THE SIEMENS OPEN HEARTH STEEL FURNACE.

(A paper read before the Sydney University Engineering Society, July 11th, 1900.)

By Basil Turner, A.R.S.M., F.C.S.,

Lecturer in Metallurgy, University of Sydney.

THE two great rival steel making processes, Bessemer and Siemens which are responsible for the present age of steel are both of comparatively recent origin.

The former was made public by its inventor Sir Henry Bessemer at the Cheltenham meeting of the British Association for the advancement of science in the year 1856, while the first experiments on a working scale with the latter process were made at Sircul near Paris, nine years later in 1865.

Practical success, however, was due to Sir William Siemens in his invention and application to the process of the regenerative furnace which bears his name. Though these two processes are of recent date, their growth has been most rapid, and their great importance at the present time is shown by the following figures taken from "The Mineral Industry," which gives the production of Bessemer and Open Hearth or Siemens steel for the three great steel producing countries in the year 1899.

In order of production the United States stands first with 7,586,354 tons of Bessemer and 2,947,316 tons of Siemens steel. Germany ranks next with a production of 4,104,115 tons of Bessemer and 1,512,343 tons of Siemens steel, whil Great Britain, though a greater producer of pig iron, the raw material from which both the Bessemer and Siemens processes manufacture steel, ranks below Germany in steel production with an output of 1,825,074 tons of Bessemer, and 3,030,251 tons of Siemens steel.

The total output of steel from these three countries (which produce about the whole of the world's yearly output), amounted in 1899 to 13,515,543 tons of Bessemer steel and 7,489,910 tons of Siemens steel.

While intending to treat of this matter later, it may be here mentioned that the tendency is for the production of Siemens steel to relatively increase and that of Bessemer steel to relatively diminish, and whereas in the case of Great Britain, a few years ago the output of Bessemer steel exceeded that of Siemens steel, at the present time the order of production is reversed.

In Germany and the States the difference between Bessemer and Siemens steel production is slowly being diminished. The Siemens Open Hearth process consists of melting down varying amounts of pig iron and steel scrap upon the hearth of a gas fired reverberatory furnace furnished with regenerative chambers, and of converting the molten bath of metal into steel by the elimination of carbon, silicon, and in short all the elements contained in and characteristic of pig iron. The chief point in the process is the utilization of the heat regenerating principle for the pre-heating of the gaseous fuel, which is necessary in order to attain in the furnace a temperature high enough to melt the charge and keep it perfectly fluid during its conversion into steel. Without such a degree of heat the process would be impracticable. As in the Bessemer so in the Siemens process, it is necessary to distinguish between the Acid Siemens and the Basic Siemens processes—a differentiation brought about by the element phosphorus.

This element more than any other has a disastrous effect on the physical properties of finished steel, a content of more than ·1 per cent. rendering the metal unfit for structural purposes. Further, this element more than any other is difficult to eliminate, whether by the Bessemer or Siemens process.

In the Acid Siemens furnace—that is a furnace provided with a hearth composed of sand—this elimination of phosphorus is impossible, and consequently the pig iron and steel scrap treated in such a furnace should not contain more than ·1 per cent. of that element.

To treat pig iron containing a higher percentage of phosphorus than ·1 per cent., of which a very large quantity is produced annually, for all iron ore contains more or less phosphorus and it may be taken as a rule that all the phosphorus contained in the ore is contained in the resulting pig iron—it is necessary to melt down such pig iron in a furnace provided with a hearth of basic material such as dolomite, and only in a furnace with such a hearth is it possible to obtain a steel free from phosphorus by what is termed the basic process, which differs in no wise from the acid process, except that with the charge of phosphoric pig iron and scrap is added a certain quantity of limestone.

The open hearth furnace as invented by Siemens, for a number of years underwent but little alteration with the exception of minor differences in detail of construction.

As a whole its dimensions increased, and as a result the earlier furnaces with a charge capacity of four tons gave way to later ones of ten, twenty, and eventually as large as fifty tons capacity.

This increase in charge capacity resulted in reduction of fuel, labor, and repairs for every ton of manufactured steel.

The standard type of furnace of increased dimensions is still largely erected, but within the last ten years several radical alterations on the design of the Siemens furnace have been made, and, later still, alterations in the process itself, which double alterations have caused many metallurgists to forsee the final and entire ascendancy of the Siemens process over its formidable rival—the Bessemer process.

The chief characteristics of the Siemens Open Hearth furnace are the utilization of gaseous fuel and of regenerative chambers.

Producer Gas.

The gaseous fuel almost invariably used is that known as Producer Gas, and is formed from the incomplete combustion of bituminous coal.

