the incoming gas and air into the right-hand regenerators, so that they may absorb in passing the heat which has just been stored there; thence they pass up through the right-hand uptakes and ports into the working chamber, where as before they mix, burn, and heat the charge. Thence they are sucked out by the chimney-draught through the left-hand ports, down through the uptakes and regenerators, here again meeting and heating the loose mass of "regenerator" brickwork, and they finally escape by the chimney-flue *O*. After another thirty minutes the current is again reversed to its initial direction, and so on.

Fig. 98. Section on *EF* through Furnace and Port Ends.

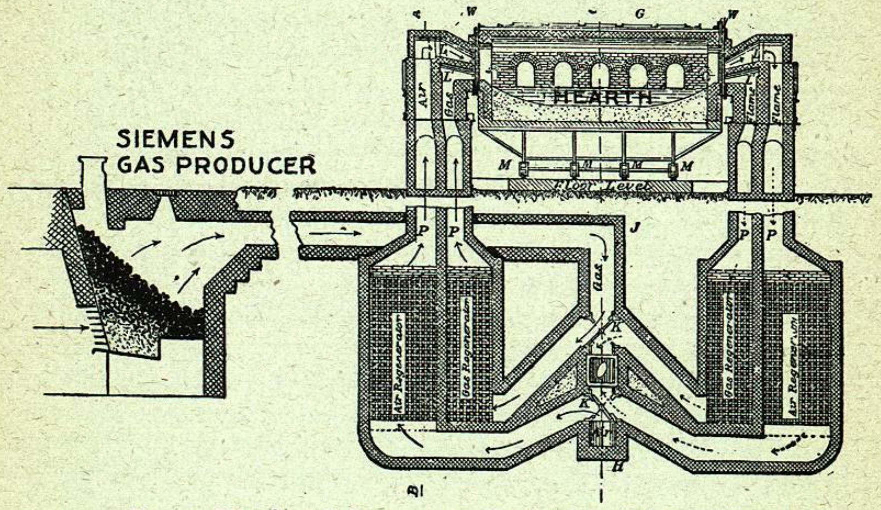

Fig. 99. Plan through Regenerators, Flues and Reversing Valves.

These regenerators are the essence of the Siemens or "regenerative furnace"; they are heat-traps, catching and storing by their enormous surface of brickwork the heat of the escaping products of combustion, and in the following phase restoring the heat to the entering air and gas. At any given moment one pair of regenerators is storing heat, while the other is restoring it. As devised by Siemens, the whole furnace was stationary. But H. H. Campbell and later S. T. Wellman have modified it by making the furnace proper, the part *WW* (Fig. 98) which contains the working chamber, movable, so that it tilts approximately around its own axis, somewhat like a barrel rolling on the floor.

In H. H. Campbell's system, which is here shown, the tilting working chamber is connected with the stationary ports *L* and *L′* by means of the loose water-cooled joint *W*. The furnace, resting on the rollers *M*, is tilted by the hydraulic cylinder *N* (Fig. 100). The slag-pockets *P* (Fig. 101), below the uptakes, are provided to catch the dust carried out of the furnace proper by the escaping products of combustion, lest it enter and choke the regenerators.

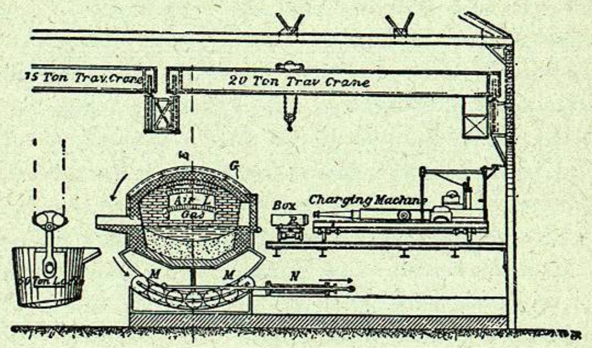

Fig. 100. Section on *CH* through Body of Furnace.

