind of pig iron is required, and suitable scrap is melted with it.

Cleaning the Castings.—When cold, the castings are cleaned by being turned over many times in a horizontal rotating barrel designed with sharp corners. The castings rub against each other, and the sharp corners hasten the detaching of the sand.

Annealing the Castings.—The articles to be annealed are carefully packed in red hematite iron ore in suitable vessels, and are carefully heated and allowed to cool down slowly.

The ore, having been crushed as small as peas, is sifted, and a mixture of two or three parts of old ore with one part of new ore is used. When new ore is used alone the "annealing" action is too keen. The containing vessels are crucibles or "pots," or cast-iron boxes called "saggers," or wrought-iron boxes.

The **pots**, or **boxes**, which may be square or circular in plan, are cast from a special mixture of white iron and scrap, and they vary in capacity according to the size of the castings to be annealed in them. For certain castings the ore and pot together may weigh 2¼ cwts., the castings for annealing ¾ cwt. When the packing of a pot or box is completed the lid is luted on. The packed boxes are then placed in the furnace.

The **furnaces** are coal-fired or gas-fired. Some are rectangular in plan, with dome-shaped roofs. They are built in rows, each furnace being connected with a flue leading to a stack. Such a furnace is shown in fig. 78.* The middle portion of the bed is raised, thus providing two passages down the sides for the fires. The boxes containing the castings are placed on this raised floor, three or four in each pile, the joints between them being sealed with fireclay or wheelswarf, and the top box completely covered with the same substance. Each furnace holds from 12 to 20 boxes. The most important articles are placed in the centre pots.

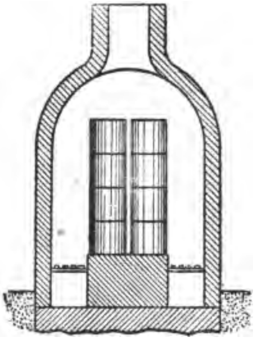
Fig. 78.—Annealing Furnace for Malleable Castings.

During Bannister's investigations from 10 to 20 boxes were placed in a furnace, and the temperature maintained was from 1,000° C. (1,832° F.) to 1,100° C. (2,012° F.) during days, the fires being damped down for nights, thus giving a bright red heat during days, and a dull red during nights. The furnace was fired from five to nine days, and allowed to cool down for two days.

In Royston's investigations† the pots, 60 in number, were charged into a black-hot furnace which had just been emptied. The door was luted and firing commenced. The temperature of the furnace on the second day was 750° C., on the third day

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* From paper by C. O. Bannister, A.R.S.M., Inst. Mech. Engineers, January, 1904.

† *Journal of the Iron and Steel Institute*, i., 1897.

it was 860° C., while on the fourth, fifth, and sixth days the furnace heat did not vary more than 40° from 860° C. As the pots became red hot, copious jets of flame were emitted and burned with a blue flame, which may be accepted as evidence of the escape of carbon monoxide (CO) from within the pots. The coal used amounted to 1¾ tons per ton of metal annealed. When the furnace had cooled sufficiently the pots were withdrawn. Three days, instead of seven, may suffice for some kinds of work.

The boxes are in due course unpacked, the castings are cleaned, and are then ready for the market.

Malleable castings, if in thin sections, can be welded The castings are not brittle, as they were before annealing, but are generally tough enough to stand bending into a U shape even when cold. They are cleaned, and are then ready for the market.

Consideration of Composition and Changes.—The pig iron used should be low in silicon, phosphorus, and manganese, as these remain unaffected during annealing and their presence in the finished casting is harmful. Manganese and sulphur retard the annealing. The pig iron used sometimes contains over ·3 per cent. of sulphur, which is not desirable. The best "metal" for the purpose is refined white hematite pig iron along with good scrap.

TABLE OF COMPOSITION.

Constituents.	Chemical Symbols.	Refined White Hematite Pig Iron before Melting.	White Hematite Pig Iron after Melting.	Castings after being Annealed.
Graphitic carbon,	C	0·61	0·19	1·56
Combined carbon,	C	3·33	3·69	0·74
Total carbon,	C	3·94	3·88	2·30
Silicon,	Si	0·61	0·57	0·57
Sulphur,	S	0·03	0·10	0·057
Phosphorus,	P	0·044	0·045	0·045
Manganese,	Mn	0·112	0·043	0·043
Iron (by difference),	Fe	Δ	Δ	Δ
		100·00	100·00	100·00

The metal takes up sulphur during melting, whether in a crucible* or in a cupola.* Royston found the following percentages of sulphur:—

Before melting = ·031.
After melting in an open crucible = ·096.
After melting in a cupola = ·161.

The coke used contained 1·60 per cent. of sulphur, which is a high percentage.

During annealing the changes induced are:—

(*a*) Change in the condition of some of the carbon;
(*b*) Reduction in the amount of carbon;
(*c*) Reduction in the amount of sulphur; and
(*d*) Reduction of some oxide of iron to the metallic state.

In Bannister's experiments the sulphur was diminished ·03 per cent. The used ore has been found to contain pellets of iron, and sulphur has been taken up by the ore when the castings were not low in sulphur before annealing. The spent ore also contains carbon derived from the castings. About half of the carbon is withdrawn from the iron, a change which is quite the reverse of that resulting from the cementation process. Most of the remaining carbon is changed from the combined state to fine-grained graphite.

The combined carbon in the pig iron lowers its melting point, increases its fluidity, and enables a clean, sharp casting to be made. The amount of combined carbon which is left in the finished casting does not impair its malleability too much.

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* For description of a crucible see p. 42, and of a cupola see p. 150.

CHAPTER XVII.

CASE-HARDENING.

SOMETIMES it is requisite that wrought-iron articles should be hardened on the surface and a little beneath. The most convenient known method of hardening is by adding carbon and then quickly quenching from a suitable temperature.

In case-hardening, the carbon addition is effected by packing the articles in a box containing a sufficiency of substances which are rich in carbon and in nitrogen. The most commonly-used substances are leather cuttings, horse-hoof pairings, potassic ferro-cyanide (popularly called prussiate of potash), and bone charcoal. The articles are embedded in one or other of the above-named substances. The lid is then closely luted with fireclay. The box and contents are placed in a furnace which is raised to a cherry-red heat (about 860° C.) and maintained at that temperature for 12 or even up to 24 hours, according to the depth of hardening wanted. The box is allowed to cool down till the contents are cold enough to bear removal—although still red hot—when they are plunged into cold water. If cooled too much before removal from the box, the articles are reheated and suddenly quenched.

Those parts which are not to be case-hardened are carefully covered with fireclay before placing in the box in which the carbonisation is carried on.

The smooth wearing parts of axles are covered with a leather sheath and placed in a furnace. When the part which is in contact with the leather is judged to have taken up enough carbon it is withdrawn from the furnace and quenched. The other end is then similarly treated.

When wrought iron—which does not contain much carbon —is embedded in charcoal and steadily heated for several days (see p. 39) to a high temperature, carbon penetrates

right to the heart of the wrought iron and converts it into steel. In case-hardening, the conversion to steel is superficial, and as it is practised on articles of finished shape they must be embedded in a substance which quickly yields carbonaceous material at such a moderate temperature as will not cause distortion of the articles.

In distinct contrast to these processes, by which iron is caused to take up carbon, is the method of treating iron castings so that the carbon is changed and withdrawn, and some of the qualities of wrought iron conferred on them.

Having in the foregoing pages dealt with the selection and working of pig irons to achieve desired ends, we are now in a position to proceed to the consideration of the composition of iron ores and their treatment in the production of pig iron suited to various requirements.

CHAPTER XVIII.

IRON ORES: THEIR COMPOSITION, CHARACTERS, AND DISTRIBUTION. KIND OF PIG IRON PRODUCED FROM EACH.

ANY large quantity of naturally-deposited matter containing metals—either in the free state or in chemical combination—may be considered an ore if the metals are present in sufficient quantity and in such a state as to permit of profitable extraction. In ores the metals are generally in combination with oxygen or sulphur, or they exist as carbonates or silicates. Less frequently, the metal or metals are in combination with chlorine or some other non-metal. When an ore contains metal which is not in chemical combination with a non-metal it is said to be "native." Certain ores are very complex, and some contain metals which are not easily separated during extraction. Ores which occur near the surface of the earth are dug or quarried; those which are found at lower depths are mined.

Iron Ores.—When iron is exposed to ordinary moist air it "rusts"—the bright, strong metal is converted into a voluminous, crumbling mass of earthy-looking matter quite devoid of the characteristic good qualities which iron possesses. Some deposits of iron ore may be looked upon as iron rust, more or less altered in composition by heat, and which have become naturally mixed with widely-varying amounts of other matter, such as silica, clay, calcic phosphates, &c. The "other matter" constitutes the **gangue** of the ore, and the gangue usually requires some flux to accompany it in the blast furnace. For example, silica (SiO_2), which forms such a large percentage of the gangue of many ores, is quite infusible even at the very high temperature of the blast furnace, but at that temperature the silica may be caused to enter into chemical combination with the flux so as to form a fluid compound and be tapped out as slag.

The ores of iron which are smelted are all essentially oxides of iron mixed with gangue, and they all contain phosphorus They may be conveniently classed thus :—

Ferrous ores—
  Blackband ironstone.
  Clayband ironstone.
  Cleveland ironstone.
  Spathic iron ore.

Ferric ores—
  Red hematite.
  Brown hematite.

Ferrous-ferric ores—
  Magnetite.
  Franklinite.
  Ilmenite.

Ferrous Ores consist essentially of ferrous carbonate (FeO,CO_2) with other matters. **Clayband ironstone** contains ferrous carbonate and clay. **Blackband ironstone** contains coaly matter in addition. **Cleveland ironstone** contains ferrous carbonate and clay, and is more highly phosphoric than the others. **Spathic ore**, or siderite,* sometimes contains a notable amount of manganese and much less phosphorus than the other ferrous ores. It is, as its name indicates, sparry or crystalline.

Ferric Ores consist essentially of ferric oxide (Fe_2O_3) with other matters. The typical red hematite of Cumberland and North Lancashire is remarkably low in phosphorus and sulphur. Of this class of ore there are several varieties. Red hematite is largely mined in small fragments, which are ruddy-coloured, have a greasy feel, and stain the hands when touched. It also exists in iron-grey masses, which, where weathered, are red-coloured. This variety is known as **pencil ore**, from the facility with which it splits into long fragments, which are sometimes used for marking sandstones. **Kidney ore** occurs in lumps with rounded surfaces which are dark steel-grey in colour. Another kind

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* From a Greek word signifying *iron*.

is found like flattened grains, and is known as **lenticular** (pea-shaped) ore. **Specular ore** is of a bluish-black colour and sparkles from many crystals on its surface.

Ferric ores, which contain a notable quantity of alumina, are shipped from the north of Ireland to the nearest districts where hematite ores are smelted. They are known in the trade as **Aluminous ores, Antrim ores, Belfast ores,** and **Irish ores.** Occasionally they are washed before being shipped.

Brown Hematites may be fairly compact or moderately soft. In colour, ores of this class vary from rich brown to yellow. They consist essentially of ferric oxide, with about 10 per cent. or so of combined water. Some kinds contain as little phosphorus as good red hematite does, while others are highly phosphoric and do not contain a high percentage of iron.

Ores of the Ferrous-ferric Type do not occur in notable quantities in the British Isles, but ores of this class, which are found in other countries, are of considerable importance.

Magnetite is found in masses in Sweden. The ore is frequently rich in iron and is usually low in phosphorus and sulphur. It is generally dark and hard. A magnet will cling to a mass of the ore and can lift small fragments of it.

Other Sources of Iron are:—

Burnt Pyrites.—This is the residue from the treatment of pyrites—an ore containing iron and sulphur, and often a small quantity of copper. In the first place the ore is broken into smaller lumps, when necessary, and slowly burned; the resulting sulphury gas (sulphur dioxide) is led into huge leaden chambers where sulphuric acid (commonly called vitriol) is made. If the "burnt pyrites" contains enough copper to more than cover the cost of its extraction it is crushed smaller than peas, mixed with salt, carefully roasted, and then leached (soaked) in water to dissolve the copper compound. The residual iron—which was oxidised during the burning of the sulphur—has a dark purple colour, and is generally known in iron works as "Purple Ore" or "Blue Billy."

Burnt pyrites and purple ore have recently become of considerable importance as sources of iron.

Flue Cinder, which is the slag from certain reheating furnaces, is also used for the production of certain classes of pig iron.

Puddlers' Cinder, or **Puddlers' Tap** (see p. 25), is smelted along with local ores, in blast furnaces, for the production of **cinder pig**. It yields a highly-phosphoric pig iron, which is well suited for the basic Bessemer process.

Mineral phosphates (apatite, &c.) are occasionally charged into blast furnaces to increase the percentage of phosphorus in the pig iron for basic steel-making.

The following figures represent, in round numbers, the composition of some of the chief iron ores :—

Constituents.	Chemical Formulæ.	FERROUS ORES.			
		Blackband Ironstone (Staffs.)	Clayband Ironstone (Ayrshire)	Cleveland Ironstone.	Spathic Ore.
Ferrous oxide,	FeO	42·0	40·0	38·0	49·33
Ferric oxide,	Fe_2O_3	6·0	...	6·0	0·8
Manganous oxide,	MnO	3·0	1·0	0·5	2·2
Silica,	SiO_2	1·5	10·5	12·0	4·0
Alumina,	Al_2O_3	0·3	5·0	11·0	0·7
Lime,	CaO	4·0	5·0	5·5	3·3
Magnesia.	MgO	2·0	3·0	3·5	2·6
Phosphoric acid.	P_2O_5	0·7	1·3	1·5	0·03
Sulphur,	S	0·5	0·2	0·3	0·04
Carbon dioxide,	CO_2	26·0	31·0	21·0	37·0
Organic matter,	...	14·0	3·0	0·7	...
Combined water,	H_2O	...	...	...	...
Total,	...	100·0	100·0	100·0	100·00
Metallic iron,	...	36·87	31·11	33·75	38·93
Phosphorus,	...	0·31	0·57	0·65	0·013

Constituents.	Chemical Formulæ.	Ferric Ores.			Ferrous-Ferric Ores.	
		English Red Hematite. Cumberland.	Spanish Brown Hematite. Bilbao.	English Brown Hematite. Northampton.	Magnetite. Sweden.	Magnetite. Sweden.
Ferrous oxide, .	FeO	...	...	1·0	23·00	27·00
Ferric oxide, .	Fe_2O_3	86·00	78·00	63·0	52·00	60·00
Manganous oxide,	MnO	0·25	1·00	0·2	2·00	0·10
Silica, . .	SiO_2	9·00	9·00	9·0	8·00	5·00
Alumina, . .	Al_2O_3	0·50	1·00	6·0	2·00	1·00
Lime, . . .	CaO	3·00	0·70	3·0	6·00	3·00
Magnesia, . .	MgO	1·00	0·20	0·5	5·00	2·00
Phosphoric acid,	P_2O_5	0·03	0·04	1·8	0·02	2·00
Sulphur, . .	S	0·04	0·03	0·2	0·02	0·01
Carbon dioxide, .	CO_2	...	...	2·0	} 2·00	...
Organic matter, .	...	...	...	...		
Combined water,	H_2O	...	10·00	13·0	...	...
Total, .	...	99·82	99·97	99·7	100·04	100·11
Metallic iron, .	...	60·20	54·60	44·88	54·29	63·00
Phosphorus, .	...	0·013	0·017	0·79	0·009	0·87

For analyses of other ores, see pp. 242, 243, and 244.

THE SUPPLY OF ORES FOR THE BRITISH IRON TRADE.

As Great Britain has been for a long period the abode of an active iron-producing people, the working-out or impoverishment of certain mining districts must come as a matter of course. At present, about twelve million tons of iron ores are annually raised in Great Britain, and about six million tons are imported.

Red Hematite Ores are mined in that part of the northwest of England which is known as the hematite district—Cumberland and North Lancashire.

The purer varieties of Brown Hematite Ores are mined in the Forest of Dean, on the Severn estuary, near to South Wales. **The less pure (highly phosphoric) Brown Hematite Ores are extensively worked** in Lincolnshire, Leicestershire, and Northamptonshire. Some of the ore beds consist largely of carbonate. Considerable quantities are quarried, calcined, and sent into Staffordshire.

Spathic Ores.—Ores of this class were mined in Weardale (County Durham), from the Brendon Hills (Somersetshire), and from Exmoor (Devonshire). The latter contained a notable percentage of manganese.

Blackband Ironstone is still mined towards the east of Scotland and in North Staffordshire.

Cleveland Ironstone exists in large quantities in the hilly district of Cleveland, in the north-east of Yorkshire.

Clayband Ironstone was formerly a chief source of British iron: at present it is only mined in a few districts where the deposits are comparatively thick and rich. It is still worked to a large extent in Ayrshire, Yorkshire, Derbyshire, Staffordshire, and East Worcestershire. In other districts the "coal balls" met with in coal-mining are often saved for use in blast furnaces.

Imported Iron Ores.—Large and increasing quantities of iron ores are brought from abroad at comparatively low freights. The imported ores comprise:—Manganese ores from India and elsewhere, chrome-iron ore from Russia and other countries, specular ore from Elba, in the Mediterranean; iron ores from Greece and the south of Spain; and, in much larger quantities, brown hematite and calcined carbonate from the north of Spain. From Dunderland, in Norway, immense supplies of concentrated ores may be obtained.

Imported ores are smelted in districts at or near the seaboard where good fuel is cheap. Of these the most convenient are South Wales, Middlesbrough (in the north of Yorkshire), and the district around Glasgow, which has the advantage of a waterway—the Clyde—a river which has been persistently deepened with commendable enterprise. To North Lancashire and Cumberland, where rich deposits of hematite ores have been found, the purer varieties of hematite ores are also imported, and smelted along with the local ores. Durham coke is much used in the blast furnaces in the hematite district in the north-west of England.

The purpose for which a pig iron is best suited is decided, in large measure at least, by the percentage of phosphorus it contains. *With few exceptions of small importance, nearly all the phosphorus which is present in the ore, the flux, and the fuel used in smelting goes into the pig iron.** The kind of pig iron made in any district will depend very much on the class, or grade, of ore which can be had there at a paying price.

The Production of Hematite Pig Iron—known also as **Bessemer Pig Iron**—for use in the acid Bessemer and the acid Siemens processes is conducted in Cumberland and in North Lancashire where good hematite ores are mined, and which are supplemented by hematite ores imported from Spain. The chief drawback to that district—apart from royalties, &c.—is the want of a good cheap fuel. The railway charge for the carriage of coke is a heavy burden. In South Wales, where good coal is abundant and fair-quality coke is cheap, brown hematite ores mined in the Forest of Dean are smelted, as are also hematite ores from the north-west of England and from Spanish ores. In the district of which Glasgow is the commercial centre, a mixture of English and Spanish hematite ores is smelted. The aluminous ores from the North of Ireland are also used in the blast furnaces producing hematite pig iron in Scotland and in the English hematite districts, both of which are convenient to Ireland. At and near Middlesbrough, adjoining the district where perhaps the finest coke in the world is made, hematite ores from Spain and from the north-west of England are smelted together. It is also well situated for dealing with Swedish ores and the Dunderland ores, which, as concentrated, are pure enough for making the best quality of hematite pig iron.

The Production of Pig Irons for use in Forges and Foundries is a feature of those districts where clayband or impure brown hematite ores exist. They are, of course, made mostly from the local ores.