Fig. I. shows a sectional elevation of a Wilson Gas Producer. It is a circular furnace built of fire-brick and bound by steel plates. The coal is charged from the top by means of the bell and hopper feed arrangement, and covers the grate bars to a depth of some four or five feet. A limited supply of air to ensure incomplete combustion is admitted underneath the grate, as also a jet of steam which induces a current upwards through the thick layer of fuel, and also gives rise to the formation of combustible gases by its decomposition in contact with glowing carbon, the products of decomposition being hydrogen and carbon monoxide according to the following equation :—

$$H_2O + C = CO + H_2$$

This reaction, though of minor importance in the formation of producer gas, is the main reaction in the production of water gas.

The second and more important reaction which takes place in the producer furnace is that which occurs between the carbon dioxide first formed in the bottom zone of the furnace, and the glowing carbon which this gas encounters in its upward passage. The carbon dioxide in the presence of highly heated carbon combines with the same, forming—carbon monoxide, as shown by the following equation :—

$$CO_2 + C = 2CO$$

The gas which results from these reactions, and which is known as Producer Gas, contains only about forty per cent. of combustible material, the remainder being inert nitrogen and a small percentage of carbon dioxide as shown by the following analysis of Producer Gas of average quality :—

CO_2	=	3·2	per cent.	(by volume).
O	=	·4	,,	,,
CO	=	22·8	,,	,,
H	=	8·5	,,	,,
CH_4	=	2·4	,,	,,
N	=	60·3	,,	,,

The producer furnace has not undergone any very great alteration in design since its introduction.

The most radical change has been one effected of late years with a view to making the furnace continuous in action, the type shown in Fig. I. having to be stopped at intervals for the purpose of cleaning the grate.

The modified producer—continuous in action—may be circular, and instead of being provided with a grate, the furnace stands in a circular shallow pan containing water, the air and steam necessary for combustion being brought up through the pan through a central cone into the producer furnace. The ashes that form, fall into the pan of water which acts as a water seal, and can be shovelled out from time to time without stopping the working of the furnace. Both types of furnace are generally located in a line some distance, say fifty to one hundred feet, from the Siemens furnaces in which the producer gas is to be utilized. The usual arrangement is for the gas from the row of producers to discharge into a main system of flues, carried overhead or underground to the Siemens furnaces. As a consequence, the heat generated in the producers the partial combustion of the coal is lost during the passage of the gas along the flues to the Siemens furnaces, and to prevent this loss, the latest improvement relative to producer furnaces is to place them adjacent to the Siemens furnace as shown in Fig. VI., whereby a double advantage results, viz. :

(1) The heat produced by the partial combustion of the coal during the formation of carbon monoxide is saved.

(2) The producer gas coming direct from the producer furnace to the Siemens furnace is hot enough to enter direct into the laboratory part of the furnace without first having to be heated by passing through a regenerative chamber, the usual practice in those plants where the producers and Siemens furnaces are plcaed apart.

The advantage gained is this: That instead of requiring four regenerative chambers, two for heating air and two for heating gas, the two latter can be dispensed with.

Siemens Furnace.

The general design of the Siemens Open Hearth furnace of the ordinary and most general type, is that shown in Figs. II. and III., of which Fig. II. is a longitudinal and Fig. III. a cross sectional elevation.

The furnace comprises three main parts :

(1) Furnace proper or laboratory part of furnace.
(2) Regenerative chamber.
(3) Flues and valves for reversals.

The third part, viz., the flues and valves for reversals, will be considered when dealing with the Open Hearth Siemens furnace erected at Lithgow.

The roof, sides, and ends of the furnace proper or laboratory, are constructed of the most refractory silica brick, of which the best known is perhaps the South Wales silica brick, made from the Dinas rock and composed almost entirely of silica.

A brick of such composition is necessary, as the heat attained in this part of the furnace is intense and would readily melt ordinary fire clay bricks.

The hearth, which has to stand more wear and tear than any other portion of the furnace, being the bed upon which the molten metal lies during its conversion from pig iron to steel, consists of steel plates upon which is laid a course of fire bricks, and upon this the hearth material proper, which in the acid Siemens process consists of pure white sand, containing about 97·5 per cent of silica, and the remainder alumina, which is fritted down in successive layers to a depth of twelve inches more.

In the basic Siemens process this hearth consists of a rammed-in mixture of roasted dolomite and tar.

The charging of the furnace is carried out through three doors at the back, while the tapping is effected through a tapping hole which passes through the front of the furnace and intercepts the hearth at its lowest part.

The Regenerative Chambers.