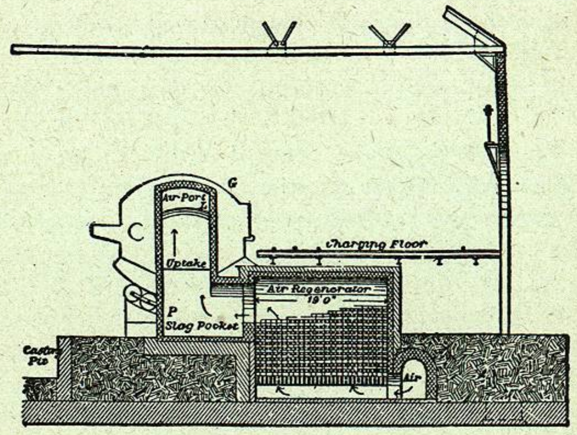

Fig. 101. Section on *AB* through Up-take, Slag-pocket and Regenerator.

Figs 98 to 101. Diagrammatic Sections of Tilting and Siemens Furnaces.

Legend: *G*, furnace body; *H*, air supply; *J*, gas supply; *K*, air reversing valve; *K′*, gas reversing valve; *L*, air port; *L′*, gas port; *M*, rollers on which the furnace tilts; *N*, hydraulic cylinder for tilting the furnace; *O*, flue leading to chimney; *P*, slag pockets; *R*, charging boxes; *W*, water-cooled joints between furnace proper, *G*, and ports *L*, *L′*.

Wellman's tilting furnace rolls on a fixed rack instead of on rollers. About 37 of these Wellman's rolling furnaces have been built and are in operation, and their capacity is from 3 to 70 tons at a time. Their production for a day of twenty-four hours would thus lie between 15 and 100 tons each. The numbers just given include two 70-ton furnaces for the Talbot process. A Wellman furnace to hold 200 tons at a time for this process has been proposed, but the advantages of such extreme size are open to question.

In the Wellman charging system the metal is packed by unskilled laborers in iron boxes, *R* (Fig 100), standing on cars in the stockyard. A locomotive carries a train of these cars to the track running beside a long line of open-hearth furnaces. Here the charging machine lifts one box at a time from its car, pushes it through the momentarily opened furnace door, and empties the metal upon the hearth of the furnace by inverting the box, which it then replaces on its car.

277. New Varieties of the Open-hearth Process. As pointed out briefly in § 265 cast iron differs from steel essentially in containing more carbon and silicon, and often more phosphorus; and the open-hearth process converts molten cast iron into molten steel either (1) by diluting its carbon and silicon by additions of scrap steel or wrought iron (*pig and scrap process*); or (2) by oxidizing its carbon and silicon, jointly by means of the oxidizing flame of the Siemens furnace, and of iron oxide added in the form of ore or scale (*pig and ore process*); or (3) by both means jointly. Because ore is usually much cheaper than scrap iron, the pig and ore process would usually be the cheaper, were it not that it must be conducted very slowly, lest the frothing due to the escape of the carbonic oxide gas, which results from the oxidation of the carbon of the metal, cause the charge to overflow. Rapid decarburization with its consequence, violent ebullition, is permissible in the Bessemer process, which lasts only as many minutes as the open-hearth process lasts hours, because the Bessemer converter is so deep that the metal is not liable to boil out of it. Further, the cold iron ore of the pig and ore process can be introduced only very slowly, lest it chill the molten metal, both directly and because its reaction on the carbon absorbs heat; this local cooling indeed is what aggravates the frothing. A cold lump of ore chills the slag immediately around it, just where its oxygen reacting on the carbon of the metal generates carbonic oxide; the slag becomes cool, viscous, and of a consistency leading to extreme frothing on slight provocation, just where the provocation to frothing is extreme through the local evolution of gas.

We will now look briefly at three new modifications of the open-hearth process, the Bertrand-Thiel, the Talbot, and the Monell.

278. The Bertrand-Thiel Process. — Bertrand and Thiel oxidize the carbon of molten cast iron by running it upon a charge of preheated but usually still solid scrap steel on the hearth of an open-hearth steel melting furnace. In this preheating the surface of the individual pieces of scrap steel has become much oxidized. When the molten cast iron is run upon it, the scrap steel quickly melts and coalesces with the cast iron: and both during and immediately after fusion the oxygen of the former is in a position to attack the carbon of the latter efficiently. The reaction between the oxygen of one and the carbon of the other is therefore extremely rapid because it occurs throughout their depth, whereas in common procedure oxidation occurs only at the upper surface of the bath of cast iron at its contact with the overlying slag. Moreover, since local cooling, with its consequent viscosity and tendency to froth, are avoided, the frothing is not excessive in spite of the rapidity of the reaction.