Basic Pig Iron, being even more highly phosphoric than the foregoing, is made in or near localities in which puddling

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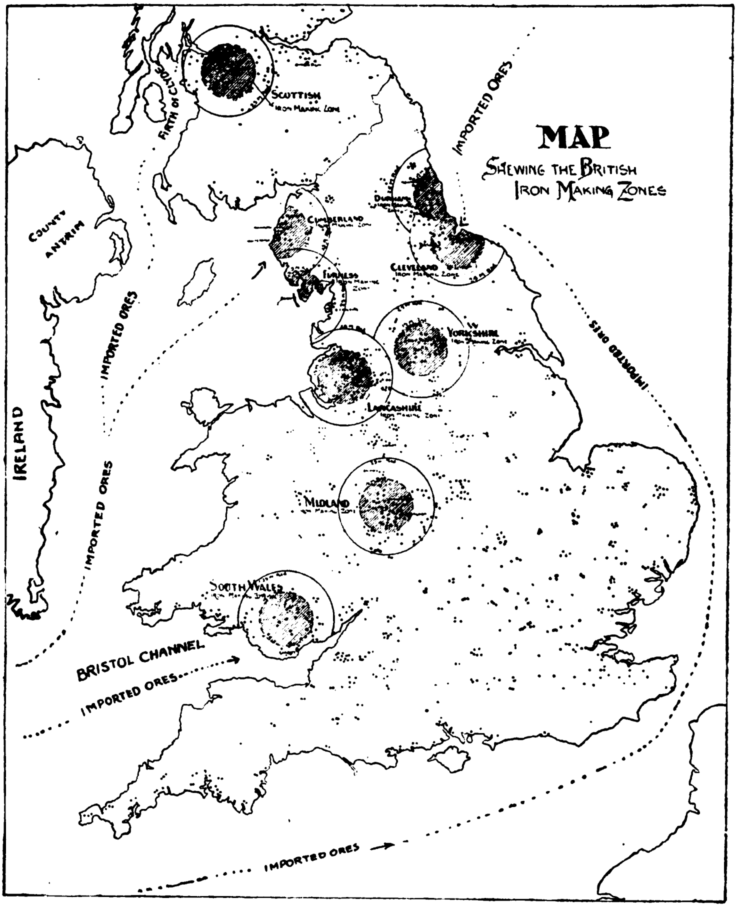
* The phosphorus exists as phosphorus pentoxide (P_2O_5), or phosphoric acid as it is more often called, in all iron ores and solid fuels.

[*To face p.* 180.



Reduced from a diagram in "Cassier's Magazine."

is, or has been, a staple industry, because there puddlers' cinder may be had cheaply and in abundance.

Ores used for Various Kinds of Pig Iron.—The purest **Swedish pig irons** are smelted from pure magnetites, with charcoal as fuel. Pig iron smelted from such ores, with such pure fuel as charcoal, is remarkably low in both phosphorus and sulphur.

Bessemer Pig Iron is made from hematite or other ores, such as magnetites and Spanish carbonates, which are low in phosphorus. The fuel and the flux require to be carefully selected. Bessemer pig iron, or hematite pig iron as it is also called, is used for the acid Bessemer and the acid Siemens processes; and sometimes, although not always judiciously, for superior castings. White hematite pig iron is used for the manufacture of malleable castings.

Foundry and Forge Pig Irons are made from blackband, clayband, and Cleveland ironstones. Phosphoric hematite and other ores are also used.

All-mine Pig Irons are made from ores. Cinder pig irons are made from a mixture of puddlers' tap (tap cinder) and local ores.

Basic Pig Iron is made in Lincolnshire from ores obtained in that county; in other districts it is made from puddlers' tap and clayband, Cleveland, or impure brown hematite ores, and some manganese ore and mineral phosphates from abroad. The proportion of puddlers' tap used is sometimes considerable; the ores used are mined or quarried not far from the works, with the exception of the manganese ore, which is always foreign.

CHAPTER XIX.

PREPARATION OF ORES FOR SMELTING.

SOME iron ores require preparation before being charged into the blast furnace. The preliminary treatment may consist of breaking or crushing lumpy ores to suitable size. Or, on the other hand, the ores which are in pellets, or even in a finer state of division, are, with advantage, pressed into blocks or briquettes and "burnt," so that the fine ore will not be so liable to be forced out of the blast furnace with the exit gases, or be so likely to "gob" the furnace or derange the working by hindering the free course of the gases. Many ores are delivered with such a large proportion of "smalls" as to cause trouble to managers and workmen.

Some poor ores are subjected to **magnetic concentration.** Such ores are crushed to powder, and caused to fall in a fine stream near to electro-magnets. The magnetic influence draws aside nearly all the metallic portion, which falls into a truck apart from the bulk of the gangue. The concentrated iron oxide is then made into blocks in the manner described above.

Besides the breaking up, or the binding, of iron ores, other treatment is sometimes called for. Some iron ores are so firmly united in the mine to layers of shale that separation of one from the other is difficult. By **weathering**—that is, by exposing to atmospheric influences for a time—the shale may be easily split off. Weathering may, to a slight extent, cause the removal of sulphur from certain ores.

All ferrous ores are subjected to preliminary heat treatment with access of plenty of air. This roasting process is known in the trade as **calcination or burning.**

The effects of calcination are:—

> The lower iron oxide (ferrous oxide) is changed into the more highly oxidised ferric oxide, and, at the same time, the oxide of manganese which is present combines with more oxygen.

Carbon dioxide is driven off.

Moisture is driven off.

Organic matter is driven off.

Carbon monoxide is occasionally given off in small amount.

Sulphur may be driven off in perceptible amount, especially if calcination is conducted slowly at a proper temperature and with access of abundance of air.

The chief chemical changes may be represented by the equations—

$$\begin{array}{ccccccc} 4FeCO_3 & + & O_2 & = & 2Fe_2O_3 & + & 4CO_2 \\ \left.\begin{array}{c}\textit{Ferrous}\\ \textit{carbonate}\end{array}\right\} & \textit{and} & \textit{oxygen} & \textit{yield} & \textit{ferric oxide} & \textit{and} & \left\{\begin{array}{c}\textit{carbon}\\ \textit{dioxide.}\end{array}\right. \end{array}$$

$$\begin{array}{ccccccc} 6MnCO_3 & + & O_2 & = & 2Mn_3O_4 & + & 6CO_2 \\ \left.\begin{array}{c}\textit{Manganous}\\ \textit{carbonate}\end{array}\right\} & \textit{and} & \textit{oxygen} & \textit{yield} & \left\{\begin{array}{c}\textit{manganoso-}\\ \textit{manganic oxide}\end{array}\right\} & \textit{and} & \left\{\begin{array}{c}\textit{carbon}\\ \textit{dioxide.}\end{array}\right. \end{array}$$

The chemical changes which take place may be further traced in the following table:—

Constituents.	Chemical Formulæ.	Cleveland Ironstone.	
		Before Calcination.	After Calcination.
Ferrous oxide,	FeO	35·00	...
Ferric oxide,	Fe_2O_3	5·55	58·43
Manganous oxide,	MnO	0·41	...
Manganoso-manganic oxide,	Mn_3O_4	...	0·56
Silica,	SiO_2	10·97	14·33
Alumina,	Al_2O_3	10·22	13·34
Lime,	CaO	4·84	6·37
Magnesia,	MgO	3·50	4·55
Sulphur,	S	0·25	0·81
Phosphoric acid,	P_2O_5	1·25	1·67
Carbon dioxide,	CO_2	18·01	...
Combined water, moisture, and carbonaceous matter,	...	10·10	...
Total,	. . . .	100·12	100·06
Metallic iron,	Fe	31·11	40·90

Advantages of Calcination.—Peroxidised iron (ferric oxide) works better in the furnace; it does not enter into chemical union with the silica in the ore and "scour" into the slag. The driving off—outside the blast furnace—of the carbon dioxide which is always present in ferrous ores prevents the overpowering of the reducing gases which require to be in excess in the blast furnace. The vast volume of gases which issue from the blast furnace are increased in value, for power purposes, by containing that lesser quantity of carbon dioxide. In like manner the preliminary driving away of moisture is an advantage. Calcined ores, being more porous, permit the blast-furnace gases to more readily permeate them, and thus the reducing action is hastened.

The shrinkage which takes place during calcination is a double advantage. In the first place, a greater *weight* of ore can be kept in the furnace, and there is produced an increased weight of pig iron, per day, in consequence. And, in the second place, the furnace works more smoothly than with an ore which would shrink during an early stage of the smelting.

Brown hematite ores, which are ferric ores with combined water, are sometimes "calcined" to drive off the water they contain, as well as the carbonic acid which is often present.

Red hematite ores are not subjected to calcination.

Calcination may be conducted in open heaps, in stalls, or in kilns. To carry on **calcination in open heaps** a piece of suitable ground is selected, a layer of small lumps of ore is laid down, and some coal is placed over it. Then alternate layers, or a mixture of ore with about 8 per cent. of coal slack, are heaped up to a height of about 6 feet, so as to form a mound, or heap, which may be of considerable length and breadth. The dimensions differ in different districts, and the amount of coal is varied to suit the nature of the ore and the conditions of working. Owing to the heat generated by the further oxidation of the ferrous and manganous oxides, it is not necessary to use much fuel. Blackband ores contain more combustible (bituminous) matter than is needed to complete the calcination, the pieces are well burned, and, in many instances, show signs of fusion.

The fuel is kindled at one end of the heap, and calcination is allowed to proceed slowly, the "burning" of a heap occupying a few weeks. Calcination in open heaps is primitive, is wasteful of fuel, and the costs for handling are high. As a compensation, much of the sulphur may be eliminated.

At Kilsyth, Scotland, the blackband ore is tipped into heaps, each about 200 feet long, 68 feet wide, and about 8 feet high. Each heap or "hearth" holds about 3,000 tons of raw ore. To start the burning, a coal fire along one end is lighted, and the draught is regulated to avoid sintering (the fusing of the masses to each other), and the burning continues for five or six weeks. The ore, before calcination, contains 34·1 per cent. of iron, and afterwards 55·5 per cent. The ore shrinks to half its original bulk during calcination. Three heaps are worked at the same time—one being filled, one burning, and the other being emptied. Railway lines are laid at a lower level for the trucks into which the calcined ore—known in Scotland as "char"—is loaded.

Calcination in stalls is a more modern method. A series of stalls consists of a long wall from which other walls project at right angles, so that each compartment, or stall, has three walls. Each stall is filled with raw ore and fuel, and the remaining side, or rather front, is temporarily built up with bricks or with lumps of ore. If of brick, air holes are left in the front wall. The fuel is kindled, and calcination continues as in the open heaps.

The raw ore may be conveniently delivered from trucks on rails which are placed above the level of the tops of the stalls, and the calcined ore delivered into trucks or barrows at a lower level.

Calcination in stalls is under better control than in heaps, as the air can be more easily regulated. The fuel consumed is slightly less.

Calcination in kilns is a more convenient and economical method than either of the foregoing. A calcining kiln is an upright shaft furnace which is open at the top, and up which a current of air passes when the kiln is at work. There is neither forced draught nor a chimney.

The Scotch kiln is built of firebricks. The raw ore and the fuel are charged at the top. A fire having been kindled in the kiln at the commencement of a campaign, the fuel which is charged with the ore in due course burns, and calcination goes on. The calcined ore is withdrawn, through openings near the bottom, directly into trucks.

The inside dimensions of the kiln represented in fig. 79 are:—Height, 40 feet; diameter at widest part, 15 feet 6 inches, contracted to 8 feet 3 inches diameter at the top of the cone which is fixed for directing the ore outwards.

The kiln delivers 40 tons of calcined ore per day, and the fuel required is equal to 3 per cent. of the weight of raw ore.

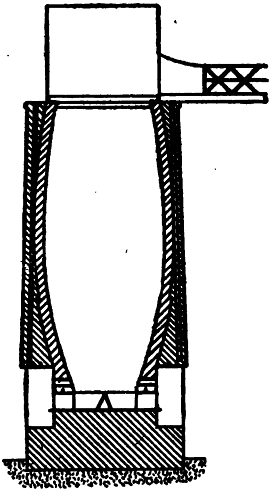


Fig. 79.—Scotch Calcining Kiln.

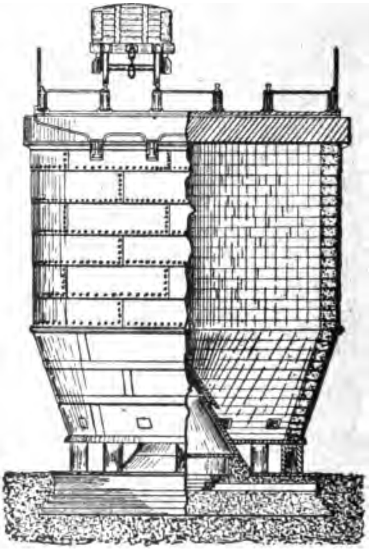


Fig. 80.—Gjer's Calcining Kiln.

Gjer's kilns are cylindrical structures of firebrick, sheathed in metal plates and set on short cast-iron columns. The ore which is to be calcined is conveyed in trucks to the top, and tipped, along with the necessary fuel, into the kiln. The air, for maintaining the combustion of the fuel and peroxidising the metallic oxides, has access by openings in the tapered part of the kiln, and also by the openings between the upper and lower parts of the hollow cone which is set centrally at the bottom. By having the central opening as arranged, dust, from the crumbling of the ore, is not likely to interrupt the smooth working of the kiln.

A kiln is about 24 feet in diameter, and is generally about 33 feet high. The consumption of fuel is low, 1 ton of small coal sufficing for the calcination of 25 tons of raw Cleveland ore. Other ores have been calcined with a smaller quantity of fuel. The kiln works continuously.

The calcined ore is withdrawn through openings, into the barrows in which it is taken to the top of the blast furnace.

CHAPTER XX.

THE BLAST FURNACE AND ITS EQUIPMENT.

THE blast furnace is a most compact and efficient erection for cheaply and quickly treating large quantities of heavy materials. In it iron ore is dealt with at a high temperature, and the iron is extracted.

The solid materials charged into the blast furnace are—

(*a*) The ore from which the iron is to be extracted,
(*b*) The fuel required to carry on the work, and
(*c*) The flux, which, on uniting with impurities in the ore and the fuel, causes the formation of *fluid* compounds.

These solids are delivered at the top of the furnace and in due course descend. A strong air blast is injected near the bottom of the furnace where the fuel is burned.

The products of the blast furnace are—

(*a*) The pig iron,
(*b*) Slag, and
(*c*) Gases,

and all three have a commercial value. They are each dealt with in the next chapter.

Blast furnaces were formerly small, and were built of heavy masonry, with a lining of fireclay blocks; now they are tall and comparatively slender in appearance. Formerly the throats were open and gases were allowed to burn at the top.

Structurally, the modern blast furnace is a tall upright cylinder, sheathed in iron or mild steel plates, and having a working lining of good firebricks. The blast furnaces in a work are built in a row, each being as close to the others as convenient. Fig. 81 shows one of the ranges of blast furnaces at Messrs. Bell Brothers' works, Port Clarence, Middlesbrough.

Near to the furnaces are grouped the arrangements for

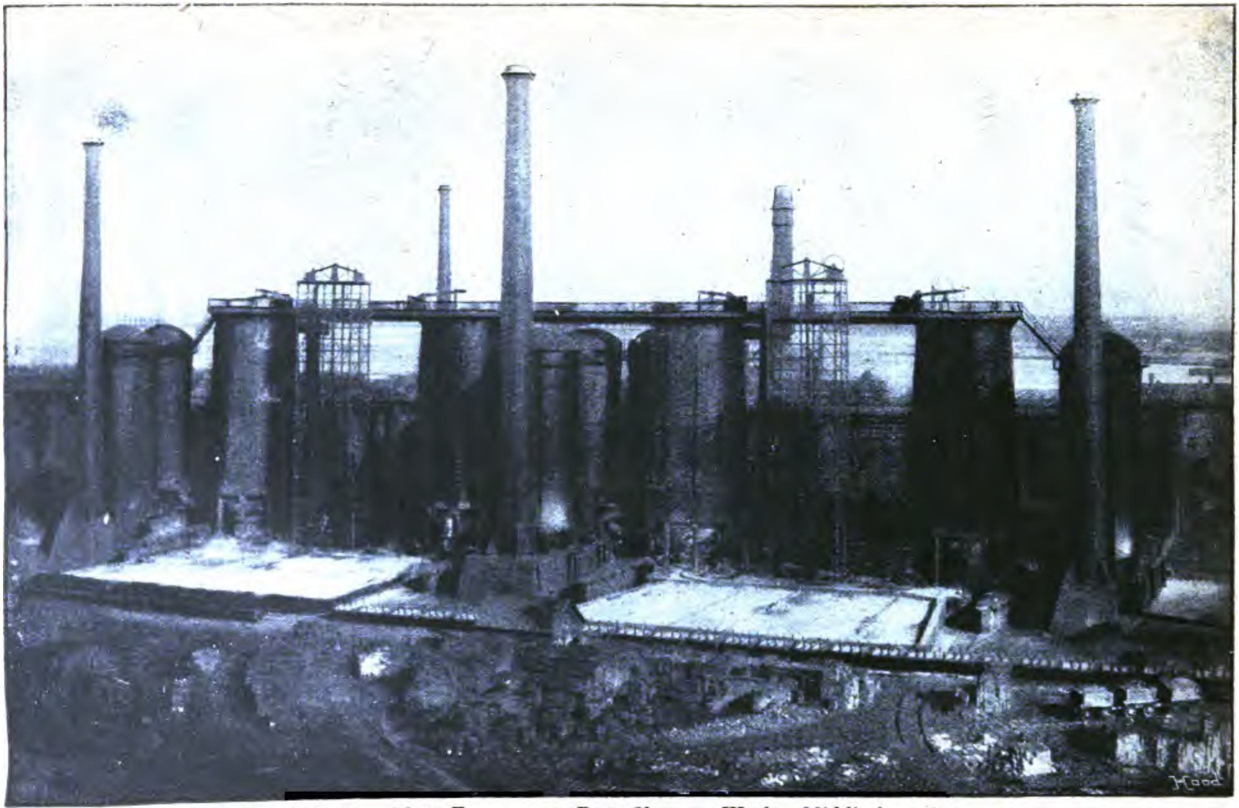


Fig. 81.—Blast Furnaces at Port Clarence Works, Middlesbrough.

hoisting the raw materials; the blowing engines for forcing, and the stoves for heating,* the air blast; pipes for conveying the exit gases; accommodation for the slag bogies or cars, and space for casting, or machinery for conveying, the pig iron which is produced.

Details of Structure.—The **foundations** for a large erection for dealing with heavy materials must be good. Firm land which can be easily drained must be selected, or expense will be entailed in providing and driving in piles and making the ground suitable. Extensive concrete foundations may be put in. The firestones, blocks, or bricks which constitute the base of the inner part of the furnace must be designed and laid in such a manner as to resist any tendency to be pushed directly upwards if the "metal" should unfortunately find a way underneath. They are generally set so as to form a shallow cavity, or an inverted arch, and are so placed that pressure from beneath forces them more tightly together.

The main body of the blast furnace is carried on cast-iron hollow columns surmounted by a lintel of heavy cast-iron or steel plates. Not only does the lintel carry the brickwork, but it also directly supports the casing of rivetted metal plates. These latter sustain the weight of the platform at the top, over which the charges for the furnace are wheeled in barrows.

Internally the furnace consists of the **hearth**, or **well**, of brickwork at the bottom, which is built up from the foundation to where it joins the brickwork of the next part—**the bosh**, or working part. Above the bosh is the **stack**, or **heat-intercepting** part.

Viewed from the top the stack expands in diameter. The widening of the diameter makes allowance for the expansion (due to heat) of the materials which are charged in from the top of the furnace, and permits the "unpacking" of the materials as they descend. The bosh contracts in diameter, so that the materials which have gone down so far may be held up until the fuel is burned away at or near the top of the well, and the then melted pig iron and slag gradually drop into the hearth, or well, where, by reason of difference of density, the slag and pig iron separate from each other, and

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* If the air supplied is *heated before* it is forced into the furnace a large saving of fuel is effected.