These are four in number and are built directly under the laboratory part of the furnace, the two inner and larger ones being for air, and the two smaller and outer chambers for gas. Good average dimensions of these chambers are about twelve feet deep, twelve feet high, and six feet wide for gas, and seven feet wide for air chambers. They are constructed of fire brick, while the heat absorbent material consists of fire clay bricks arranged chequerwise, while the top two or three rows where the heat is greatest consist of silica brick.

Communication between the chambers and the laboratory part of the furnace is effected by means of flues, of which there are three leading from the top of the air chambers, and two from the gas chambers.

The ports or openings from which the air discharges from the flue into the laboratory part of the furnace are usually placed at a higher level than the ports from which the gas discharges into the furnace, as with this arrangement it is found that a better mixing of air and gas result than in those furnaces in which the gas and air ports are placed alternately at the same level, and furher that the roof wears better, having a protective stratum of air between it and the flame.

Communication between the regenerative chambers and the air and gas flues, and with the stack, is effected at the bottom of the former. Upon the supposition that the furnace has been working some time, and that air and gas are admitted into their respective chambers in this instance being the two right hand ones, the air and gas during their passage upwards abstract heat from the red hot brick work, and emerge from their respective ports into the laboratory part of the furnace at a temperature considerably above ignition point. They mix, burn, and the resulting heated products of combustion traverse over the hearth and descend through the air and gas flues at the opposite end of the furnace into the left-hand pair of chambers.

During their passage downwards through the chambers the highly heated products of combustion give up thier heat to the chequer brick work and pass out at the bottom exits in a comparatively cold state to the stack. It is evident that the right-hand pair of chambers is losing and the left-hand pair gaining heat.

Flues and Valves.

At definite intervals, generally half-hourly ones, by means of valves, the current is reversed by bringing the two left-hand chambers into communication with the air and gas supplies, and the two right-hand chambers into communication with the stack. By this reversal the cold air and gas pass into and through those chambers which have been heated, while the heated products of combustion pass out, and heat the chambers which in the preceding half-hour have been cooled.

Improvement in Design.

The great fault in the design of this type of furnace is the position of the regenerative chambers which lie immediately beneath and form the foundation upon which rest the massive hearth, roof, and walls of the laboratory part of the furnace. Such a foundation is subject to expansion and contractions, resulting from variations in temperature, movement ensues which cannot but have a prejudicial effect on the life of the furnace.

An improvement in design which has been carried out in connection with some furnaces has been to place the regenerative chambers parallel to, but behind, the laboratory part of the furnace, taking the front of the furnace to be the tapping hole side. In such cases the furnace foundation has been built up solid.

Tilting Furnace.

Perhaps the greatest alteration on the design of the Siemens Open Hearth furnace is that made by Messrs. Campbell and Wellman, both of which metallurgists have introduced tilting furnaces. The first of Campbell's tilting furnaces was erected in 1890, it being a basic hearth furnace.

A cross sectional elevation is shown on Fig. IV.

The laboratory portion of the furnace is placed on rockers, and the tap hole is above the slag line.

By tilting with an hydraulic cyclinder, the whole or any part of the charge is poured out when desired.

The advantages of the tilting device are as follows :—

(1). Such an alteration in design admits of the tapping hole being placed above the surface of the metal until the furnace is tilted for tapping, and as a result the tapping hole never gets blocked, and defies for hours all efforts to tap the charge as at times occurs in the stationary hearth type of furnace.

(2). A part or the whole of the metal can be poured out at any time, or the slag can be poured off if desired, which is a great advantage in certain stages of the basic process.

(3). The tilting furnace admits of what is termed the use of direct metal, a term to be explained when dealing with the most recent open hearth practice.

Wellman Charging Machine.

Another alteration in design, or rather a distinct invention, is the Wellman electric charging machine, designed by Wellman, of the Wellman-Seaver engineering firm, which is responsible for the erection of the most modern and efficient open hearth steel making plants in the States, and which is now extending its sphere of operations to the Continent and England.

The charging machine does away with the most laborious and most expensive item, from a labor standpoint, of the open hearth process, viz., hand charging.

Hand charging is in keeping with furnaces of five tons capacity but in charging a furnace of fifty tons capacity this method is most inadequate, and yet was the sole method practised until the introduction of the Wellman charging machine, and still is the ordinary method of charging.

The Alabama Steel and Ship-building Co., of Ensley, Alabama, have just erected a plant of ten Wellman Tilting Furnaces of fifty tons each. The plant is provided with two Wellman charging machines which make it possible for two men to charge the ten furnaces, and handle close to one thousand tons of material in twenty-four hours.