279. The Talbot Process. — To enlarge the scale of operations makes strongly for economy in the open-hearth process as in other high temperature ones. (See below.) Yet the use of an open-hearth furnace of very great capacity, say of 75 or of 100 tons per charge, has the disadvantage that such very large lots of steel, delivered at relatively long intervals, are less readily managed in the subsequent operations of soaking and rolling down to the final shape, than smaller lots delivered at shorter intervals. To meet this difficulty Mr. B. Talbot carries on the process as a quasi-continuous instead of an intermittent one, operating on 70-ton lots of cast iron in such a way as to draw off part of the resultant steel in 20-ton lots at relatively short intervals, and charging a fresh 20-ton lot of cast iron to replace each lot of steel thus drawn off. Besides minor advantages, this plan has the merit of avoiding an ineffective period which occurs in common open-hearth procedure just after the charge of cast iron has been melted

down. At this time the slag is temporarily rich in iron oxide and silica, resulting from the oxidation of the iron and of its silicon which occurs as the charge slowly melts and trickles down. Such a slag not only corrodes the furnace lining but also impedes dephosphorization, because it is irretentive of phosphorus. Further, the relatively low temperature impedes decarburization. Clearly, no such period can exist in the continuous process.

280. The Monell Process. At a relatively low temperature, say 1300° C., the phosphorus of cast iron oxidizes and is removed much faster than its carbon, while at a higher temperature, say 1500° C., carbon oxidizes in preference to phosphorus. It is well to remove this latter element early, so that when the carbon shall have fallen to the proportion which the steel is to contain, the steel shall already be free from phosphorus and so ready to cast. In common open-hearth procedure, although the temperature is low early in the process, *viz.*, at the end of the melting down, dephosphorization is then impeded by the temporary acidity of the slag, as just explained. At the Carnegie works Mr. Monell gets the two dephosphorizing conditions, low temperature and basicity of slag, early in the process, by pouring his molten but relatively cool cast iron upon a layer of preheated lime and iron oxide in the open-hearth furnace.

Because of these two conditions so favorable to dephosphorization, the removal of the phosphorus from the metal to the slag is actually very rapid. At the same time the ebullition from the formation of carbonic oxide gas, by the oxidation of the carbon, is so strong that it puffs up the resultant phosphoric slag enough to make most of it run out of the furnace, thus both removing the phosphorus permanently from danger of being later deoxidized and returned to the steel, and partly freeing the bath of metal from the heat-insulating blanket of slag. Yet frothing is not excessive, because the slag is not, as in common practice, locally chilled and made viscous by cold lumps of ore.

281. The Bessemer Process. — The chief advances in the Bessemer process have been the use (1) of molten cast iron direct from the blast-furnace, or "direct metal"; (2) of "mixers" in which the cast iron from several blast-furnaces is mixed together, so as to equalize its composition; (3) of "car-casting," or casting the molten steel in moulds standing on a train of cars. In addition to these, which are advances not in the nature but in the administration of the process; (4) the basic Bessemer or Thomas process has come into extensive use.

282. Direct Metal and the Mixer. — Until lately the cast iron for the Bessemer process has nearly always been allowed to solidify in pigs, which were next broken up by manual labor, and remelted at great cost. It has long been seen that there should be a great saving if this remelting could be avoided, and "direct metal," *i. e.*, the molten cast iron direct from the blast-furnace, be treated in the Bessemer process. The obstacle is that, owing to unavoidable irregularities in the blast-furnace process, the silicon- and sulphur-content of the cast iron vary to a degree and with an abruptness which the Bessemer process can hardly tolerate.

Sulphur, which is not removed in the acid Bessemer process, *i. e.*, the Bessemer process in its original form, injures the steel so greatly that it must be held below a limit, fixed in each case by the uses to which the steel is to be put. Further, the point at which the process should be arrested is recognized by the appearance of the flame which issues from the converter's mouth, and variations in the silicon-content of the cast iron treated alter this appearance, so that the indications of the flame become confusing, and control over the process is lost. Moreover, the quality of the resultant steel depends closely on the temperature of the process, and this in turn depends upon the proportion of silicon, the combustion of which is the chief source of the heat developed. Hence the importance of having the silicon-content constant. This was brought about at the Carnegie "Edgar Thomson" works by Captain W. R. Jones's invention of the "Mixer," which is simply a great reservoir into which successive lots of molten cast iron from all the blast-furnaces available are poured, forming a great molten mass of some two hundred or more tons. This is kept molten by a small flame playing above it, and successive lots of the cast iron thus mixed are drawn off, as they are needed, for conversion into steel by the Bessemer process.