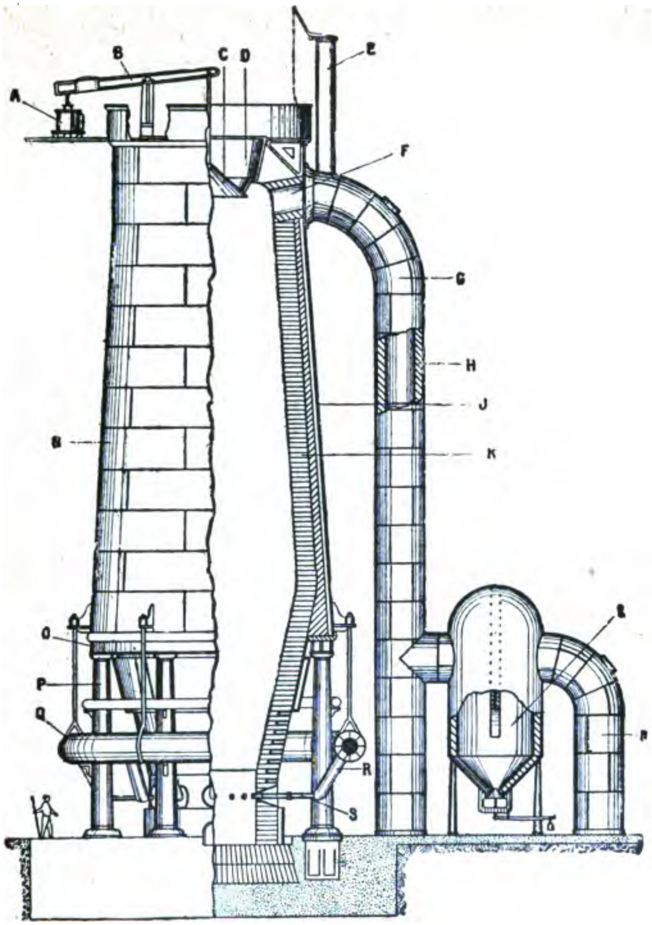

Fig. 82.—Modern Iron-smelting Blast Furnace.*

A, Cylinder with plunger.
B, Beam.
C, Cone.
D, Cup.
E, Uptake.
F, Outlet for gases.

G, Downtake or downcomer.
H, Firebrick lining.
J, Iron plates.
K, Firebrick lining.
L, Dust-catcher.
M, Downtake from dust-catcher.

N, Iron plates for shell.
O, Lintel.
P, Iron columns.
Q, Horse-shoe main.
R, Goose neck.
S, Tuyere.

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* Details from *The Designing and Equipment of Blast Furnaces*, by John L. Stevenson.

are in due course each tapped out, in the fluid condition, from the furnace.

The inner lining of the furnace is of good firebricks or blocks. Bricks are now preferred to the large blocks which were formerly favoured for furnace-building. True, they need more setting and cementing, but bricks are more likely to be thoroughly kiln-fired. Large blocks may be raw in the heart, and cause trouble when the furnace becomes hot in course of a campaign. Bricks of secondary quality are used to back the bricks which constitute the lining. A space of 1 inch or more is left between the bricks and the metal sheathing, so that the structure may not be distorted when the brickwork gives way slightly after starting the working of the furnace. The interspace may be partially filled with granulated slag.

The "**Cup and Cone**" is an arrangement for charging the solids and distributing the charge in the furnace in the manner best suited to the working conditions. The arrangement keeps the throat of the furnace closed, except at the instant of charging in the materials, thus enabling most of the blast-furnace gases to be collected. The "cup" consists of iron castings, which, when bolted together and fixed in position, complete a structure which is like the wider part of an inverted hollow cone. The "cone" is also of iron castings bolted together and finished to fit the lower edge of the cup. It is suspended to one arm of a counterpoised beam. The charge of solid materials is tipped from barrows into the circular, tapered trough formed by the cup and cone. When the beam is released the cone* descends, and the materials slip into the furnace. The cone immediately rises, by the weight of the counterpoise at the farther end of the beam, and closes the "mouth" or "throat" of the furnace.

In order to avoid the jerking which would arise from the sudden lowering and raising of the cone, a water cylinder with a plunger and a curved connecting pipe is provided. A rod from the plunger within the cylinder is fastened to the weighted end of the beam. On being released, the beam end cannot travel faster than permitted by the flow of water from the upper exit of the cylinder through the connecting pipe (see top left part of fig. 82) to the lower part of the cylinder,

* Generally called the "bell" by blast-furnace men.

under the plunger. And when the cone begins to rise the beam cannot move faster than allowed by the checked flow of water up the connecting pipe to the top part of the cylinder—above the plunger. The plunger cannot but move slowly and smoothly. The water acts as a cushion, and a moderated and steady lowering and raising of the "bell" is insured.

The diameter and the angle of the cone have a marked effect on the working of the furnace to which it is fitted. It is most important that it should be correctly designed, so as to cause the charge to be spread in the furnace without the lumpy portions of the charge accumulating either in the centre or towards the lining of the furnace. A blast furnace will not work smoothly unless the lumps are fairly well mixed among the "smalls." If the cone is not wide enough, there will be an accumulation of finer ore in the centre and of lumps towards the sides of the furnace; if it is too wide, lumps will gather in the centre. In either case, the ascending gases, which carry on much of the furnace work, will find easy passage between the lumps; and where the smalls are close together there will be comparative stagnation and a tendency to furnace derangement. Hence the great importance of a cup and cone properly proportioned to the furnace and the ores, &c., so that the lumps and the smalls will be well mixed through each other when charged.

The air required to urge the fire within the furnace is forced in through tuyeres which are, at regular intervals, let into the furnace at an uniform level above the hearth. The work of the furnace is carried on by the fuel and the products of combustion. As the latter ascend they meet with, and impart heat to, the descending solids. At the top, the gases are led off from the furnace through an outlet, or outlets, into the downcomer, and from thence into the culverts, which convey them for further use.

The air supply is forced by powerful blowing engines through the stoves in which the air is heated.* The hot air from the hot-blast stoves is conveyed through a large brick-lined iron pipe known as the hot-blast main. A short brick-

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* Hot air is used in all iron-smelting blast furnaces except those producing cold-blast pig iron.

lined pipe connects the hot-blast main with the **horse-shoe main.** **The horse-shoe main** is a large brick-lined iron pipe which almost entirely encircles the furnace. It is carried on brackets which are bolted to the cast-iron columns at a suitable height. Pipes called **goose-necks** descend at regular intervals, and conduct the air supply from the horse-shoe main to the **tuyeres** through which the air is directly forced into the furnace.

As the **hot-blast tuyeres** (which are not brick lined like the horse-shoe main, nor exposed to the air as are the goose-necks) are constantly subjected to the heat of the furnace, means must be taken to prevent the melting of the iron of which they are made, and no better method is known and practised than that devised by Mr. Condie, a West of Scotland blast-furnace manager, shortly after the hot blast was introduced by James Beaumont Neilson. Condie's tuyere—known as the **Scotch tuyere**—consists of a wrought-iron pipe, generally about 1 inch diameter, formed into a tapering coil around which melted pig iron has been moulded to the shape shown in section in fig. 83. When the tuyere is in position a plentiful supply of water is caused to flow through the coiled pipe. The water carries off heat so quickly that the iron pipe cannot melt.

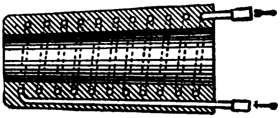
Fig. 83.—Scotch Tuyere.

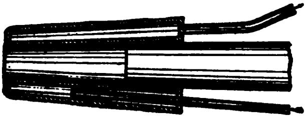
Fig. 84.—Staffordshire Tuyere.

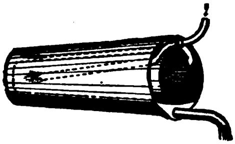
Fig. 85.—Lloyd's Spray Tuyere.

Other forms of tuyeres are the **Staffordshire tuyere** (fig. 84) and **Lloyd's spray tuyere** (fig. 85).

In **Foster's Patent Tuyere** the water is drawn through the cooling coil. This new method possesses distinct advantages.

In furnaces designed for a very large output the tuyeres are made of bronze or of pure copper, and are surrounded by a larger bronze "block tuyere" or "Jumbo." The water blocks now so extensively used outside blast-furnace boshes are often made of bronze.

Dimensions and Output.—An improved blast furnace belonging to Dud Dudley (17th century) produced 7 tons of pig iron in one week. The output was deemed so excessive that a riot ensued, and the new blowing arrangements were destroyed! A fully-equipped American blast furnace working on easily reduced ores has produced on an average 500 tons of pig iron per day. The present output is about 430 tons per day.

A modern blast furnace of average capacity may be of the following dimensions:—

Height of furnace,	80 feet.
Diameter at throat,	14 ,,
,, top of bosh,	21 ,,
,, top of hearth,	12 ,,
Number of tuyeres,	8 to 16.
Diameter of tuyeres,	up to 6 inches.
Pressure of blast,	10 lbs. per square inch.
Temperature of blast,	1,400° F.

For regular working the angle or slope of the bosh should be about 75°. Rapid working depends on the design of the furnace, the blast supply, the nature of the burden, and other points.

Furnaces of large capacity work economically. A tall furnace does not require so much coke for the reduction of ore as a shorter furnace does. But the height of a furnace is limited by the frailty of the fuel—which is more easily crushed than the other components of the charge. The mechanical condition of the ore is also an important factor. There is at the present time a tendency to abandon furnaces of 100 feet in height in favour of 90 or 80 feet furnaces. The diameter of a blast furnace must not be too great, or the air blast will not be able to get near enough to the centre.

Blowing engines consist essentially of large cylinders with clack valves which respond to the movement of the piston within—opening to admit air while the piston moves in one direction, and closing when it moves in the opposite direction. The air piston is worked from a steam engine, or, as in many new installations, a gas engine. Air which enters the cylinder is forced into the cold-blast main, which conducts it under pressure either to the hot-blast stove, or directly to the blast furnace.

The Stoves for preheating the air for use in the blast furnace were originally like boilers and chests: they were made of malleable iron plates, and afterwards of cast iron. These remained in use till the introduction of cast-iron pipe stoves, which are still employed in some works. By means of pipe stoves air can be heated to a temperature of 1,000° F.,* and maintained steadily at a temperature of about 800° F., at which the limit of endurance of cast iron is reached. There is also a danger of much leakage at the joints or sockets. A great saving of fuel and a larger output of pig iron accompanied each increase of temperature arising from improvements in the construction of the stoves.

Firebrick hot-blast stoves worked on the regenerative system satisfactorily heat the blast to 1,400° F., and even up to 1,500° F., and enable a still further saving of fuel to be effected, and the pig iron output to be further increased.

Hot-blast Pipe Stoves are oblong chambers of brickwork enclosing a range of cast-iron pipes, and they may be heated either by a coal fire, or by gas from the blast furnaces. Two pipes, with several sockets cast on at equal distances apart, are laid horizontally along the chamber. Arched pipes are arranged, each extending from one of these horizontal pipes to the other, and having their ends carefully cemented in a socket of each. Stops are placed at intervals in the horizontal pipes, so as to cause the air, which is forced in at one end, to travel successively from the first horizontal pipe to the others many times. As the air travels through the pipes it becomes highly heated and expanded.

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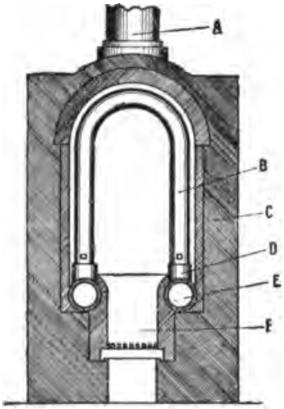
* Many iron-masters believed that when the air was heated above 600° F. they were on dangerous ground.

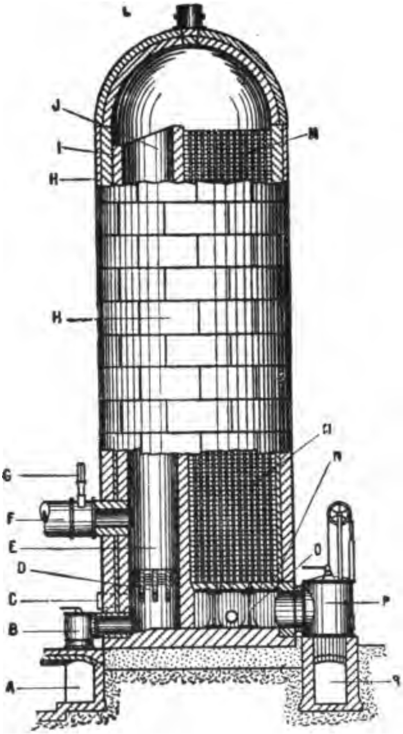
There are several modifications in the design of such stoves. In the **pistol pipe stove** the upright pipes are curved over at the top, and an internal division extends nearly to the end of the curved part, and causes the air to travel up and down the same pipe. This arrangement reduces by half the number of sockets. In the **Swedish stove** all the pipes are laid horizontally, and the bends which unite them are jointed outside the stove. Leakage at the joints can thus be detected at once, and if a pipe is supposed to be cracked the jointings can be undone, the pipe taken out and examined, and, if necessary, renewed without much trouble.



A, Chimney.
B, Arched pipe.
C, Brickwork.
D, Socket for pipe.
E, Horizontal pipe.
F, Grate.

Fig. 86.—Cast-iron Hot-blast Stove.

The first **firebrick hot-blast stove** was designed by the late Mr. Edward A. Cowper. Such stoves are heated by blast-furnace gas, and worked on the regenerative system as applied in the Siemens furnace. A **Cowper stove** (like others of modern design) is externally a tall, upright, cylindrical shell, with dome-shaped roof, of mild-steel plates. The plates are firmly rivetted together so as to form a gas-tight structure, and a lining of firebrick is built within to protect the plates. A firebrick flame-flue or combustion chamber of elliptical section, and approaching to the full height of the stove, is constructed. Divisions are arranged at the lower part of the chamber to split the gas into sheets, so that speedy and complete combustion is effected with little excess of air. Cowper's stove is sketched in figs. 87 and 88—the latter being on a scale double that of the former.



A, Culvert for gases from blast furnaces.
B, Blast-furnace gas valve.
C, Air inlet.
D, Divisions.
E, Combustion chamber or flame-flue.
F, Outlet for hot blast.
G, Hot-blast valve.
H, Iron or mild-steel plates.
I, Firebrick lining.
J, Combustion chamber or flame-flue.
L, Manhole.
M, Regenerative brick.
N, Grids.
O, Columns.
P, Chimney valve.
R, Culvert to chimney.

Fig. 87.—Cowper's Hot-blast Stove.

The remainder of the interior is filled in with firebricks, so designed and laid as to form a number of hexagonal (six-sided) passages, each extending from iron grids near the bottom of the stove up to the level of the top of the combustion chamber. The bricks which make up the "honeycomb filling" leave passages of about 6 or 7 inches wide, separated from each other by walls 2 inches thick. To minimise lodgment of dust carried over in the blast-furnace gas, the inner corners are slightly rounded and the topmost bricks are tapered. The grids are carried on girders supported on short iron columns. There are cleaning doors near the top and manholes near the bottom, as well as one at the top of the dome. The stove is set on a substantial foundation, and flues are arranged underground for the conveyance of the blast-furnace gas, and for taking off the spent gases to the chimney. Gas, air, and chimney valves are provided, and will be better understood by an examination of the sketches.

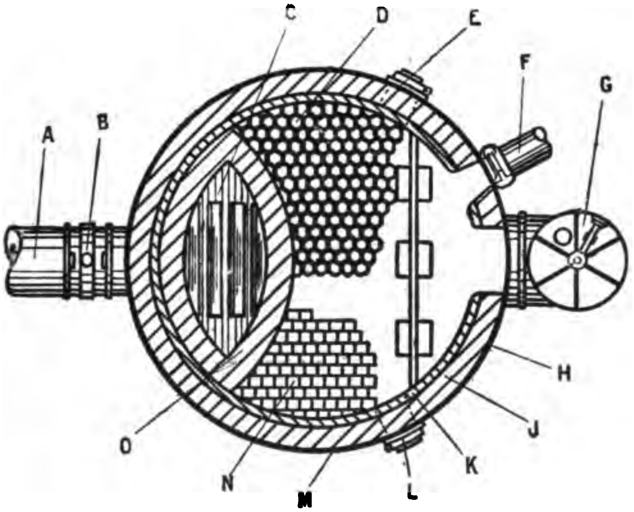


Fig. 88.—Plan of Cowper's Hot-blast Stove.

A, Hot-blast pipe.
B, Hot-blast valve.
C, Combustion chamber or flame-flue.
D, Regenerator (hexagon) bricks.
E, Inner firebrick lining.
F, Cold air inlet.
G, Chimney valve.
H, Iron or mild-steel plates.
J, Firebrick lining.
K, Columns and supports for grids.
L, Opening to regenerators.
N, Grids for supporting regenerator bricks.
O, Brickwork lining for flame-flue chamber.

Other forms of firebrick stoves are:—

The Whitwell,
The Massick & Crookes,
The Ford & Moncur, and
The Cowper-Kennedy.

They are all worked on the same principle as the Cowper stove.

Working the Hot-blast Stoves.—Blast-furnace gas [*] is admitted to the combustion chamber through the gas valve. At the same time air is admitted through the adjoining air valve. The combustion chamber being hot, ignition takes place and a long tongue of flame shoots up the combustion chamber. The hot products of combustion travel up the flame-flue and down through the hexagonal passages, imparting much heat to the brickwork before being drawn off through the chimney valve to the tall stack by which they escape into the atmosphere. When the bricks have thus been heated sufficiently, the supply of gas and air is turned off and the chimney valve is closed. Air, forced in by the blowing engine, is now sent through the cold-blast valve into the stove, and the air becoming heated by contact with the hot brickwork while travelling up the passages and down the combustion chamber, emerges through the hot-blast valve (at a temperature of 1,500° F. to 1,100° F.) to the blast furnace. When the stove has cooled down to the lower temperature the open valves are closed and the closed ones opened for the entrance of blast-furnace gas and air for reheating. Air is forced through the neighbouring stove, which has been highly heated in the interval. The stoves are worked in pairs or double pairs, or in sets of three.

The current of gas from the blast furnace unavoidably carries in dust which impairs the efficiency of the stove by covering the regenerative brickwork with a coating which does not readily transmit heat. As a consequence each stove requires to be cleaned at intervals, or arrangements are made for driving out the dust by the blast at each change of the stove.

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[*] See composition on p. 221.

The hoists or lifts by which materials are hoisted to the top of the blast furnace may be either vertical or sloping, and they may be worked by means of a winding engine driven by steam, by pneumatic or by hydraulic pressure, or by a water balance. The newest and best method is by means of electricity.

For the **vertical hoist** with direct winding, a tower is built with its top higher than the charging platform at the top of the furnace. A wheel and axle surmounts the tower, and over the wheel a rope passes, which is fastened at one end to the movable platform or cage, while the other is attached to a drum in the engine-house. When the drum is caused to revolve, the rope is coiled round it, and the movable platform or lift, with its laden barrows, is raised. On reversing the direction of the revolving drum, the moving platform, with the empty barrows, descends. Hoisting plant may be duplicated, and arranged so that as one lift is raised the other descends. In fig. 81 hoists are shown. In this instance they are lattice-work structures with wheels at the top.

In the **inclined hoist** the track from the ground level to the furnace tops generally slopes at an angle which is largely determined by the space at disposal. The movable platform —which, having one pair of wheels larger than the other, remains level—is pulled up by means of cables.

For working the **water-balance lift**, water is steadily pumped to a cistern at the top of the furnace. Two platforms are worked together. Under the sole of each platform there is a tank. Water is run into the tank of the movable platform which is at the top, in quantity more than sufficient to counterbalance the weight of the other platform and its load. On being released the water-laden platform descends and the other one is raised. The water is then run out of the tank of the platform which is at the bottom. At the same time water is allowed to flow into the tank of the platform which is then at the top.