Fore-Hearth.

The Wellman-Seaver Engineering Co. is also responsible for the important innovation of attaching a fore-hearth to the Wellman tipping furnaces, the metal being tapped into this fore hearth instead of into a ladle before being teemed into moulds.

The advantages of this modification are :

(1). In case of a leaky stopper or any other trouble connected with the stopper or nozzle, the furnace is tipped back so as to run the charge of metal back into it so that the stopper or nozzle may be made good.

(2). The metal need not be made so hot in the furnace as would be expedient if it were to be poured out a ladle as in common practice.

The advantages will be made apparent when considering the practice at the Siemens furnace erected at Lithgow.

A tilting furnace with fore hearth attached is shown in Photograph I. which shows a most modern type of Siemens open hearth furnace, erected for the Hamilton Steel and Iron Co., of Canada, rolled forward from its horizoutal position for casting into ingot moulds through the fore-hearth.

The Lithgow Furnace.

The Siemens open hearth furnace erected at the Eskbank Iron and Steel Works, Lithgow, for Mr. William Sandford, and which has the distinction of being the first furnace for manufacturing steel erected in Australia, is a furnace of recent type and one already referred to, viz., that type in which the producer furnaces are placed alongside the Siemens furnace.

This as already stated, results in a two-fold economy of fuel and of construction, two regenerative chambers being required instead of four, the two for gas being dispensed with. When desired, in this type of furnace the waste heat and waste gases can be used to help in again producing gas.

The patentee of the furnace is Dr. Frederick Siemens and it is well-known as the "New form Siemens" steel melting furnace. Figs. V. and VI. of plan and section of the furnace show clearly the different parts while the external appearance is shown by photographs II., III. and IV.

The chief point of difference between this and the form of furnace already described and shown in Figs. II. and III., other than those points of difference in the position of the producer furnaces and in the number of regenerative chambers, being two instead of four is that the air and gas ports are at one end of the furnace only and not at both ends.

The gas passes direct from the producers of which there are two, through a short flue and port direct into the laboratory part of the furnace and without the intervention of a regenerative chamber.

There it mixes with air which enters through the adjoining air port from the regenerative chamber in which it has been heated. The flame describes a semi-circle as it were, and the products of combustion pass out through the second air port down through the second air regenerative chamber to the stack, the adjacent gas port communicating with the second producer furnace meanwhile remaining closed.

The dimensions of the producers are height five feet ten inches, width three feet seven inches, depth five feet, and the central division between the two does not extend downwards to the grate as shown in Fig. VI., so that when the valve of one producer is closed the gases from that producer pass over crosswise into the producer whose valve to the laboratory part of the furnace is open.

The two gas valves are operated by the one lever, and the opening of one is accompanied by the closing of the other. Each producer is provided on top with a cup and cone arrangement for feeding coal, and one steam jet as shown in cross section Fig. VI., suffices for the two grates. The two regenerative chambers as shown on Fig. V. and Fig. VI. are situated directly under the producers.

Each of these chambers is about ten feet long, ten feet high, and three feet nine inches wide, and is filled with chequer work of fire brick, surmounted by silica brick.

One valve, a butterfly valve, suffices to bring one regenerative chamber into communication with the incoming cold air and, the other chamber containing the outgoing products of combustion into communication with the flue leading to the stack.

By throwing the valve, by means of a lever which is operated from the furnace floor, a reversal takes place, whereby the regenerative chamber previously in communication with the stack is now in communication with the air inlet, while the chamber which was in communication with the air is now in communication with the stack.

Simultaneously with this reversal of the air current a reversal of the gas current is made, which is effected simply by raising or lowering a lever on either side of the fulcrum of which, are suspended two valves.

By pushing up the rod worked from the furnace floor, which is attached to the lever, one valve is lifted off its seat and communication between the producer and the laboratory portion of the furnace results, while the other valve falls on its seat and blocks communication. By pulling down the rod the relative position of the valves is reversed and the reversal of gas and air valves are so made that one pair of gas and air ports are opened, while of the corresponding pair the air port is open and allows the products of combustion to pass into the regenerative chamber in communication with the stack, while the gas port is closed.

These reversals of air and gas currents take place half-hourly. The laboratory portion of the furnace consists of silica brick sides, ends, and roof, with a hearth composed of pure white sand, the dimensions of which being eight feet by eight feet nine inches and the holding capacity approximately a four ton charge.

The whole structure is firmly braced by iron castings and tie rods, and the hearth is supported on an iron hearth plate resting on girders. The bricks used throughout in construction are fire bricks for pro-