This device not only makes the cast iron much more uniform, but also removes much of its sulphur by a curious slow reaction. Many metals have the power of dissolving their own oxides and sulphides, but not those of other metals. Thus iron dissolves its own sulphide freely, but not that of either calcium or manganese. Consequently, when we deoxidize calcium in the iron blast-furnace, it greedily absorbs the sulphur which has dissolved in the iron as iron sulphide, and the sulphide of calcium thus formed separates from the iron and unites with the slag floating upon that iron. In like manner, if the molten iron in the mixer contains manganese, this metal unites with the sulphur present, and the manganese sulphide, relatively insoluble in the iron, slowly rises to the surface, and there reaching the air, its sulphur oxidizes to sulphurous acid, which escapes. The use of the mixer, and through it that of direct metal, has now become general.

There still remains some irregularity in the silicon-content of the cast iron, and consequently in the temperature developed in the process, but this is met by throwing into the converter, during the process itself, a variable quantity of cold scrap steel (the crop-ends of rails and other waste pieces), and also in the United States by introducing a variable quantity of steam into the air which is blown through the molten iron. This is decomposed, with great absorption of heat and consequent lowering of the temperature, affording a most convenient way of regulating the temperature. If the temperature threatens to be too low, it may be raised by so inclining the converter that the layer of metal through which the blast from certain of the tuyeres passes shall be so thin that here the blast shall oxidize much iron, which thus becomes a source of heat, though an expensive one.

283. The Car-casting System deserves description chiefly because it shows how, when the scale of operations is as enormous as it is in the Bessemer process, even a slight simplification and a slight heat-saving may be of great economic importance.

Whatever be the form into which the steel is to be rolled, it must in general first be poured from the Bessemer converter in which it is made into a large clay-lined ladle, and thence cast in vertical pyramidal ingots, Fig 103. To bring them to a temperature suitable for rolling, these ingots must be set in heating or soaking furnaces (§ 293, p. 375). This should be done as soon as possible after the ingots are cast, both to lessen the loss of their initial heat and to make way for the next succeeding lot of ingots, a matter of great importance because the charges of steel follow each other at such very brief intervals. Two converters working together have made 4958 charges of ten tons each, or a total of 50,547 tons, in one month, or at an average rate of a charge every seven minutes and twenty-four seconds throughout every working day. It is this extraordinary rapidity that makes the process so economical and

determines the way in which its details must be carried out. Moreover, since the mould acts as a covering to retard the loss of heat, it should not be removed from the ingot until just before the latter is to be placed in its soaking furnace.

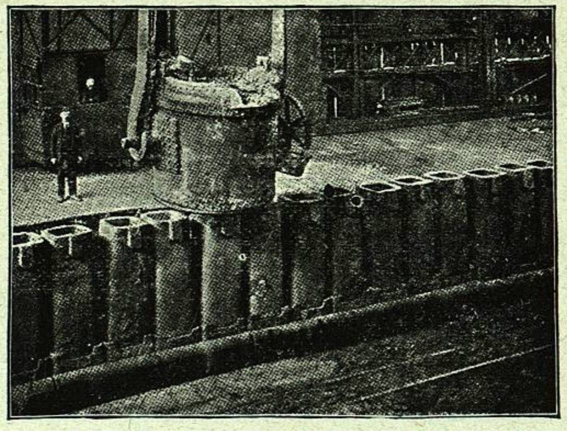

Fig. 102. The Car-casting System of F. W. Wood.

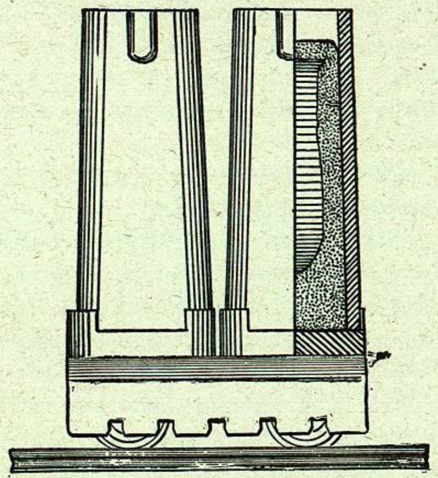

Fig. 103. Mould Car for the Car-casting System, Showing the Tapered Ingot inside the Mould.