Within recent years there have been considerable developments in the equipment of blast furnaces. Water for cooling is now plentifully supplied. There has been a liberal augmentation of blowing and heating power. Charging is expeditiously performed by means of electrically-propelled skips which quickly travel on aerial rails and discharge through a rotating distributor into the furnace, the whole being controlled by one man at the bottom. Costly machines for "casting" the iron into pigs as it comes from the furnace, or cranes for removing the pig iron from the sand beds and breaking and delivering into trucks, have also been provided.

Some modern appliances are described in the appendix to this volume.

CHAPTER XXI.

THE WORKING OF A BLAST FURNACE.

THE work done in a blast furnace is the extraction of iron from ores and the production of pig iron, which is the crude, impure form in which iron is tapped from the blast furnace.

As delivered at the blast furnace the ore contains—

(*a*) Iron and manganese.
(*b*) Oxygen in chemical union with these metals.

(*c*) Earthy impurities (the gangue) associated with the metallic oxides.
(*d*) Moisture, which is soon vaporised in the blast furnace, and escapes as steam in the exit gases.

It need not be more than mentioned, at this point, that the ores contain the iron which is wanted, that the fuel supplies the heat and the chemical energy needed, and that the function of the flux is to form, by combining with the gangue, a slag basic enough to absorb most of the sulphur of the fuel and ore, and fluid enough to flow from the furnace when tapped.

The ore and the flux make up the burden of the furnace; the ore, flux, and fuel make up the charge. This statement may be expressed thus :—

$$\left.\begin{array}{l}\textbf{Burden.}\left\{\begin{array}{l}\text{Ore.}\\ \text{Flux.}\end{array}\right.\\ \qquad\qquad\;\text{Fuel.}\end{array}\right\}\textbf{Charge.}$$

A certain number of charges—enough to fill the space at the cup and cone—make up a round.

The smooth working of a furnace, and the character of the pig iron produced, depend largely on the relative weight and quality of the burden to the weight and quality of the fuel. It is the fuel that "carries" the burden. If the ore and flux together are heavy, in proportion to the fuel, the furnace is said to have a heavy burden. But if, on the other hand, the ore and flux together are light, in proportion to the fuel, the furnace is said to have a light burden. By increasing the burden on a furnace the output may be increased, while less fuel is required per ton of pig iron produced.

Fuel.—The subject of fuel is dealt with in Chapter xxiii. But it may be noted here that the kind of fuel used in the blast furnaces of a district depends on the local supplies, or on the price at which fuel from another district can be introduced.

Coal and Coke.—Where the coal is suitable for coking it is coked, but if it is not of a coking nature it is used in the "raw" state—that is, without being coked before charging. Coke is preferred to coal for blast-furnace purposes. It yields a more intense local heat, and is stronger than coal. Blast furnaces which are to be coke-fed are built of a greater height than those intended to be coal-fed.

Raw Coal is used in Scotland and in North Staffordshire. In some South Staffordshire works both coal and coke are charged; in other districts in Britain coke is used almost exclusively.

Other Fuels.—**Charcoal**, which is the purest of the solid fuels, is much used in Sweden, because in that country coal is not plentiful, and wood—which is converted into charcoal by a process like coking—* can be profitably grown. **Lignite**, or brown coal, which is abundant in some parts of Germany, is used in some blast furnaces there. **Anthracite** has been employed in some of the Welsh blast furnaces, is charged in small quantities into a few English blast furnaces, and is freely used in some American ones. It requires a strong blast. In districts in process of being cleared for civilisation **wood** has been used as fuel. The use of dried and compressed **peat** has been proposed.

For composition of fuels see p. 226.

Flux.—For the purpose of providing lime to act as a flux

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* Charcoal was prepared long before coal was coked. The earliest methods of making coke were clearly copied from the practice of charcoal burning.

for the silica and alumina in the iron ore, &c., and which are infusible at the blast-furnace temperature, limestone forms part of most blast-furnace charges. The limestone contains calcic carbonate (CaO, CO_2) and is soon calcined: the carbon dioxide is liberated and escapes in the blast-furnace gases. The lime (CaO) which is left enters into combination with silica, forming calcic silicate, a compound the melting point of which is below the temperature of the blast furnace. Compound silicates melt still more easily, as explained on p. 229.

Some ores are **self-going or self-fluxing**; in them the proportions of silica and lime—which, when highly heated, mutually combine with each other to form a compound which becomes fluid at a high temperature—are (naturally) so proportioned that addition of flux is unnecessary.

By judiciously mixing iron ores in proper proportions, a self-fluxing burden may be charged into the furnace. A good example of this practice is seen in the Fordingham district, where the limey iron ores of North Lincolnshire are mixed with the more siliceous iron ores of Mid-Lincolnshire. These ores vary very widely in composition, but the following may be taken as approximately representing the percentage of the chief components:—

Chief Constituents.	Fordingham Ore.	Mid-Lincolnshire Ore.
Metallic iron,*	33	39
Metallic manganese,* . .	1·5	1
Silica and alumina, ...	11	22
Lime, ...	19	4

It is customary to load up separately the ore from the various well-marked layers of the quarry or mine, and to stock each in a separate "drop" at the blast furnaces. From these the ore is withdrawn in such quantities as will yield a smooth-working mixture, thus utilising all the Fordingham ores and guarding against the old erratic results.

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* These exist in the ore in a highly-oxidised state.

In making up a blast-furnace burden, as much suitable iron-bearing material as possible should be used as can be had at a reasonable price.

The work done in a blast furnace includes—

(*a*) Reduction of the iron and manganese compounds to the metallic state, and
(*b*) Separation of the iron from the gangue.

Incidentally, the iron takes up carbon (C) from the fuel, and silicon (Si), phosphorus (P), and sulphur (S), which have been reduced from materials in the charge. The compound of iron with these (and sometimes other) elements constitutes pig iron. The term "cast iron," which is sometimes applied, is confusing: cast iron is pig iron which has been cast into a finished shape.

In a working blast furnace there are steady movements of materials in opposite directions. The solid materials—the ore, the fuel, and the flux—which are charged in at the top of the furnace, descend gradually. These are met by an ascending current of hot reducing gases which seek their upward way between the pieces of descending materials. By tracing, separately, each of these counter currents, an understanding of the working may be arrived at.

The Upward Current.—The air for the blast furnace is forced by the blowing engines along the cold-blast main to the hot-blast stoves, where it is heated. From the stoves the hot air is sent through the hot-blast main, horse-shoe main, goose-necks, and tuyeres into the furnace. In the furnace the hot air is brought into contact with fuel which is already glowing; the oxygen of the air enters into chemical union with the combustible elements of the fuel and creates a very high temperature. The chemical action of oxygen on excess of incandescent fuel produces carbon monoxide, as explained on p. 209.

Carbon monoxide, being eager for more oxygen, takes it from those descending oxides which part most easily with it. This transferring of oxygen is known as **reduction,** and the substance which parts with its oxygen is said to be reduced.

Oxide of iron is readily reduced to metallic iron by the action of hot carbon monoxide and other reducing gases in the ascending current. The up-going gases not only perform the chemical duty of reducing the ore, but they impart much heat to the solids which are on their way down. On reaching the top of the furnace the gases are taken off through one or more openings into the downtake, or "downcomer," or "bustle pipe," and set to do more useful work. When the gases are quite spent they are led off by the chimney into the air.

The Course of the Solid Materials in the Blast Furnace.—The ore, fuel, and flux are conveyed by barrows to a weighing machine, and are then hoisted to the platform at the top of the furnace. The contents of the barrows are tipped into the circular hollow formed by the cup and cone. The "fillers," as the men at the top of the furnace are called, withdraw to a safe distance and lower the cone, thereby charging and spreading the materials in the furnace. The cone is then raised into position, and thus the mouth of the furnace is closed and the further escape of gases—which occurred during the momentary lowering of the cone—is prevented.

The solids are soon acted on by the hot reducing gases, but it is not until the hottest zone of the furnace is reached that the reduction and separation are completed.

Provision is made in the design of the blast furnace for the expansion due to the heating of the descending materials. When a certain point is reached, however, a diminution occurs —fuel is burned and the pig iron and slag become molten and drop down into the well of the furnace. There the pig iron and slag separate from each other because of the difference of density. Slag, being lighter, floats on the top of the pig iron and is tapped off as often as required. The pig iron is tapped from the furnace every twelve, eight, or six hours, and even more frequently in some instances.

The pig iron as it is tapped from the furnace may be allowed to flow into the recesses previously moulded in sand in the slightly sloping terrace in front of the blast furnace, which is known as the "pig bed." The pig iron flows down the runner—which is a channel in the sand traversing nearly the entire length of the pig bed—into the moulded cross channels which are known as the "sows," and from the sows into the "pig" moulds which are again at right angles.

Each "pig" is about a yard long and weighs over 1 cwt.

As the molten pig iron comes from the furnace it is allowed to flow to the end of the runner and along the lowest "sow" into the connected "pig" moulds. When these are filled with fluid pig iron the runner is blocked below the next sow and a way is made for the metal to flow along the sow into the next row of pigs. Thus, one by one the rows receive the pig iron until the "cast" is finished; that is, until all the iron obtainable at that time from the hearth has run out (fig. 89). Steps may be taken to hasten the cooling of the pigs, which, when sufficiently solidified, are broken off from the sows, and the sows from the runners. These are broken

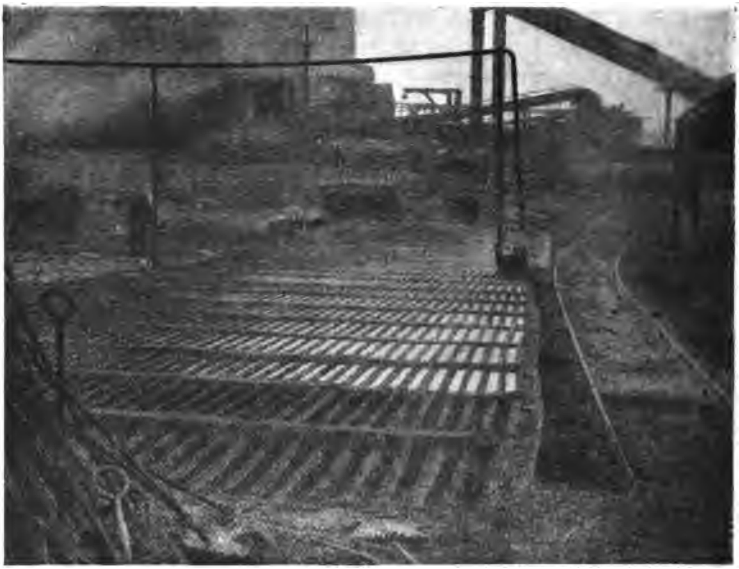

Fig. 89.—Pig Beds in front of Blast Furnace.

into useful sizes. In due course all the pig iron is lifted and conveyed to trucks.

In some other countries it is customary to "cast" the pig iron under cover.

From a mechanical point of view, sand is a suitable substance in which to cast pig iron; from a chemical standpoint, it is one of the worst materials known. Various other substances have been suggested and some have been tried, such as coke dust and fine ore. In Sweden, heavy cast-iron troughs or trays are extensively used as moulds for pig iron, with good results.

In a blast furnace which is making pig iron, all, or nearly all, the iron is reduced; the proportion of manganese and of silicon reduced will depend on the conditions prevailing in the furnace, and the conditions will decidedly influence the amount of carbon and sulphur in the pig iron produced. With very few exceptions nearly all the phosphorus compounds in the ore, fuel, and flux are decomposed, all but a little of the phosphorus going into the pig iron.

Of the descending materials in a working blast furnace all that retain their oxygen go into the slag, and (with the exception of some sulphur which is collected in the slag) all that are reduced go into the pig iron.

The chemical work of a blast furnace is effected by a strongly reducing action.

The chemical reactions which take place are:—

Carbon, when burned in a blast furnace, forms carbon monoxide (CO). This is believed to be effected in two stages. Firstly, carbon dioxide (CO_2) is formed—

$$\underset{\textit{Carbon}}{C} \quad \underset{\textit{and}}{+} \quad \underset{\textit{oxygen}}{O_2} \quad \underset{\textit{yield}}{=} \quad \underset{\textit{carbon dioxide}}{CO_2}$$

and then the dioxide is converted by the excess of glowing carbon into carbon monoxide, thus—

$$\underset{\textit{Carbon dioxide}}{CO_2} \quad \underset{\textit{and}}{+} \quad \underset{\textit{carbon}}{C} \quad \underset{\textit{yield}}{=} \quad \underset{\textit{carbon monoxide.}}{2CO}$$

In the course of his extensive investigations on blast-furnace gases the author has been unable to find carbon dioxide in the gases drawn off from the hearth. But whether carbon dioxide is formed in the first instance, or the monoxide is formed directly, there can be no difference in the chemical or the thermal effects.

Although there is reason to believe that the cyanides which are present in the gases in the lower regions of the blast furnace exert influence in carrying on reduction, and that hydrogen must have a notable effect, the chief agent in carrying on reduction must be either hot carbon or carbon monoxide, both of which are present in large quantities. The action of the latter may be represented by the following chemical equations :—

Reduction of ferric oxide—

$$Fe_2O_3 + 3CO = 2Fe + 3CO_2$$

Ferric oxide and carbon monoxide yield iron and carbon dioxide.

Reduction of manganese oxide—

$$Mn_3O_4 + 4CO = 3Mn + 4CO_2$$

Manganese oxide and carbon monoxide yield manganese and carbon dioxide.

Reduction of phosphorus pentoxide (often called phosphoric acid)—

$$P_2O_5 + 5CO = 2P + 5CO_2$$

Phosphoric acid and carbon monoxide yield phosphorus and carbon dioxide.

Reduction of ferric oxide takes place in the upper region of the stack, but is not completed till the still unreduced portions of the ore reach the bosh.

The composition of the gases from charcoal-fed and coke-fed blast furnaces proves that oxidation of carbon or carbon monoxide to carbon dioxide takes place.

Carbon Impregnation.—Hot iron can decompose carbon monoxide, thus—

$$2CO = C + CO_2.$$

The carbon so liberated enters into combination with, or deposits carbon on, the spongy pig iron.

It has been experimentally proved that, on a small scale, carbon monoxide cannot reduce silica. We may therefore represent it as being directly reduced by carbon, thus—

$$SiO_2 \quad + \quad 2C \quad = \quad Si \quad + \quad 2CO$$

Silica and carbon yield silicon and carbon monoxide.

It is not safe, however, to assume that reactions on the small scale are the same as those which take place on a large scale.

In the formation of slags chemical union takes place between the lime of the flux and some of the silica of the ore or the ash of the fuel, and the reaction may be represented thus—

$$2CaO \quad + \quad SiO_2 \quad = \quad 2CaO \,.\, SiO_2$$

Lime and silica yield silicate of lime.

Any free alumina which may be present would also combine with silica, and the reaction may be stated thus—

$$2Al_2O_3 \quad + \quad 3SiO_2 \quad = \quad 2Al_2O_3 \,.\, 3SiO_2$$

Alumina and silica yield silicate of alumina.

The silicates of lime and alumina unite to form a compound silicate. Some blast-furnace slags have a composition which can be summed in the formula—

$$2Al_2O_3, 3SiO_2 \quad + \quad 6(2CaO, SiO_2).$$

Calculation shows such a slag to consist of—

Silica	(SiO_2), . .	38·14	per cent.
Alumina	(Al_2O_3), . .	14·41	„
Lime	(CaO), . .	47·45	„

Other oxides are present in the slags, notably oxide of manganese (MnO) and magnesic oxide or magnesia (MgO). These replace, as far as they can, the lime: being bases they can combine with silica. Very rarely blast-furnace slags are produced which contain no lime.

When a furnace is working on a light burden the slag produced is generally white or grey; when the burden is heavy a dark coloured or black slag is usually produced. Such dark or black slags contain ferrous oxide (FeO) which, when in combination with silica, forms a very fluid compound at the blast-furnace temperature. These black, ferrous, scouring slags are very severe on the furnace lining. Slags containing manganese in notable amount may be brown or yellow coloured. Portions which contain manganese and much silica are green coloured. If much lime is present the slag may have a cold, stony appearance, while presence of much alumina is usually shown by the opalescent character of the slag.

Quickly-cooled slags are glassy and present a shell-like (conchoidal) fracture, but if cooled slowly the same slag may be dull in appearance.

Disposal of Blast-furnace Slag.—The slag issues from the furnace in the fluid condition, and is allowed to flow into iron tubs or ladles which are set on trucks or trolleys. It may be (*a*) applied to useful purpose, or (*b*) be tipped on heaps and encumber the ground, or (*c*) be granulated and carried away by rivers, or (*d*) be conveyed to sea on barges and tipped into deep water.

Of late years a considerable quantity of blast-furnace slag has been granulated in water and made into cement or bricks. Slag wool is also made, and large quantities of slag are used for road making and mending and for "ballast" between railway sleepers. In some iron-making districts the whole of the slag is utilised.

Slag intended to be tipped on heaps may either be allowed to solidify in the large ladle in which it is caught and the "ball" tipped on the slag hill, or as soon as the ladle is full it may be taken to the top of the slag hill and the contents poured out there.

On the European continent it is customary in some works to permit the slag to trickle to the nearest river. Contact with the water into which it flows has the immediate effect of breaking it up into grains, and these are carried away by the current.

CHAPTER XXII.

THE PRODUCTS OF THE BLAST FURNACE.

THE chief aim of the blast-furnace manager is the production of good pig iron at the lowest possible cost. In recent times the value of the bye-products—gas and slag—have received a considerable amount of attention.

Pig Iron.—The purpose for which a lot of pig iron is best suited, and the price it will command, is largely determined by the percentage of phosphorus which it contains. It has already been pointed out that, with few exceptions, almost all the phosphorus in the blast-furnace charge goes into the pig iron. Hence, it follows, that in order to regulate the amount of that element in the pig iron which is to be produced, the charge must be carefully selected. If pig iron with a small percentage of phosphorus is required, care must be taken to exclude ore, fuel, and flux which contain more than a little of that element—for unfortunately none of these are quite free from phosphorus, and the total amount may irretrievably injure the quality of the pig iron. On the other hand, some classes of pig iron, such as that used in the basic Bessemer process, must contain a decided amount of phosphorus, and, within a limit which is seldom if ever exceeded, more phosphorus is desirable. In a lesser, but essential, degree phosphorus is necessary in foundry pig iron.

The following may be taken as representating, in round numbers, the composition of certain pig irons:—

Constituents.	Swedish.	Bessemer.	Foundry.	Forge.	Cleveland.	Basic.
Graphitic carbon,	2·00	3·30	2·75	2·00	3·20	0·50
Combined carbon,	2·00	0·50	0·75	1·00	0·50	2·80
Silicon, . .	1·20	2·20	2·00	1·00	2·60	0·50
Phosphorus, .	**0·03**	**0·05**	**0·90**	**1·30**	**1·60**	**3·00**
Sulphur, . .	0·01	0·04	0·09	0·10	0·08	0·07
Manganese, .	3·00	0·50	0·60	0·50	0·60	2·00
Iron, . . .	91·76	93·41	93·41	94·10	91·42	91·13

Analyses of grades of certain classes of pig iron will be found on p. 241.

By giving attention to the temperature of the blast furnace and the condition (whether basic or otherwise) of the slag, the percentage of silicon, of carbon, and of manganese may be regulated fairly well.

The best system for producing pig iron containing only a small percentage of sulphur is to carefully select raw materials which contain a low percentage of sulphur. This, however, involves a high cost, and recourse must be had to means and conditions which will cause much of the sulphur either to go off in the gases or go into the slag. The latter is the less objectionable method. A furnace which is working hot and with abundance of lime in the burden is not so likely to yield a sulphury pig iron, but if the furnace is comparatively cold and the slag produced is deficient in lime, a pig iron high in sulphur will result.

Carbon exists in pig iron in two states at least (*a*) as combined carbon, and (*b*) as graphitic carbon. In the latter condition the carbon is not in chemical union with any other element: it exists in the free state, and at times in flakes so large and so loose that they may be detached.

The percentage of carbon in the pig iron produced depends very much on the quantity and quality of the fuel. Apart from other conditions, a furnace which is hot and supplied liberally with fuel is likely to contain much carbon, especially graphitic carbon; and the high temperature and the surplus energy which that implies, having an active reducing effect, tends to the production of pig iron rich in silicon.

In "finishing materials" such as ferro-silicon, in which silicon predominates, the carbon is not plentiful, and it exists chiefly in the graphitic state. Manganese acts differently · where there is much manganese—unless it is interfered with by silicon—the percentage of combined carbon is higher than in ordinary pig irons. A comparison of the analyses on pp. 237 and 238 shows clearly these differences.

For the production of a pig iron containing a high percentage of silicon, the proper blast-furnace conditions are:—

(*a*) *Presence of Plenty of Siliceous Matter*, especially such as can be easily reduced. Certain ores are prone to yield highly siliceous pig iron, even if the percentage of silicon in the ore is not great.

(*b*) *A High Temperature*, which means plenty of spare energy in the furnace to cause the reduction of much silica (SiO_2) to silicon (Si).

(*c*) *The Furnace working slowly.*—This condition allows more time for the reduction to be effected.

(*d*) *Not too much Lime in the Burden.*—If there is plenty of lime present the silica will combine with it and be carried into the slag, but if lime is comparatively scarce the free silica will be left more open to reducing influence.

There is no intention to suggest that all the above conditions will exist at the same time, but each one tends to the production of siliceous pig iron. Contrary conditions will result in the production of a pig iron in which the content of silicon will be comparatively low.

For the production of a pig iron with much manganese in it, it is necessary to have—

(*a*) *A large amount of manganese* in the blast-furnace charge.

(*b*) *A high temperature:* manganese oxide in quantity is more difficult to reduce than iron oxide.

(*c*) *Presence of abundance of lime* in the charge. Lime, being basic, will combine with the free silica, and the silica being thus satisfied will not so readily combine with the (basic) oxide of manganese of the ore.

The blast-furnace conditions may be briefly summarised thus:—

To produce a pig iron

	Fuel should be	Lime should be
High in carbon, . . .	Abundant.	...
,, silicon, . . .	,,	Not too plentiful.
,, manganese, . .	,,	Abundant.
Low in sulphur, . . .	,,	,,

Grey and White Pig Iron.—A blast furnace which is working on a light burden (see p. 203), or at a high temperature, produces, as a rule, grey pig iron; that is, pig iron which contains much carbon and silicon—the silicon, as usual, causing much of the carbon to pass into the graphitic state.

On the other hand, a blast furnace which is working on a heavy burden, or at a comparatively low temperature, generally produces a white pig iron; that is, a pig iron containing less carbon and silicon, and in which most of the carbon is chemically combined with the iron.

Mottled pig iron is intermediate in composition, and may be looked on as an intimate mixture of the two kinds.

Grey pig iron has a higher melting point than white pig iron; in other words, it requires a higher temperature to melt the grey variety. When melted, grey pig iron is more fluid than white pig iron. Melted grey pig iron expands just before solidifying. This enables it to take a sharp impression when cast in a mould, hence it is most suitable for fine castings. White pig iron does not so expand before beginning to solidify. During melting and cooling, white pig iron passes through a pasty stage which is favourable for puddling.

The chief characteristics of grey and white pig iron from an ordinary blast furnace burden for foundry or forge iron may be conveniently summarised and compared thus:—

GREY PIG IRON.	WHITE PIG IRON.
Contains much carbon.	
Most of the carbon is in the graphitic state.	Most of the carbon is combined.
Contains a high percentage of silicon.	Does not contain so much silicon.
Contains much manganese.	Does not contain so much manganese.
Contains little sulphur.	Contains more sulphur.
Average specific gravity about 7·1.	Average specific gravity about 7·5.
Is large-grained (open-grained), grey, soft, and tough.	Is fine-grained (close-grained), white, hard, and brittle.

Grey Pig Iron.	White Pig Iron.
Melting point, about 1,400° C.	Melting point, about 1,300° C.
Is more fluid when melted than is white iron.	Is not so fluid when melted as grey iron is.
Expands just before solidifying.	Passes into a pasty condition when below its melting point.

It must be distinctly understood that the above table shows the characteristics of average pig iron of each kind. There are exceptions. The physical condition and appearance (which may not inaptly be called the texture) of a pig iron—whether grey, mottled, or white—are affected by its chemical composition, the rate at which it has been cooled, and by other circumstances. The appearance of the fracture is not a safe guide in grading pig irons. The grading should be arranged according to analyses. Sometimes the grey pig iron from a blast furnace actually contains less silicon than a white pig iron from the same or a previous cast. A blast furnace working smoothly on a proper burden is not so likely to produce such abnormal pig irons, but if a "slip" has occurred the pig iron may easily show a deceptive fracture. Swedish pig iron, which is "chilled" by being cast in thick iron moulds, is white on the under part of the plate (or pig), while the upper part of the same pig iron is grey. The bottom part is hard, the upper part is soft. The percentage of silicon is nearly the same in each part, but in the lower portion the combined carbon predominates. In the upper part the carbon is mostly in the form of graphite in fine grains—not in scales, as one finds it in grey pig iron which has been cast in sand.

Grading of Pig Irons.—It is customary to call the richest grey pig iron "No. 1." It is the dearest of its class, and rightly so, since, on account of the greater consumption of fuel used in its production, it costs more. Pig iron which is less grey is called No. 2, and so the grading goes on through the mottled pig iron to the whitest of all.

Staffordshire part mine pig iron—which is made chiefly from North Staffordshire ore, Northampton ore, and a little flue cinder—is generally graded as mine foundry No. 1, mine foundry No. 2, mine foundry No. 3, grey forge, forge, strong forge, mottled, and white. Cinder foundry pig iron is generally sold in mixed numbers 1, 2, and 3. Very rarely cinder No. 1 pig iron is ordered. Other cinder pig irons are cinder forge, mottled, and white.

Fig. 90.—Fracture of Grey Pig Iron.

Fig. 91.—Fracture of Mottled Pig Iron.

Fig. 92.—Fracture of White Pig Iron.

Fig. 93.—Fracture of Pig Iron, White at Bottom, Grey at Top.

In Scotland it is usual to grade pig irons as No. 1, No. 3, No. 4, mottled, and white. Some makers quote No. 2, and all will select it when wanted. Several ironmasters have their own manner of grading. One grades thus:—No. 1, No. 3, No. 3 hard, No. 4, mottled, and white. Another one grades No. 1, No. 3 special, No. 3 soft, No. 3 foundry, No. 3 close, and No. 3 hard. Lots which are sold under the Scotch pig-iron warrant system as G.M.B. are made up in the proportion of three-fifths of No. 1 and two-fifths of No. 3.

The grading of pig iron in the United States is complicated. Thirteen grades have been mentioned and nine grades are well-known, viz. :—Silver grey, No. 1 soft, No. 2 soft, No. 1 foundry, No. 2 foundry, No. 3 foundry, grey forge, mottled, and white. It has been suggested that the following six grades should suffice :—Silvery iron, soft iron, foundry iron, grey forge, mottled, and white. The practice of purchasing pig iron by analysis has established itself in the States, and is finding extensive acceptance. Other considerations must, however, count as well as composition.

SLAGS.—The slag from a blast furnace which is smelting iron ores is made up of the gangue, the fixed constituents of the flux, and the ash of the fuel. All the gangue, except the portion which is reduced, goes into the slag. The fixed constituents of the flux includes all except carbon dioxide, organic matter, and water.

The quantity of slag will depend chiefly on the amount and the nature of the gangue. Ores which contain much gangue requiring plentiful addition of flux will, of course, yield more slag than ore or ores containing a comparatively small quantity of self-fluxing gangue. Self-fluxing gangue consists of silica and bases in such relative proportions that no addition of flux is necessary to produce a mixture, or slag, which can readily be melted at the working temperature of the blast furnace. The amount of slag produced varies widely. It has been stated as between 10 cwts. and 35 cwts. per ton of pig iron produced.

Slags from blast furnaces which are producing white pig iron, contain, as a rule, more silica than a neighbouring furnace which is producing grey pig iron. This is quite natural. There has not been such an abundant reduction of silica during the making of white pig iron, therefore more silica must be left free to go into the slag.

The following are approximate analyses of average slags:—

Constituents.	Chemical Formulæ.	From Clayband Ores.	From Cleveland Ores.	From Mixed Hematite Ores.
Silica,	SiO_2	36	28	34
Alumina,	Al_2O_3	16	22	13
Lime,	CaO	42	40	51
Magnesia,	MgO	4	7	1
Manganous oxide,	MnO	1	0·2	1
Ferrous oxide,	FeO	...	0·8	
Sulphur,	S	1		
Alkalies, &c.,	...		...	
Calcic sulphide,	CaS	...	2	...
		100	100·0	100

GASES.—A working blast furnace emits an enormous volume of gases. William Jones stated* that the gases from the Scotch (coal-fed) blast furnaces averaged over 230,000 cubic feet at the temperature (500° F.) at which they left the blast furnace. James Riley considered† that the volume of gas, measured at ordinary temperature and pressure, from 1 ton of coal measured 130,000 cubic feet, while from 1 ton of coke the gases measured 180,000 cubic feet under like conditions.

The weight of the gases, per ton of pig iron produced, is about 7 tons.

The gases from the blast furnace were called "**waste gases**," and the term was quite correct at one time. Now that, after discharging fully their duties in the blast furnace, they perform much useful work, the term **surplus gas** would be more accurate, but the generally accepted name—**blast-furnace gas**—is sufficient. Because of the presence of certain constituents, the surplus gas is strongly reducing. An excess of powerfully reducing gases must be present in the surplus gas or the work of the blast furnace could not be carried on. Now, those

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* *Iron and Steel Institute Journal*, 1885, ii., p. 412.

† *Ibid.*, 1898, i., p. 33.

Eighteen Babcock & Wilcox Boilers, each of 3,140 square feet heating surface, arranged for firing with blast furnace gases and coal.

Installed at the Works of Messrs. Bolckow, Vaughan & Co., Ltd., Middlesbrough.

constituents which have reducing power are capable of combining rapidly with oxygen and evolving much heat. Blast-furnace gas is therefore carefully collected and utilised for heat-raising and steam-raising.

The following may be noted as fairly representative analyses of blast-furnace gases :—

Constituents.	Chemical Formulæ.	From Charcoal-fed Furnace.	From Coke-fed Furnace.	From Coal-fed Furnace.
Reducing gases—				
Carbon monoxide, . .	CO	25	28·00	28·0
Hydrogen, . . .	H_2	4	1·00	5·5
Methane or marsh gas, .	CH_4	1	0·25	4·5
Total combustible gases,		30	29·25	38·0
Inert or neutral gases—				
Carbon dioxide,* . .	CO_2	12	15·00	8·6
Nitrogen, ...	N_2	58	55·75	53·4
		100	100·00	100·0

Steam-raising by means of surplus blast-furnace gas may be carried on by burning the gas with a regulated amount of air in a "front" or grate and combustion tube of an ordinary boiler, or by the well-known Babcock & Wilcox boilers compactly enclosed, as shown in the opposite illustration.

But the tendency of the times is to utilise the gas by generating power direct in a gas engine rather than by means of steam. Increased power (perhaps three or four times as much) may be obtained by means of the gas engine.

The gases from many (indeed nearly all) coal-fed blast furnaces are condensed and scrubbed so as to recover the ammonia, tar, and oils from them. The scrubbed gases are used for heat-raising and other purposes.

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* Under certain conditions carbon dioxide acts as an oxidising gas.

At one work the blast-furnace gas
Distils the tar and ammonia liquor,
Heats the hot-blast stoves,
Provides steam for the whole works,
Melts the steel in the steel foundry,
Heats the core stoves for three large foundries,
Burns the ore briquettes in 12-chamber kilns,
Distils the coal for the gas works supplying the village,
Supplies fuel for an enamel brickwork a mile away, &c.

Fig. 94.—Front of Boilers Fired with Blast-furnace Gas.

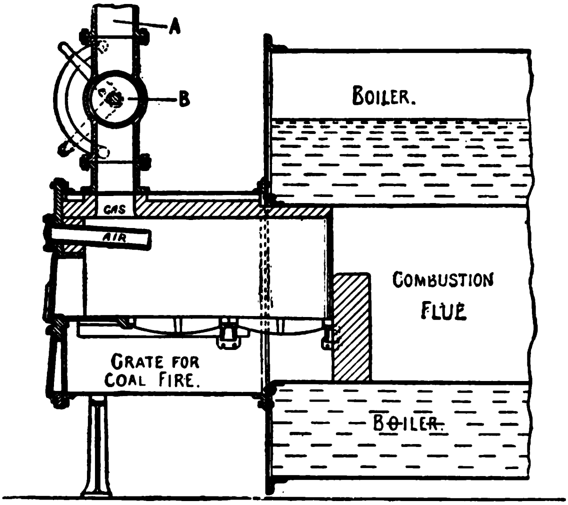

Fig. 95.—Sketch Showing Section of Arrangement for Utilising Blast-furnace Gas for Steam Raising.

Fig. 96.—Engine Worked by Blast-furnace Gas.

CHAPTER XXIII.

NOTES ON FUELS, FLUXES, REFRACTORY MATERIALS, &c.

FUEL is "anything that feeds a fire." A substance to be of service as a fuel must be capable of burning rapidly, and of giving forth much heat while burning. Cheap fuel is an important point in connection with manufactures.

Burning results from the kindling of inflammable material where air* in proper quantity has free access, and combustion is continued by the chemical combination of oxygen with the fuel. Slow combustion (breathing, decay, &c.), on the one hand, and the very rapid combination causing explosion or conflagration, on the other hand, do not come within the present scope.

The chief components of solid fuel are :—

Carbon.
Hydrogen.
Compounds of carbon and hydrogen.

Oxygen.
Nitrogen.
Ash.

The three first are of service because they can combine with oxygen and yield much heat: the remaining three are worse than useless from a heat-raising point of view—they contribute nothing, but are heated by the burning of the other constituents.

The following simple experiment may help to make clear how the components of a solid fuel act when heated :—Into a small crucible put 2 grammes of powdered coal. Cover with a lid, and apply heat from a Bunsen burner or other smokeless flame to the bottom part of the crucible. In the course of two

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* Air contains about one-fifth of its volume of the active gas called oxygen.

or three minutes take off the lid and examine its under part. Globules of water should be seen. If not, the experiment has been hurried by too hot a flame, or has not been continued long enough. After a trial or two the correct conditions will be found. Replace the lid, increase the heat, or set the crucible further down into the tip of the flame, and allow to remain for some time. Smoke will issue from the crucible, and shortly afterwards a flame will appear round the edge of the lid, showing clearly that an inflammable gas is being driven off from the coal by heat. Continue the heating for an hour before removing from over the flame. When the crucible has become cold, examine the contents, which should consist of a black substance either in powder or caked together (coke), and which has not been burned away even on the application of prolonged heat. Weigh the contents and replace in the crucible. Then, with the lid off, continue the heating. The mass in the crucible will glow, and after a time a white or coloured residue (ash) will be left. Heat and air do not affect it. When cool, weigh the ash.

The experiment shows that the coal contained—

(*a*) Water.

(*b*) Matter which was driven off (volatilised) by heat, and, on coming into contact with air, could easily be burned. From other experiments these are known to be hydrocarbons (which are compounds of carbon and hydrogen) and other gases.

(*c*) Matter (fixed carbon) which could only be burned by heating, with excess of air; and

(*d*) A residue (ash) which could not be burned off.

Heat Value.—When 1 lb. of carbon enters into chemical union with enough oxygen to form carbon dioxide (CO_2), sufficient heat is generated to raise 8,080 lbs. of water 1° on the Centigrade thermometer, or 8,080 Centigrade heat units. But if the 1 lb. of carbon cannot have more than enough oxygen to form carbon monoxide (CO), the heat generated is only equal to 2,400 heat units.* On further oxidation of the resulting 2⅓ units of carbon monoxide (CO) into carbon dioxide (CO_2) another 5,600 heat units are generated.

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* "Heat units" are also known by the terms "calorific power" (Latin, *calor* = heat) or "calorific value."

When 1 lb. of carbon is fully burned, 3⅔ lbs. of carbon dioxide are formed and about 11 lbs. of nitrogen accompany the necessary oxygen, making about 13⅔ lbs. in all. Beyond the oxygen (and nitrogen) stated, an excess of air is necessary in practice. All these gases are heated to the temperature of the furnace, and thus a great deal of heat is carried away up the chimney. A "draught" is created thereby.

The heat value, or calorific power, of hydrogen is 34,000 when oxidised under favourable experimental conditions to form water, the chemical formula of which is H_2O—a formula which indicates that two atoms of hydrogen have entered into chemical union with one atom of oxygen. But in practice the water is converted into steam—which is H_2O in the gaseous state. That conversion requires such an expenditure of energy (or heat) that less than 29,000 heat units are left over. Every pound of hydrogen when burned combines with 8 lbs. of oxygen to form 9 lbs. of steam. Owing to the large quantity of steam formed and to the capacity of steam for carrying off heat, the surplus heat derived is not so large as from the burning of 1 lb. of carbon.

The composition of solid fuels varies considerably, but an idea of their composition may be gathered from the following table:—

	NATURAL FUELS.			PREPARED FUELS.	
	Wood.	Bituminous Coal.	Anthracite.	Charcoal.	Coke.
Fixed Carbon,	25	56	82	92	87
Hydrocarbons, &c.,	52	33	10	1	2
Ash,	1	5	6	4	8
Water,	22	6	2	3	3
	100	100	100	100	100
Sulphur in the ash,	...	1	1	...	1

Coals may be classified thus—

1. Bituminous coal.
    (*a*) Caking, or coking.
    (*b*) Non-caking.
2. Anthracite.

Bituminous coals may burn either with a long or a short flame. The long-flame coal is useful for reverberatory furnaces. Anthracite does not produce much flame when burning.

Our coal deposits were formed from plants, and it may be instructive to briefly consider their formation. To begin with, plants, when in life, decompose carbon dioxide (CO_2), giving back oxygen to the air while retaining the carbon. They also absorb water (H_2O). From carbon and water they build up cellulose or woody fibre, the composition of which is $C_6H_{10}O_5$ or $C_6(H_2O)_5$. In a byegone geological period immense forests were covered over, and for long ages the plants (club mosses, trees, &c.) were subjected to the influence of the internal heat of the earth.* This caused decomposition. The volatile matters were partially driven off and fixed carbon concentrated. This concentration is strongly marked in anthracite. Most of the ash is from earthy matter which intermingled with the covered-over trees, &c.

When coal which is of a coking nature is highly heated for some time without access of air, or air in very limited amount, it is converted into coke. During coking, water and the volatile hydrocarbons are driven off. The result is a further concentration of carbon and the production of a strong fuel which is capable of generating an intensely high temperature.

Good coke does not contain much volatile matter and not more than a moderate amount of ash. It is strong, lustrous, dense, and at the same time porous. It must be strong so as to withstand well the crushing of materials in a cupola or a tall blast furnace. When a coking oven is very hot, some of the liberated hydrocarbons become decomposed; hydrogen is

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* As one descends a mine he can hardly fail to note the rise in temperature.

set free and finely-divided carbon is deposited on the coke. The shining silvery lustre is taken as evidence of the coke having been prepared in a highly-heated coke oven.

When coke is porous its numerous small pores may become filled with the hot gases in the furnace and the coke will burn quickly when kindled. Density along with porosity implies that the material comprising the walls of the cells, or pores, is compact; otherwise the coke would crumble.