These conditions are fulfilled by the car-casting system of Mr. F. W. Wood of Sparrows Point, Md., in which the moulds, while receiving the steel, stand on a train of cars (Figs. 102 and 103), which are immediately run to the side of the soaking furnace.

When any individual ingot begins freezing within its mould, it naturally freezes from without inwards; and the crust of solid steel gradually thickens and grows stronger as the freezing proceeds, Fig. 103. When this crust has grown so thick and strong that it can endure without collapsing the grip of the tongs needed to transfer the ingot to the soaking furnace, the tapered mould is withdrawn by lifting it from the tapered ingot which it encloses, and is set on an adjoining train of cars. The ingots are then charged directly into the soaking furnace. The mould-train now carries its empty moulds to a cooling yard, and, as soon as they are cool enough to be used again, carries them back to the neighborhood of the converters to receive a new lot of steel.

In this system there is for each ingot and each mould only one handling in which it is moved as a separate unit, the mould from one train to the other, the ingot from its train into the furnace. In the other movements, all the moulds and ingots of a given charge of steel are grouped as a train, which is moved as a unit by a locomotive.

In the early days of the Bessemer process the advantages which car-casting offered were recognized, and plans for carrying it out were proposed. But a very grave difficulty in the way of any such system was that, in pouring the steel from ladle to mould, more or less of it occasionally spatters, and these spatterings, since the steel as soon as it solidifies is extremely tenacious, if they strike the rails or the running gear of the cars, obstruct and befoul them, preventing the movement of the train. But this cannot be tolerated, because the economy of the process requires extreme promptness in each of its steps. This difficulty prevented casting upon cars. At that time, and indeed until the invention of Mr. Wood's car-casting system, the plan followed was much more expensive. The moulds stood not on cars, but directly on the floor of a casting pit while receiving the molten steel. When the ingots had so far solidified that they could be handled without having their crust break through, the moulds were removed and set on the floor to cool, the ingots were set on a car and carried to the heating furnace, and the moulds were then replaced in the casting pit. Here each mould and each ingot was moved as a separate unit twice, instead of only once as in the car-casting system; the ingots radiated away great quantities of heat in passing naked from the converting mill to the soaking furnaces, and the heat which they

and the moulds radiated while in the converting mill was not only wasted, but made this mill, open-doored as it was, so intolerably hot that the cost of labor there was materially increased.

The way in which Mr. Wood met the difficulty of spattering the tracks and running gear was a most simple one. It consisted, as shown in Fig. 103, in so shaping the cars that they completely protect both their own running gear and the track from all possible spattering, a device which, simple as it is, has materially lessened the cost of the steel and greatly increased the production.

283 *A*. Increase in the Rate of Production of a Pair of Bessemer Converters. — This is shown in Table 15.

Table 15. — *Maximum Production of Ingots by a Pair of American Converters, in gross Tons per Week.*

Year	Tons
1870	254
1880	3,433
1889	8,549
1899, for a month the average weekly production was	11,233
1902	13,703
1903	15,704*

* World's record for two ten-ton converters.

Thus in thirty-three years the rate of production per pair of vessels has increased more than sixty fold.

The production of European Bessemer works is very much less than that of American. Indeed the whole German production of acid Bessemer steel in 1899 was at a rate but slightly greater than that here given for one pair of American converters for that year; and three pairs if this American rate was continued, would produce almost exactly as much steel as all the sixty-five active British Bessemer converters, acid and basic together, produced in 1899.

284. Range in Size of Converters. — In the Bessemer process, and indeed in most high-temperature processes, to operate on a large scale has, in addition to the usual economies which it offers in other industries, a special one, arising from the fact that from a large hot furnace or hot mass in general a very much smaller proportion of its heat dissipates through radiation and like causes than from a smaller body, just as a thin red-hot wire cools in the air much faster than a thick bar equally hot. Hence the progressive increase which has occurred in the size of converters, until now some of them can treat a 20-ton charge, is not surprising. But, on the other hand, when only a relatively small quantity of a