The favourite coke of many foundry and blast-furnace managers is made in bee-hive ovens. Much coke is now made in retort ovens which are arranged in batteries, each coking chamber being about 33 feet long, 6 feet high, and 1 foot 6 inches wide—the actual width depending on the nature of the coal. The crushed coal intended for coking is quickly dropped from two 2-ton overhead hoppers into a hot coking chamber. In more modern coking plant the crushed coal is compressed in a mould and the block is charged into the hot coking chamber. The gases which come off are scrubbed to extract the ammonia and other valuable "residuals," and then passed along with a regulated amount of air to be ignited and burned in passages at the sides and underneath the coking chamber. When the coking is finished a ram pushes out the block of coke.

Charcoal is prepared by drying and heating wood, under a covering of non-combustible matter, or in a kiln, till it is charred as black as coal. The volatile matters (water and hydrocarbons) are nearly all driven off. There is less ash in charcoal than in coal.

FLUXES.—Substances which are to be used for fluxing* must be of a chemical nature opposite to that of the substances which are to be fluxed. The chief idea is to form from the gangue a fluid slag. If silica (which is of an acid nature) predominates in the gangue of an ore, the flux must be basic (see p. 26). Lime (CaO) being cheap is freely used. Monosilicate of lime ($2CaO, SiO_2$) is a common constituent of blast-furnace slags. But if a furnace temperature is not equal to the

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* The words "fluxing" and "fluid" are from the Latin and signify *flowing*.

task of melting a compound of such high melting point, a base which will form a compound, or slag, of lower melting point must be used in order to work a metallurgical process successfully. In such a case ferrous oxide (FeO) will be supplied, so that the silica may form with it silicate of iron ($2FeO, SiO_2$), which melts at a moderate furnace temperature. Ferrous silicate is the chief constituent of the slag from a puddling furnace. The puddling furnace cannot be relied on to melt silicate of lime, and, besides, lime has been found to interfere seriously with the quality of wrought iron. It is, however, used sparingly with success. Lime, being a cheaper flux than iron oxide, is used where enough heat can be had, as in blast-furnace practice and in the manufacture of steel.

Silicates with two bases are, as a rule, more fusible than those containing either of the bases singly. When required, a second substance is selected to assist in the fluxing of gangue. Of this a well-known instance is the charging of aluminous ore along with limestone when smelting English hematite ore. The result is a slag containing silicate of lime and alumina. This compound silicate melts at a lower temperature, and so helps blast-furnace working. In smelting clay-band ironstone it is not necessary to add more than one fluxing material, because clay (which constitutes the bulk of the gangue) contains both silica and alumina. Addition of the necessary lime, therefore, leads to the formation of the compound silicate of lime and alumina.

SUMMARY OF COMMON FLUXES.

Silica . . acts as a flux for ferrous oxide.
Ferrous oxide „ „ silica.

Silica . . „ „ lime.
Lime . . „ „ silica.

Lime . . „ „ clay.
Clay . . „ „ lime.

Alumina (Al_2O_3) may act as a base when silica predominates, or may act as an acid when lime is the chief component.

Magnesia (MgO) may, in part at least, be substituted for lime. Its silicate does not melt quite so readily, but magnesia tends to form a hard slag which can, when cold, be usefully applied. Under certain conditions magnesia readily combines with sulphur.

Manganous oxide (MnO) may also with advantage replace some of the lime.

Ferrous oxide (FeO) is out of place in blast-furnace slag.

Fluor spar is useful for increasing the fluidity of certain slags and is very helpful as a desulphuriser. Its use in iron and steel works is steadily increasing.

REFRACTORY MATERIALS for metallurgical purposes are such as successfully withstand chemical, mechanical, and thermal* actions.

They are required to resist combination with oxygen, thus differing from fuels. They are required to resist chemical union with gangue or slag, thus differing from fluxes. They should also be able to withstand continued exposure to intense heat, and also sudden changes of temperature, without softening, cracking, or changing shape.

Refractory materials are chiefly composed of

I.	Silica,	SiO_2
	Titanic oxide,	TiO_2
II.	Alumina,	Al_2O_3
	Chromic oxide,	Cr_2O_3
	Ferric oxide,	Fe_2O_3
III.	Lime,	CaO
	Magnesia,	MgO
IV.	Impurities—	
	Ferrous carbonate,	$FeCO_3$
	Iron pyrites,	FeS
	Potash,	K_2O
	Soda,	Na_2O

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* From Greek thermè = heat.

Class I. = acid substances.
Class II. = neutral „
Class III. = basic „

Class IV.—Lime and magnesia are amongst the most fatal impurities of fireclays. All the iron compounds are injurious to firebricks, but the most serious is iron pyrites (FeS_2). When a firebrick is kiln-burnt this loses half its sulphur and forms the highly-fusible ferrous sulphide, which gradually combines with silica and fuses. Potash and soda are alkaline substances, and presence of either or both in more than minute quantities is highly injurious to acid refractory materials and in a lesser degree to the others.

A good refractory material is simple in its composition; one substance, or substances of a like constitution and chemical nature, must largely predominate in its composition, with enough component of an opposite chemical nature to hold it together, yet not enough to cause it to flow or soften at the temperature of the furnace or lining for which it is used. Take as examples the lining and the walls of a Siemens furnace. The furnace is worked at a very high temperature. The working lining is made up of silver sand, which, being very pure, does not even frit with the intense heat of the furnace. A small quantity of loam or of impure sand (which can be melted at the furnace temperature) is added as a binding material. The bricks of which the walls and the roof are built require a stronger binding, and this is supplied by mixing about 2 per cent. of lime, made into a thick cream with water, to the crushed siliceous rock of which the bricks are made. Fireclay, on the other hand, usually contains more binding material (chiefly alumina) than is required.

In selecting a refractory material for a furnace one of the first considerations is the chemical nature of the slag. Will it be acid or basic? A refractory substance of the same nature, or a neutral substance, must be selected. The amount of binding material must be determined by the temperature at which the furnace is to be worked.

The chief **acid refractory materials** used in iron and steel works are:—

Silver Sand, largely imported from Belgium; ordinary brown sand, and crushed Dinas (South Wales) rock.

Ganister.—Found abundantly near Sheffield. In its composition silica largely predominates, but it also has in itself enough binding material to enable it to hold firmly together while enduring the commotion and the heat incidental to a Bessemer blow.

Fireclay which, as already noted, is over-rich in binding material, and suffers in its heat-resisting qualities in consequence.

Clays of greater purity than fireclays.

Fire-stones, which are capable of withstanding great heat and considerable alterations of temperature without cracking.

Silica Bricks.—These are made by mixing siliceous (quartzose) rock—which has been broken and crushed—with cream of lime; moulding, drying, and kiln-firing. When broken, these bricks show a rough fracture—pieces of quartz showing up distinctly amongst the finer particles and the binding of lime. Prominent yellowish spots indicate the presence of iron oxide in very small amount. The bricks are tender when cold; they must be handled carefully, and kept from exposure to damp. When heated they expand, and they are not so tender as when cold.

Ganister Bricks resemble silica bricks in material, method of manufacture, and general character.

Firebricks are made by selecting, tempering (or weathering), grinding, and sifting the fireclay, mixing it with water, moulding, drying, and then kiln-firing at a temperature almost approaching to whiteness. The bricks are allowed to cool down slowly in the kiln after the fire has been withdrawn.

It is usual to incorporate sand, or old, clean bricks, in order to diminish shrinkage and increase their power of resisting heat. Coke dust is sometimes added.

Firebricks contract during drying and firing; they thus differ from silica bricks, which expand during burning and also when in use. When broken across, firebricks show a much finer grain than silica bricks.

The following table shows, approximately, the composition of the chief acid refractory materials:—

Constituents.	Chemical Formulæ.	White Sand (Dried).	Gan-ister.	Fire-clay.	Silica Brick.	Fire-Brick.
Silica,	SiO_2	98·5	94·6	56·7	96·0	65·0
Alumina,	Al_2O_3	1·0	1·5	30·0	1·0	31·0
Ferric oxide,	Fe_2O_3	...	1·0	1·5	1·0	2·0
Ferrous oxide,	FeO					
Lime,	CaO	0·5	0·6	1·0	1·7	1·0
Magnesia,	MgO		0·1	0·2	0·1	0·3
Alkalies— Potash and soda,	K_2O Na_2O	...	0·2	0·6	0·2	0·7
Water,	...	...	2·0	10·0	...	...
		100·0	100·0	100·0	100·0	100·0

Basic Refractory Materials have been referred to at some length in Chapters ix. and xii., and a table of analyses appears on p. 85.

Dolomite is not of a basic nature until its carbon dioxide* (CO_2) has been driven off by calcination. Some firms purchase calcined dolomite. This saves a considerable amount on railway carriage, but there is danger of deterioration by damp during transit. Dolomite bricks are usually made in steel works. Magnesia bricks are, as a rule, bought ready made.

Magnesia Bricks, which are very dense, are composed of burnt, ground magnesite, and may be bound with tar, strongly pressed, and kiln-fired. These are dark coloured. Other brands are bound with magnesic chloride, and have a ruddy colour, due to the presence of a little ferric oxide. These, when fractured, show a grain resembling firebrick. Some brands contain more than 90 per cent. of magnesia.

Neutral Refractory Materials include chrome iron ore, bauxite, and carbon.

Chrome Iron Ore†—the chief components of which are an oxide of chromium (Cr_2O_3) and ferrous oxide (FeO)—may be used in the form of lumps cemented in position with fine

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* Sometimes spoken of as carbonic acid. † See analysis on p. 245.

ore and tar. Bessemer converters thus lined last remarkably well.

Chrome Bricks are made of crushed chrome iron ore mixed with tar, pressed, and kiln-fired. They are black or of a deep purple colour, and show a moderately rough fracture when broken (see analysis on p. 245).

Bauxite Bricks are made of crushed bauxite, and have clay for a binding material. In colour they are yellowish-brown. They are moderately dense and externally firm. Their fracture may perhaps be described as resembling oatmeal of medium fineness. The fractured parts may be worn away by rubbing with the finger tips (see analysis on p. 245).

Carbon is a strictly neutral substance. It withstands a high temperature if oxygen has not access to it. Where the conditions inside a furnace are non-oxidising, carbon does not burn.

During the working of an iron-smelting blast furnace, a "carbonaceous concrete" is formed in the bosh. It is this concrete which protects the brickwork from the fluxing action of the slag. According to the late Sir I. Lowthian Bell, "the solvent power of the slag over the brick was almost as much as the solvent power of water over sugar."* The carbonaceous concrete has been found to be several inches thick, and to contain about 46·6 per cent. of carbon. Bricks of similar composition have been used for blast-furnace boshes. In percentage of carbon the blast-furnace "concrete" does not differ much from ordinary graphite crucibles.

Plumbago or **graphite** is used in the manufacture of crucibles and for facing moulds for iron and steel castings. In composition plumbago varies over a wide range. The following figures may be accepted as representing fair average quality:—

Fixed carbon, . . .	77	per cent.
Volatile matters, . . .	3	"
Ash, ...	20	"
	100	

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* *Iron and Steel Institute Journal*, 1887, ii., 117.

DEOXIDISING AND RECARBURISING MATERIALS. — The following notes are added to supplement the references to those in preceding chapters:—

Spiegel-eisen is a compound German word signifying "mirror-iron." It is highly crystalline, and, when fractured, displays large brilliant plates—hence the name. It is made in blast furnaces, and cast in pigs or in slabs. It may, with comparative ease, be broken into fragments (crystals) which are very hard and difficult to powder, and it is not easily melted. The trade practice is to charge it into the converter in the liquid state or into the furnace (not into the ladle) in a highly-heated condition.

As the percentage of manganese increases, there is a slight rise in the percentage of carbon. See analyses on p. 237.

Ferro-manganese.—The percentage of manganese is higher in ferro-manganese than in spiegel-eisen. It was originally made in crucibles; afterwards it was manufactured in a reverberatory furnace. Now it is regularly made in blast furnaces from ores containing much manganese, and a richer variety is manufactured in electric furnaces. Ferro-manganese is grey, finely granular, moderately hard, and is more friable (that is, more easily broken) than spiegel-eisen.

The percentage of carbon increases slightly as the manganese increases. See analyses on p. 237.

As stated in previous chapters, ferro-manganese is used for mild steels, and spiegel-eisen is added for medium (higher carbon) steels, because the quantity of ferro-manganese required to give to the steel a low percentage of carbon will do so without yielding more than the desired percentage of manganese. On the other hand, the amount of spiegel-eisen which would give to the steel the required percentage of manganese would yield a greater amount of carbon.

To make this more clear—

100 lbs. of 60 per cent. ferro-manganese would contain 60 lbs. of manganese and about 6¼ lbs of carbon.

400 lbs. of 15 per cent. spiegel-eisen would contain 60 lbs. of manganese and about 17¾ lbs. of carbon.

Spiegel-eisen usually contains from 15 to 25 per cent. of manganese, ferro-manganese contains over 40 per cent.

Silicon is useful for promoting soundness in steel castings and in steel ingots. It appears to have the power of increasing the solubility of carbon monoxide, thus lessening the tendency to cause blow-holes by keeping the gas in the occluded state until after the steel has solidified. The beneficial effects of silicon have been recognised in iron foundries since 1884. Certain pig irons containing silicon in noted amount (known as glazed pigs, blazed pigs, and silky pigs) are used as **softeners.** Good, sound iron castings may be made by the judicious mixing of proper quantities of softener with pig irons which are of themselves too white for foundry purposes. Pig iron very rich in silicon is now made in blast furnaces, and is called **ferro-silicon**: if also rich in manganese it is called **silico-spiegel.** Analyses are noted on p. 238.

Very rich silicon alloys are now made in electric furnaces.

Aluminium—a silver-white, soft, and remarkably light metal, which is prepared in a fair state of purity in electric furnaces—possesses marvellous powers for inducing soundness in ingots. Its presence even in small amount lessens segregation—a fact pointed out by Pourcel some years ago, and amply confirmed by Benjamin Talbot.

An alloy containing the three valuable components—silicon, aluminium, and manganese—is made by Messrs. Blackwell, of Liverpool.

APPENDIX.

ANALYSES OF FINISHING MATERIALS, SOFTENERS, ORES, &c.

Spiegel-eisen.

Constituents.	Chemical Symbols.	*	
Combined carbon,	C	4·27	4·76
Manganese,	Mn	8·11	19·67
Silicon,	Si	0·11	·83
Phosphorus,	P	0·08	·08
Sulphur,	S	...	·01
Iron,	Fe	87·40	Δ
		99·97	100·00

Ferro-Manganese.

Constituents.	Chemical Symbols.	*		*	
Combined carbon,‡	C	5·63	5·90	6·17	6·38
Manganese,	Mn	41·82	60·58	71·32	81·35
Silicon,	Si	0·42	0·93	1·12	0·88
Sulphur,	S	...	0·007	...	Trace.
Phosphorus,	P	0·10	0·19	0·162	0·23
Copper,	Cu	...	...	0·33	...
Iron,	Fe	51·90	Δ	20·65	Δ
		99·87	100·000	99·752	100·00

* Analyses by Mr. T. E. Holgate.

Δ By difference.

‡ Including, in some instances, a little finely-divided graphite. Mr. T. W. Hogg, Newburn, found beautiful crystals of nitro-cyanide of copper in the residue undissolved in acid. These are also found in bear, which is an accumulation of iron, &c., in the lowest part of a blast furnace.

FERRO-SILICON.*

Constituents.	Chemical Symbols.					
Graphitic carbon,	C	2·40	1·70	1·20	0·62	0·55
Combined carbon,	C	0·14	0·11	0·23	0·35	0·11
Total carbon,	C	2·54	1·81	1·43	0·97	0·66
Manganese, .	Mn	3·25	2·16	1·95	2·29	1·07
Silicon, .	Si	8·54	10·18	14·00	16·13	17·80
Sulphur, .	S	0·064	0·055	0·078	0·050	0·041
Phosphorus, .	P	0·047	0·104	0·076	0·090	0·115
Iron, . .	Fe	Δ	Δ	Δ	Δ	Δ
		100·000	100·000	100·000	100·000	100·000

SILICON-SPIEGEL.

Constituents.	Chemical Symbols.				
Graphitic carbon, .	C	0·33	0·67	1·13	0·90
Combined ,, .	C	1·85	0·98	0·29	0·30
Total ,, .	C	2·18	1·65	1·42	1·20
Manganese, . .	Mn	19·64	19·74	22·98	24·36
Silicon, . . .	Si	10·74	12·60	14·19	15·94
Phosphorus, . .	P	0·074	0·080	0·095	0·085
Iron, . . .	Fe	67·56	66·10	61·60	58·30
		100·194	100·17	100·285	99·885

The above analyses are by Mr. T. E. Holgate, Darwen. Absence of sulphur may be noted. The author of this book did not find more than traces of that element in any of the many samples he examined. He found consignments from various makers to average over 0·2 per cent. of phosphorus. although samples with 0·08 per cent. of phosphorus were not wanting.

* Analyses by Mr. T. E. Holgate.
Δ Iron by difference—not stated in Mr. Holgate's analyses.

TABLE SHOWING STEADY INCREASE OR DECREASE OF ELEMENTS IN THE VARIOUS GRADES OF PIG IRON.

The following figures show the composition of the grades of the well-known "Glengarnock" brand of Scotch pig iron. The table is constructed from the diagram prepared from analyses made to illustrate a paper by Mr. W. H. Pretty for the Manchester Association of Engineers, 1904:—

Constituents.	Chemical Symbols.	No. 1.	No. 2.	No. 3. Soft.	No. 3. Hard.	No. 4.	For Engine Cylinders, &c.	For Engine Cylinders, &c.
Graphitic carbon, .	C	3·5	3·35	3·20	3·10	3·0	2·90	2·8
Combined ,, .	C	·15	·20	·25	·30	·35	·40	·45
Total ,, .	C	3·65	3·55	3·45	3·40	3·35	3·30	3·25
Silicon, . . .	Si	3·50	3·25	2·90	2·50	2·10	1·60	1·10
Phosphorus,* . .	P	0·60	0·62	0·64	0·65	0·66	0·68	0·70
Sulphur, . . .	S	0·025	0·03	0·033	0·035	0·04	0·045	0·050
Manganese, . .	Mn	1·0	0·98	0·96	0·95	0·93	0·91	0·90
Iron, ...	Fe	Δ	Δ	Δ	Δ	Δ	Δ	Δ
		100·000	100·00	100·000	100·000	100·00	100·000	100·000

* It is unusual for phosphorus to show so marked an increase in the lower grades. Δ By difference.

Typical Analyses of Pig Irons.*

	Grade.	Graphitic Carbon.	Combined Carbon.	Silicon.	Phosphorus.	Sulphur.	Manganese.	Iron.
Cumberland hematite,	No. 3	3·51	0·17	2·49	0·035	·040	0·14	By difference.
East Coast ,,	,, 3	3·32	0·47	2·33	0·050	·057	0·87	
Cleveland, . . .	,, 3	3·00	0·17	2·75	1·54	·050	0·50	
West Yorkshire, .	,, 3	3·10	0·35	3·00	0·97	·063	0·95	
Lincolnshire, . .	,, 3	2·76	0·75	2·14	1·27	·036	1·80	
Derbyshire, . .	,, 3	2·97	0·35	2·47	1·40	·035	0·80	
Northamptonshire, .	,, 3	3·04	0·08	2·75	1·69	·020	0·29	
Nottinghamshire, .	,, 3	3·20	0·15	2·70	1·10	·040	0·40	
Lancashire, . .	,, 3	3·25	0·18	3·03	0·67	·051	0·71	
North Staffordshire, .	,, 3	2·90	0·47	2·50	1·25	·035	2·05	
Ayrshire, . . .	,, 3	3·01	0·47	2·33	0·56	·027	0·89	
,, . . .	,, 3	2·57	0·43	2·63	1·15	·033	1·49	
Lanarkshire, . .	,, 3	3·10	0·19	3·15	0·81	·014	1·50	
Stirlingshire, . .	Close No. 3	2·72	0·68	1·56	0·61	·101	1·08	
South Staffordshire, .	Cold blast	2·50	0·55	1·05	0·48	·101	0·55	
North Yorkshire, .	,,	2·52	0·63	0·98	0·10	·046	0·48	
Monmouthshire, . .	,,	2·60	0·66	0·93	0·35	·092	0·56	

* From Paper by Peter Munnoch, Middlesbrough; Cleveland Institution of Engineers, February, 1905.

COMPOSITION OF SCOTCH PIG IRON.

Constituents.	Chemical Symbols.	No. 1.	No. 3.	No. 3. Hard.	Forge.
Graphitic carbon, .	C	3·46	3·14	2·93	2·66
Combined ,, .	C	0·25	0·38	0·47	·55
Total ,, .	C	3·71	3·52	3·40	3·21
Silicon, . . .	Si	3·39	2·43	1·64	1·39
Phosphorus, . .	P	0·91	0·91	0·92	1·27
Sulphur, . . .	S	0·03	0·03	0·04	0·06
Manganese, . .	Mn	1·78	1·62	1·49	1·28
Iron, ...	Fe	Δ	Δ	Δ	Δ
		100·00	100·00	100·00	100·00

CLEVELAND PIG IRON (MUNNOCH).*

Grade	Graphitic Carbon.	Combined Carbon.	Silicon.	Phosphorus.	Sulphur.	Manganese.	Iron.
No. 1, . .	3·30	0·10	3·50	1·60	·02	0·65	By difference.
,, 2, . .	3·20	0·15	3·30	1·57	·03	0·65	
,, 3, . .	3·00	0·30	2·75	1·57	·05	0·60	
,, 4 Foundry, .	2·85	0·40	2·25	1·55	·08	0·55	
,, 4 Forge, .	2·50	0·70	1·75	1·57	·13	0·50	
Mottled, . .	1·77	1·30	1·10	1·58	·25	0·30	
White, . .	Nil.	3·05	0·75	1·60	·45	0·20	

Δ By difference.

* Table of ideal analyses, Cleveland Institution of Engineers, February 1905.

ANALYSES OF ORES.

Constituents.	Chemical Formulæ.	Staffordshire Pottery Mine.	Staffordshire Pottery Mine. Calcined.	Frodingham Iron Ore.	Mid Lincolnshire Iron Ore.
Ferrous oxide, . .	FeO	42·18	6·43	...	...
Ferric ,, . .	Fe_2O_3	6·29	80·88	44·66	60·91
Oxide of manganese, .	MnO	2·93	1·85*	2·32	traces
Silica, . . .	SiO_2	1·50	3·00	7·38	13·24
Alumina, . . .	Al_2O_3	0·22	0·16	5·95	8·03
Lime, . . .	CaO	4·20	4·10	18·27	1·60
Magnesia, . . .	MgO	1·80	1·30	3·51	0·06
Phosphoric acid, .	P_2O_5	0·70	1·15	0·68	1·02
Sulphuric ,, .	SO_3	1·02	1·15	0·06	0·03
Bituminous matter, .	...	39·29		...	...
Combined water, .	H_2O		...	13·29	15·35
Carbon dioxide, . .	CO_2			3·82	
Loss on ignition, .	...	...	0·31	...	...
		100·13	100·33	99·94	100·24
Metallic iron, . .	Fe	37·20	61·60	31·26	42·64

* Oxidised to Mn_3O_4.

ANALYSES OF BILBAO ORES—ORCONERA IRON ORE COMPANY.*

Constituents.	Chemical Formulæ.	Vena.	Campanil.	Rubio.	Spathic Ore.		
					Grey.	White.	Calcined.
Ferrous oxide,	FeO	...	...	...	55·844	56·344	2·402
Ferric oxide,	Fe_2O_3	79·96	78·03	78·29	1·000	3·357	87·142
Alumina,	Al_2O_3	1·44	0·21	1·15	0·180	0·090	0·100
Manganous oxide,	Mn_2O_3	0·70	0·86	0·74	1·850	2·100	2·000
Lime,	CaO	1·00	3·61	0·50	2·250	1·800	2·650
Magnesia,	MgO	0·55	1·65	0·02	0·160	0·250	0·105
Silica,	SiO_2	8·10	5·91	8·80	4·500	1·200	4·700
Sulphuric acid,	SO_3	0·10	0·01	0·05	1·715	1·200	0·686
Sulphur,	S	0·05	Trace	0·04	...	...	...
Phosphoric acid,	P_2O_5	0·03	0·03	0·02	0·017	0·025	0·016
Carbonic acid,	CO_2	...	5·00	...	32·500	33·640	0·200
Combined water,	H_2O	8·25	4·60	10·55	...	...	...
Total,		100·18	99·91	100·16	100·016	100·006	100·001
Metallic iron,	Fe	55·97	54·62	54·80	43·70	45·73	62·85

NOTE.—The sulphur in samples of Vena and Rubio is higher than usual. The metallic iron in samples of calcined spathic ore is rather favourable, the average of seven cargoes shipped this year being 59·58 per cent.

* *Iron and Steel Institute Journal*, ii., 1886, p. 94.

IRON ORES MINED NEAR THE MEDITERRANEAN SEABOARD.

Constituents.	Chemical Formulæ.	Cartagena Ore.	Garrucha Ore.	Elba Ore.
Ferric oxide, . .	Fe_2O_3	72·05	79·46	81·14
Ferrous oxide, . .	FeO	Nil	...	2·64
Manganese oxide, .	Mn_3O_4	2·96	2·40	0·20
Silica, ...	SiO_2	4·30	7·25	3·58
Alumina, . . .	Al_2O_3	0·80	0·27	2·85
Lime, ...	CaO	7·28	2·34	0·10
Magnesia, . . .	MgO	1·30	0·54	0·10
Phosphoric acid, . .	P_2O_5	0·03	0·04	0·04
Sulphuric oxide, . .	SO_3	0·03	0·28	0·13
Carbon dioxide, . .	CO_2	7·10	7·04	...
Combined water, .	H_2O	4·00		6·97
Moisture, . . .	H_2O	...	...	1·95
		99·85	99·62	99·70
Iron in dried ore, .	...	50·75	55·62	59·95
,, ore as received,	...	47·87	49·62	58·85
Phosphorus in ore, .	...	0·013	0·017	0·017

COMPOSITION OF BRICKS.

The following are analyses of good quality bricks as supplied to steel works by British firms :—

Constituents.	Chemical Formulæ.	Magnesite Bricks.*		
Magnesia,	MgO	94·24	91·32	91·50
Lime,	CaO	0·64	1·40	2·10
Silica,	SiO_2	3·20	5·30	0·35
Alumina, Ferric oxide,	Al_2O_3 Fe_2O_3	1·74	1·80	6·05
Alkalies—potash and soda,	K_2O Na_2O	0·18	0·18	not estimated.
		100·00	100·00	100·00

Constituents.	Chemical Formulæ.	Bauxite Brick.		Chrome Brick.*
Silica,	SiO_2	3·50	35·80	5·20
Titanic oxide,	TiO_2	3·08	3·70	0·50
Alumina,	Al_2O_3	51·40	55·80	13·90
Chromic oxide,	Cr_2O_3	...	...	53·66
Ferric oxide,	Fe_2O_3	38·37	3·40	16·20
Ferrous oxide,	FeO	...		
Lime,	CaO	2·46	0·90	0·78
Magnesia,	MgO	0·79	Sundries	9·22
Alkalies—potash or soda,	K_2O Na_2O	0·40	not estimated.	0·54
		100·00	100·00	100·00

CHROME IRON ORE.—COMPOSITION OF AVERAGE SAMPLE.

Constituents.	Chemical Formulæ.	
Silica, Titanic oxide,	SiO_2 TiO_2	2·00
Alumina,	Al_2O_3	19·25
Chromic oxide,	Cr_2O_3	41·67
Ferrous oxide,	FeO	14·70
Lime,	CaO	3·75
Magnesia,	MgO	17·66
Loss on ignition—combined water, &c.,	...	0·97
		100·00

*** Tarry matter (about 5 per cent.) for binding was burnt off before making analyses.**

ANALYSES OF GASES.

PRODUCER GAS.

Constituents.	Chemical Formulæ.	Scotch Steel Work.*	American Steel Work.	
Reducing gases—				
Carbon monoxide, . .	CO	25·7	16·5	22·3
Hydrogen, . . .	H_2	11·8	8·6	28·7
Methane or marsh gas, .	CH_4	2·3	2·7	1·0
Total combustible gases,		39·8	27·8	52·0
Inert or neutral gases—				
Carbon dioxide, . .	CO_2	6·3	9·3	6·1
Nitrogen, ...	N_2	53·9	62·9	41·9
		100·0	100·0	100·0

WATER GAS AND NATURAL GAS.

Constituents.	Chemical Formulæ.	Water Gas.	Natural Gas.
		Approximate Average.	Approximate Average.
Reducing gases—			
Hydrogen, . . .	H_2	49·00	22·00
Carbon monoxide, . .	CO	44·00	0·60
Methane or marsh gas, .	CH_4	0·50	67·00
Ethylene or olefiant gas, .	C_2H_4	...	1·00
Ethane or ethyl hydride, .	C_2H_6	...	5·00
Total combustible gases,		93·50	95·60
Other gases—			
Carbon dioxide, . .	CO_2	3·25	0·60
Nitrogen, ...	N_2	3·25	3·00
Oxygen, ...	O_2	...	0·80
		100·00	100·00

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* Steam-urged producer, fed with bituminous coal slack.

AMERICAN IRON ORES.

The American continent is rich in iron ores, and in the fuels, fluxes, and refractory materials necessary for extracting iron and for carrying on the manufacture of iron and steel.

The richness of their virgin fields, the enterprise of the inhabitants, and the rapid development in many directions of this great continent have contributed to the enormous expansion of the iron and steel trades.

Analyses of some of the chief iron ores are noted on this and the following pages. On this page the figures were obtained from dried samples, those on pages 248 and 249 show the composition of natural (undried) samples.

IRON ORES (DRIED), LAKE SUPERIOR DISTRICT.

	Gogebic Range.	Marquette Range.	Menominee Range.	Mesaba Range.	Vermilion Range.
Iron, maximum, .	64·15	66·53	60·28	63·56	65·00
,, minimum, .	48·16	39·78	37·60	52·00	59·20
Phosphorus, maximum,	0·128	0·415	1·28	0·11	0·166
,, minimum,	0·018	0·012	0·012	0·023	0·038
Manganese, maximum,	6·95	4·70	4·60	3·00	0·25
Silica, maximum, .	23·80	40·60	41·53	15·97	9·28
,, minimum, .	2·57	2·76	4·33	2·80	4·77

SOME AMERICAN ORES.

	Gogebic Range, Lake Superior.		Marquette Range, Lake Superior.			Menominee Range, Lake Superior.	
Iron,	57·79	49·10	57·66	40·08	52·03	55·37	50·91
Phosphorus,	0·038	0·061	0·012	0·052	0·169	0·012	0·616
Manganese,	0·32	6·13	0·09	0·029	0·41	0·01	0·74
Silica,	3·27	3·93	5·69	34·75	6·59	8·68	5·44
Alumina,	0·70	1·06	1·60	1·23	0·82	1·72	2·50
Lime,	0·10	0·11	0·16	0·36	1·38	0·50	2·20
Magnesia,	0·12	0·08	0·12	0·05	0·53	1·21	1·45
Sulphur,	0·017	0·005	0·006	0·005	0·011	0·033	0·112
Water,	9·76	9·82	9·30	4·00	14·00	8·14	8·58
Other Volatile Matter,	3·14	6·10	0·95	1·44	1·03	...	4·57

SOME AMERICAN ORES.—*Continued.*

	Mesaba Range, Lake Superior.		Vermilion Range, Lake Superior.		Cornwall Bank, Penn.	Clinton Ore.	Newfoundland Ore.
Iron, ...	56·65	46·23	55·94	57·65	57·05	47·50	51·62
Phosphorus, ...	0·026	0·053	0·036	0·063	0·007	0·52	0·99
Manganese, ...	0·43	0·66	0·10	0·06	0·064	0·10	0·36
Silica, ...	2·54	5·74	8·15	8·77	8·65	11·20	7·14
Alumina, ...	0·13	2·23	3·84	1·66	1·30	4·89	3·21
Lime, ...	1·66	0·09	0·29	0·26	2·74	5·53	4·21
Magnesia, ...	1·49	0·19	0·30	0·18	3·94	...	1·44
Sulphur, ...	...	0·012	0·006	0·01	2·83	0·18	0·018
Water, ...	9·44	17·00	5·50	5·50	...	...	...
Other Volatile Matter, . .	3·14	7·58	1·79	1·03	...	...	...

Cornwall Bank Ore contains 0·75 per cent. of Copper.

American Ore Supplies.—As already mentioned, the American continent is rich in iron ores. The extensive deposits in the Lake Superior regions contain a high percentage of iron. The ores are, in many places, easily quarried. Much ingenuity has been displayed in contriving plant for digging and handling the ores. The chief ore fields are far from the fuel deposits. The means employed for transporting the ores are ingenious and enterprising. Steam shovels dig out the ore; buckets mounted on endless bands carry the ores to vessels or to railway trucks; capacious steamers which can take in cargoes of 12,000 tons are quickly loaded, and convey the ore over the great North American Lakes, where discharging is conducted with the utmost despatch, the largest vessels being emptied in the course of five or six hours.

It is not unusual to transport the ore a distance of 700 or 800 miles. At Gary, on the southern shore of Lake Michigan, immense iron and steel works have been laid out. The ore for these works is taken direct from the lake steamers to the storage bins or heaps. For works in and around Pittsburg and other towns it is necessary to convey the ore a considerable distance by train. The trucks are lifted bodily and the contents are tipped into large bins. As the great lakes are frozen during the winter months, enormous heaps of ore must be accumulated during the "open" season to keep the furnaces going.

To face p. 251.

BLAST FURNACE HOIST.

Constructed by the Lilleshall Co., Ltd., at the Works of Messrs. John Lysaght, Ltd., Scunthorpe.

Modern Hoisting Machinery.—A modern, well-equipped American blast furnace working on rich ore requires, on an average, about one ton of solid material at the top every minute. Electrically-driven hoisting machinery has been set up for dealing with this quantity.

On the opposite page is an illustration of a modern hoisting plant by the Lilleshall Company, Limited, Engineers, Oakengates, Shropshire.

The following abridged description of the plant is taken from *The Iron and Coal Trades Review:*—The solids—ore, fuel, and flux—are conveniently tipped from railway trucks into storage bunkers. From the bunkers the solids are dropped into special buckets carried on transporter cars. Each bucket has a capacity of 6½ cubic yards, and can be closed by a gas-tight lid. Through the centre of each there passes a strong shackle extending upwards from the cone, the lower part of which closes the bottom opening of the hopper. Each hopper rests on a turntable on the transporter car. The turntables are revolved by an electric motor during filling, thus securing uniformity of loading at the storage bunkers. Each turntable is mounted on a separate weighing machine which has three steelyards—for ore, fuel, and limestone weighings—and each steelyard is provided with a poise which can be locked at any desired position. The weighing apparatus is also furnished with an automatic weight-recorder which prints the variations from the required load. Fig. 97 shows the transporter car—which is driven by a 22 horse-power motor—for conveying the buckets from the storage bunkers to the foot of the blast furnace incline. The incline supports a travelling trolly which is moved by means of a winding

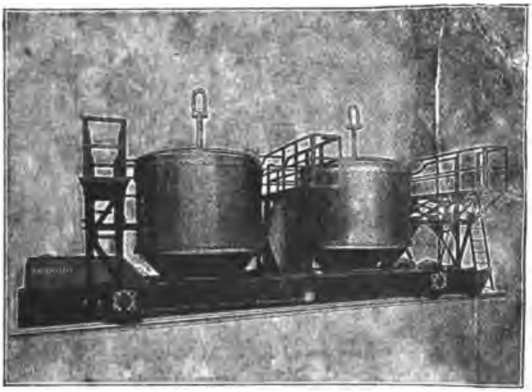


Fig. 97.—Demag Transport Car with two Charging Buckets.

engine. To convey the weighed charge to the furnace top the shackle of a loaded bucket is connected to the travelling trolly, the winding engine is set in motion, and the bucket, with its contents, is lifted from the transporter car and taken evenly up the track until it arrives at the curved part of the upper rail. The bucket is then brought to rest on the seat at the furnace mouth. A gas-tight joint is made by means of an asbestos rope which is carried in a groove in the seat. Fig. 98 shows the hopper at the top, and the illustration on the opposite page shows a view of the plant. The bucket cover is then lowered and the internal cone at the bottom of the bucket is set free, while at the same time the bell of the furnace is automatically lowered. The material drops into the furnace with, it may be mentioned, the minimum breakage of coke, and the charge is evenly distributed in the furnace. As the top of the hopper is closed the quantity of gas escaping is negligible.

Fig. 98.—Charging Bucket being placed in position at top of Blast Furnace.

When the contents of the bucket have been discharged the bucket is lifted off the furnace. Simultaneously the cover is lifted, so that all gas is cleared from the bucket during its descent. The empty bucket is placed on the transporter car, the next bucket is carried upwards and its contents are charged into the blast furnace.

To face p. 253.

Babcock & Wilcox Electric Overhead Crane with pig iron "comb."

Installed at Messrs. Gjers Mills & Co., Ltd., Ayresome Ironworks, Middlesbrough.

Handling Pig Iron at Blast Furnaces.—As previously stated, the pig iron as it flows from the blast furnace may be run into moulds previously prepared in the sand beds in front of the furnace. After the pig iron has solidified it may be lifted by hand and carried to trucks. This, however, involves hard labour and is costly.

For more quickly dealing with the pig iron produced, **pig-lifting and pig-breaking plant** is employed. When the pig iron has solidified, each sow is broken off from the runner, and a sow with all its pigs attached—a lot known as a "comb"—is taken by an overhead crane to the pig-breaking machine.

The illustration on the opposite page shows a "comb" suspended from the electric **overhead crane** at the Ayresome Works, near Middlesbrough. This handy crane was erected by Messrs. Babcock & Wilcox, Limited, and has a span of 110 feet. It can carry a load of 5 tons at the rate of 400 feet per minute.

By means of a pig-breaking machine—which consists essentially of a block and rams, the latter worked by hydraulic pressure—each pig in turn is held down and broken into two pieces, and the sow and runner are also broken into pieces of suitable size. All the pieces slide down a shoot into trucks which are placed in position to receive them.

For another method, the pig iron as it is tapped from the blast furnace is collected in casting ladles and conveyed to a **pig-casting machine.** Such machines consist of long endless metal chains which carry a continuous series of iron moulds fixed across the chains. As the chains travel, the moulds are brought in succession under the spout of the ladle and charged with fluid pig iron. The molten metal is quickly cooled by water which is sprayed during the continuance of the travel. By the time a filled mould has reached the sprocket the pig iron, in the form of cakes about 21 inches long, 10 inches broad, and only ¾ inch thick, has become solid enough to be fit for dropping. Each mould is inverted as it rounds the sprocket, and as a consequence the solidified pig-iron cakes drop into a trough of water, from which it is delivered by an endless belt into trucks. While the moulds are still inverted and returning to the pouring or filling point, they are sprayed with lime-water. The heat of the moulds drives off the water, and a protecting coating of lime is left on the moulds, which are then ready to receive another lot of pig iron from the ladle.

In some instances the pig iron is tapped from the blast furnace into a ladle and taken direct to a converter or to a basic open-hearth furnace. But, as the composition of the pig iron in a blast furnace is subject to variation, which, of course, leads to irregularities in subsequent working, this system has been abandoned in several works and mixers have been installed.

Mixers are receptacles in which pig iron is stored. They have usually a capacity of about 300 tons, but much larger mixers are not uncommon. All the pig iron from the blast furnaces in a work may be poured into the mixer, and quantities are withdrawn from time to time as required. A mixer is a convenient storing receptacle; in it the composition of the pig iron tends to become averaged, thereby leading to more steady working of steel-making processes. Modern mixers resemble tilting open-hearth furnaces in design. Some mixers have gas producers and regenerators, and in these a considerable amount of refining is sometimes effected.

Wellman Rolling Furnace, with Electrical Tilting Gear.

Installed at the Works of Messrs. Le Gallais, Metz & Cie., Dommeldingen, Luxembourg.

Movable Furnaces.—In the **Wellman** Rolling Furnace, the body, which is roughly rectangular in section, is enclosed in a strong cage constructed of steel plates, channels, and angle bars, with stout tie-rods. The walls and roof are of silica bricks and a suitable lining is put in. The furnace is mounted on strong steel ribs supported on heavy blocks.

Rolling is effected by means of hydraulic rams, the cylinders of which are mounted on trunnions at their lower ends. The upper ends of the piston-rods are attached to the body of the furnace. To move the furnace water is admitted to the top part of the cylinder. In case of accidental failure of the hydraulic system the furnace returns to its normal position, or in the event of any hitch or accident occurring during tapping the pouring can be instantly stopped.

Slag can be poured off at any time during the working of a charge, and every particle of metal and slag can be removed after each charge. A movable furnace can be easily brought into position to facilitate repairs.

As the taphole is kept above the level of the charge during working, it does not require to be "made up" to resist the pressure of the molten charge, but is only loosely covered to exclude air. It is, therefore, easily opened as soon as the metal is in correct condition for tapping. This is particularly advantageous when making special steels.

Some furnaces are provided with electric (instead of hydraulic) tilting gear. A photograph of such a furnace is reproduced on the opposite page. It is a view of a Wellman rolling furnace built at Dommeldingen, Luxembourg, by Messrs. Wellman, Seaver & Head, Limited, and shows the furnace in its ordinary working position with the taphole above the level of the charge. The electric motor is also shown, as well as the gearing for working the rack and pinion. These latter are enclosed in metal casing.

The regenerative chambers are not placed under the furnace as in the Siemens design, but are arranged side by side in pairs at each end of the furnace. The ports are mounted on flanged wheels and can be moved away from the furnace ends to allow the furnace to be tilted. This is clearly shown in the illustration on the opposite page, and in the frontispiece. When pouring is finished the ports are again moved towards the furnace ends. Movable ports permit ready access for repairs.

The success of movable furnaces paved the way for the introduction of modified steel-smelting processes, such as the Talbot and the Bertrand-Thiel.

Charging Machines.—Open-hearth furnaces have been increased so much in capacity that charging machines have become an imperative necessity for dealing with the heavy tonnage of pig iron and scrap to be charged.

The materials to be charged are placed in long narrow charging boxes, each capable of containing about one or two tons, or even more. Charging boxes are made of steel plates, one end consisting of a steel casting having a slide and an opening to which an attachment may be made. These are shown on the right lower part of the illustration on the opposite page.

The charged boxes are brought within the range of the arm of the machine. The arm is thrust forward, and by mechanical movements is locked to one of the full boxes. This is borne to an opened door of the furnace, is pushed in, and, by a rotary motion of the arm, is turned over. By these movements the materials in the box are dropped in the furnace. The box is then withdrawn, turned into its former position, and deposited on the trolly from which it was taken. Other charged boxes are similarly dealt with, so that a furnace is quickly charged.

The illustration on the page opposite shows an overhead charging machine installed by Messrs. Wellman, Seaver & Head, in the Parkhead Works, Glasgow.

Charging by hand is hot, exhausting work, and occupies much more time than machine charging.

A 50-ton charge, which would take four men four or five hours to repair and charge, may be charged in one hour by a charging machine.

Quick charging by a machine, leads to larger output in a given time, and materially reduces costs for fuel.

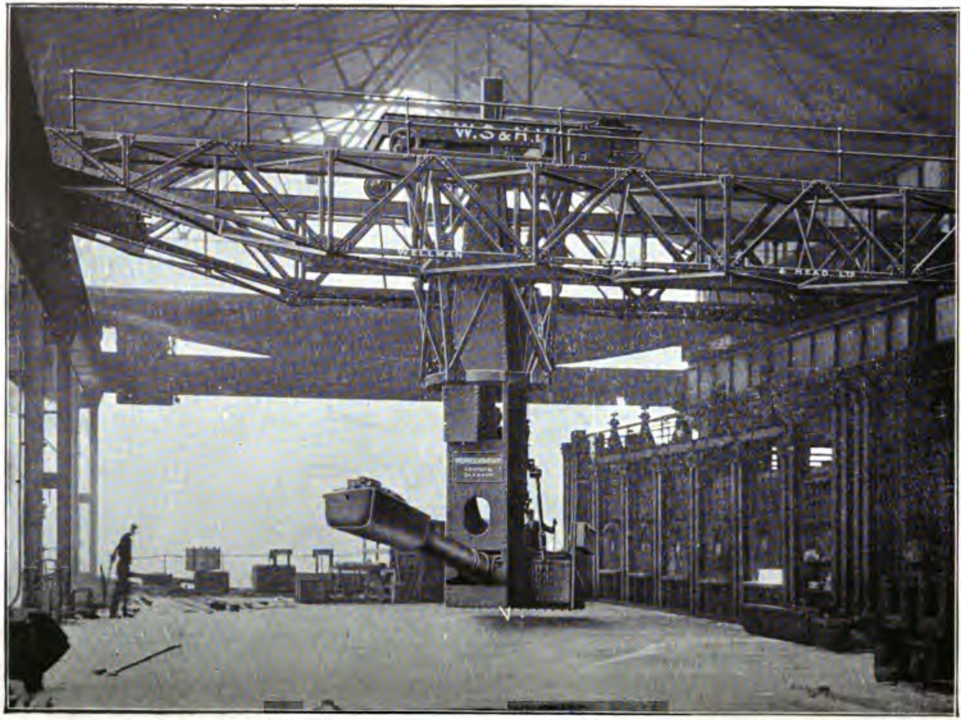
Originally, charging machines were worked by hydraulic power, they are now actuated by electricity. Formerly they were set on broad gauge rails laid parallel with the range of furnaces, and the boxes were brought on a narrow gauge railway directly in front of the furnaces. But many modern machines are worked on the overhead system, and as the arm can be rotated to any degree, the trolly rails may be run in any direction near the furnaces. Large and heavy pieces of metal are placed on a fork or strong peel, and can then be charged by a machine.

In the illustration facing the next page a Wellman overhead charging machine is shown in the act of conveying a box.

Wellman Open Hearth Charging Machine.

Installed at the Works of Messrs. Beardmore & Co., Ltd., Glasgow.

[To face p. 257.



Wellman Open Hearth Charging Machine.

Installed at the Works of Messrs. Wm. Beardmore & Co., Ltd., Glasgow.

The applications of electricity to the various branches of iron and steel manufacture are of great importance. Among such applications mention may be made of the following :—

I. Separation of magnetic (iron-containing) portions of finely-crushed ore from non-magnetic portions of the ore. Some ores which are too poor in content of iron may be successfully treated and the richer portion profitably made into briquettes and smelted.

II. Lifting of iron and steel goods, such as pig iron, plates, rivets, etc. This is, in many instances, more convenient than attaching by hooks, etc.

III. Driving of rolling mills and other kinds of machinery, such as cranes. Electric power is cheaply generated from blast-furnace gas, and is used for driving blowing engines, mills, etc.

IV. Smelting iron ores. Only in exceptional circumstances—as, for instance, where ores are cheap or of superior quality and suitable water power is abundant—can electric smelting be economically carried on.

V. Producing special alloys, free from or containing only traces of carbon, producing high-grade ferro-silicon, etc.

VI. Refining iron and steel.

Owing to want of space the first five sections cannot be dealt with in this volume, and the sixth can only be treated in outline.

Electric refining furnaces are of two classes—

(*a*) **Arc furnaces,** including the Girod, Heroult, Keller, Nathusius, and Stassano furnaces. In these the high temperature is derived from the electric arc between the electrodes, the heat from which is largely reflected or reverberated from the furnace roof.

(*b*) **Induction furnaces,** including the Grondal-Kjellin, Frick, and Rochling-Rodenhauser furnaces. In these the high temperature is induced by the resistance to the current while passing through the metals in the furnaces.

For refining purposes the advantages of an electric furnace over an ordinary fuel-fired furnace arises from the rapidity with which a high temperature can be attained and the ease and constancy with which it can be kept up. No deleterious element (such as sulphur) is introduced by the heating agent, and no gases (which are liable to be occluded) are introduced during the refining. Thus a pure metal, almost free from occluded gases, can be produced. Overkilling is impossible.

There is another point in favour of electric furnaces: an intense **local** heat can be produced—thereby bringing about a rapid reaction between the metal and the slag which acts as the refining oxygen carrier—at points far from the walls and roof of the furnace.

In shape the **Grondal-Kjellin furnace** may be said to be like a grindstone laid flat. For convenience in working it is mounted for tilting, and has tapholes at different levels. It is constructed of highly-refractory bricks and has a working lining of magnesite. An annular space is grooved in the working lining, and into this the cold or the molten metal, as the case may be, is charged. In the centre of the furnace a primary coil is placed: the metal ring in the annular space constitutes the secondary coil. "An alternating electric current passing through this primary coil forms an induced current in the ring of metal contained in the hearth. As this ring forms a single circuit round the core, the current induced in it is approximately equal to the primary current multiplied by the number of turns in the winding of the coil. . . . A portion of the charge is left in the furnace after each tapping, and pig and scrap are added to this in proper proportion, so as to arrive at the desired carbon content. As soon as the metal is properly 'killed' the furnace is tilted and the contents tapped into a ladle. . . . The upper part of the furnace serves as a charging platform, and the necessary materials are easily charged by removing the brick covers."

The photograph reproduced on the opposite page shows a Grondal-Kjellin furnace at Messrs. Jessops' Steel Works, Brightside, Sheffield. This furnace is provided with its own generator set and control gear. It is capable of carrying a charge of 30 cwts., and the maximum current consumed is 250 kws.

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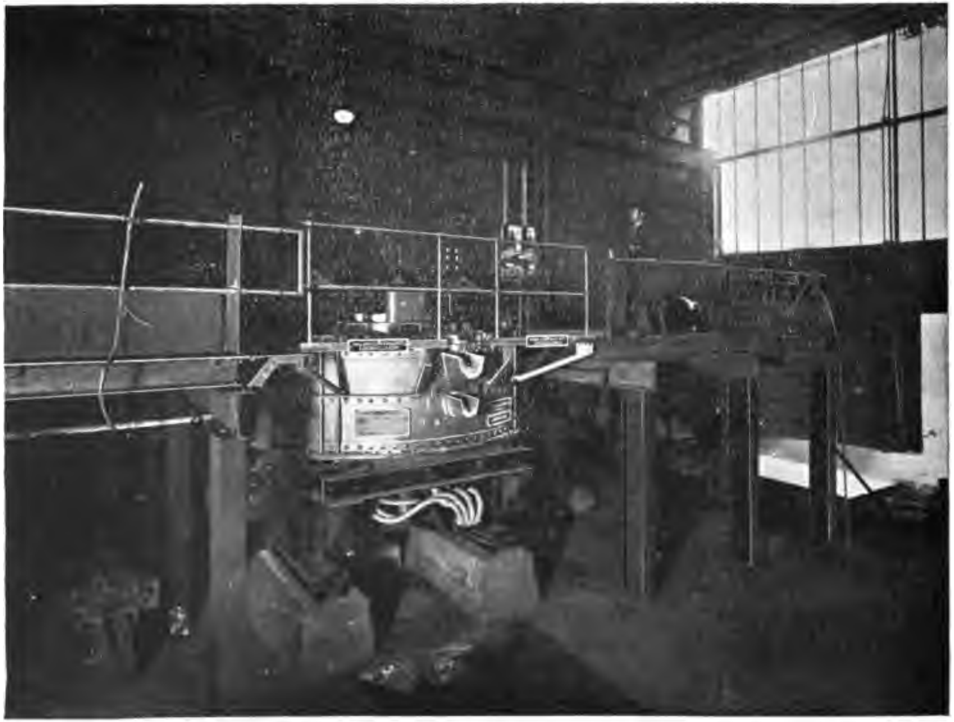

Wellman Electric Induction Furnace (Gröndal Kjellin Patents).

Installed at Messrs. Wm. Jessop's Brightside Works, Sheffield.

CITY AND GUILDS OF LONDON INSTITUTE.

SYLLABUS—IRON AND STEEL MANUFACTURE.

The Examinations will be held in three grades. Candidates will be permitted to present themselves for the Examination in Grade I. in a year previous or subsequent to that in which they present themselves for examination in Grade II., or to enter for both Grade I. and Grade II. in the same year. No Candidate will, however, receive a Certificate until he shall have passed the Examinations in both grades. The successes of Candidates in either grade will be notified to the Secretaries of the Centres at which they were examined.

Prizes will be awarded on the results of the Examination in Grade II. to those Candidates only who have passed Grade I. in a previous year, or who pass both parts in the same year.

Candidates for the Final Examination must hold a Certificate in Grade II.

In order to encourage Teachers to devote special attention to those processes of Iron and Steel Manufacture which may be most suitable for their respective districts, the Syllabus has been divided into two parts, and in the Examination a number of questions will be given so as to allow considerable choice in the selection. All Candidates will, however, be expected to afford evidence of a general knowledge of the subject as a whole, and in order to pass in the first class a Candidate will be expected to answer satisfactorily, questions both in Iron Manufacture and in Steel Manufacture. In the Final Examination, Candidates will be permitted to select their questions either from one section only or from both.

GRADE I.

Manufacture of Iron.

1. Composition and general characters of the chief ores of iron.
2. Construction and mode of working of blast furnaces.
3. Hot and cold blast; effects of these and of variations in amount of fuel and flux on the production and character of the iron made.
4. Physical characters of pig irons from various classes of ore. Grey, mottled, and white irons. Bessemer, mine, and cinder pigs. Numbering of irons.
5. Physical characters of charcoal, coal, and coke used for iron smelting.
6. Chemical and physical properties of iron used for foundry purposes.
7. Chemical and physical properties of forge pigs.
8. Refining, puddling, and the production of finished iron.

9. Chemical composition of fettling and of wrought iron.

10. A general knowledge of the construction of furnaces, hammers, and rolls required for the manufacture of wrought iron.

11. Manufacture of malleable iron castings from crucibles, cupolas, or the open-hearth furnace. Practice and theory of ore annealing.

Manufacture of Steel.

12. Compositions and properties of the materials used for acid and basic linings for converters and steel furnaces.

13. Outline of the construction of cupolas, converters, and of the general arrangement of a Bessemer plant.

14. Outline of the construction of gas producers, melting furnaces and regenerators, and of the general arrangement of an open-hearth steel plant.

15. Ingot moulds, nozzles, and stoppers; making up the taphole, and repairing the bed of the open-hearth furnace between heats.

16. Outline of the reactions involved in the various processes.

17. A general idea of reheating furnaces, soaking pits, hammers, and rolls used for converting ingots into the various forms of steel required for the market.

18. General knowledge of the furnaces used for melting in crucibles by means of coke or gas.

19. Chemical and physical characteristics of coke suitable for steel melting.

20. Composition and physical characters of the various materials used for the manufacture of crucible steel—viz., Swedish, Walloon, and Lancashire hearth bars, unconverted and cemented, charcoal, Swedish white iron, the various classes of steel scrap, and ferro-manganese.

21. Hammering, rolling, and reeling of crucible steel.

22. Shear and double shear steel, composition and method of manufacture.

23. Testing steel in tension, with arithmetical calculations connected therewith.

GRADE II.

Manufacture of Iron.

1. Preparation of raw ores for smelting; changes in composition thereby produced.

2. Mechanical preparation of iron ores. Magnetic concentration.

3. Subsidiary appliances required in the construction and working of blast furnaces—*e.g.*, hoists, blast heating stoves, and apparatus for utilisation of surplus gases.

4. Mechanical charging appliances. Pig casting machines, pig breakers, and similar appliances.

5. Chemical nature of fluxes requisite under various conditions. Composition of slags.

6. Handling and utilisation of blast-furnace slags.

7. Chemical composition of charcoal, coal, and coke used for iron smelting. Composition of gases from the blast furnace.

8. Chemical and mechanical characteristics of pig irons from various classes of ore.

9. Iron-founding, including cupolas, moulds, ladles, and foundry appliances.

10. Machine moulding, core making, foundry sand and compositions.

11. Production of castings of special kinds—*e.g.*, large castings, fine castings, chilled castings, &c.

12. The theory of puddling. Machine puddling.

13. Mechanical properties of the various qualities of wrought iron. Composition and tests of wrought iron suitable for various purposes.

14. Direct production of wrought iron.

15. Composition of iron suitable for the production of malleable castings. Conditions under which carbon separates from white iron. Other changes during the annealing process.

Manufacture of Steel.

16. Theory of the acid Bessemer blow. Theory of the acid open-hearth process. Slags produced.

17. Theory of the basic Bessemer blow. Theory of the basic open-hearth process. Slags produced.

18. The functions of manganese, silicon, and aluminium. Influence of varying quantities of silicon and manganese on the temperature of the acid Bessemer blow.

19. Comparative advantages and disadvantages of blowing metal direct from the blast furnace, and re-melted in cupolas.

20. Chemical and physical characteristics of coke suitable for Bessemer cupolas and of coal for gas producers. Composition of producer gases.

21. Bessemer, open-hearth, and crucible steel castings. Nature and elimination of blowholes.

22. Low pressure surface blown modifications of the Bessemer process and their products.

23. Modified open-hearth processes conducted in tilting furnaces, &c.—*e.g.*, the Talbot process, the Bertrand-Thiel process, &c.

24. Methods of dealing with emergencies—*e.g.*, hot or cold heats or blows.

25. Manufacture and compositions of clay and plumbago crucibles. Annealing clay crucibles. Stands and covers. Sanding.

26. The cementation process. Bar numbers.

27. Impurities eliminated or introduced in crucible melting. Calculation of mixtures.

28. Causes leading to "runners" in crucibles—*e.g.*, inclusion of basic granules, frost-crack, &c.

29. Practice of hardening and tempering steel.

FINAL EXAMINATION.

Candidates for this Examination will be expected to answer questions dealing with subjects included in Grades I. and II., and may select their questions from one section only, or from both. The following additional subjects will also be included.

Manufacture of Iron.

1. Geographical and geological distribution of iron ores. Relation of composition to geological distribution.
2. Handling and transportation of iron ores and other materials employed.
3. Thermal calculations relative to the calorific value of fuel and of blast-furnace gases, and to the reactions of the blast furnace.
4. The testing of cast iron otherwise than by chemical analysis.
5. Theories of puddling. Calculations relative to the yield of pig iron of given composition.
6. The micro-structure of pure iron, of wrought iron, and of various kinds of cast iron.
7. The production of spiegel-eisen, ferro-manganese, ferro-chrome, and ferro-silicon, in the blast furnace. Properties of these alloys.
8. The applications of electricity in the production of iron and iron alloys.

Manufacture of Steel.

1. The relative position of the steel trade in the chief steel-making countries, and the reasons for the adoption of certain methods or processes in particular countries or districts.
2. The general arrangement of a steel works, and the appliances and methods used in handling, charging, rolling, pressing, hammering, or otherwise shaping large masses of steel.
3. Chemical and thermal calculations relative to the various steel processes, and to producer gas.
4. Liquation and segregation in ingots. Methods of producing sound and uniform metal.
5. Influence of heat treatment of steels of various kinds. Theory of hardening, tempering, and annealing.
6. Special materials used in steel manufacture, such as ferro-chrome. ferro-nickel, tungsten, &c. Properties of the special steels so produced,
7. Influence of carbon and other elements on the tenacity and ductility of the various qualities of steel. Composition necessary to fulfil given mechanical specifications.
8. Applications of electricity in the production of steel.

INDEX.

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