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A Treatise
— upon the —
Siemens' Martin Process
— of making —
Steel upon the Open Hearth.

— With illustrations and specimens —

By
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The Siemens' Martin Process of making Steel upon the Open Hearth.

Although the commercial success of this process is of very recent date, the principles upon which it is founded as well as their practical adaptation, have been known for a very long time. One of the oldest methods of making steel consisted in the immersion of wrought iron bars into a bath of molten cast iron. The steel thus produced was rendered marketable by subsequent fagoting and welding. This now extinct manufacture was carried on at Paal in Styria, and the steel thus produced was sold under the name of "Pool" steel in the markets of all the world. The first description of this process is contained in Réaumur's "Art of converting Iron into Steel" published in 1722. Réaumur states that "Iron is transformed into steel by immersing it for a short time in melted cast iron." This process of steel manufacture is in use in some countries and has already been described by Vanaccio in his Pyrotechnie Book 1 Chapter 7. Réaumur also states that steel may be obtained "by fusing iron scrap in cast iron" and that he has obtained forge steel by mixing cast iron with one fourth to one third of wrought iron. Réaumur states that oxyd of iron may be substituted for wrought in the above reaction.

The "French Journal des Mines" contains records of experiments on this same subject by Chalut and Clouet as early as 1798. In that year Clouet states that iron or cast steel is obtained by remelting pig metal with oxyd of iron, one or the other resulting, according as more or less of the oxyd is employed. Mushet has since made steel in the same way. Two forms of furnaces existed in England as early as 1812 for making cast steel by reaction, and have been described by Hassenfratz. One is a crucible furnace, the other a reverberatory with dishing bed. The mixture of cast iron, scraps, clippings, etc. being thrown into the crucibles or on the furnace bed, the metal fuses, accumulates at the bottom and becomes covered with slags. When the ebullition ceases, showing that the carbon has been burned off, the liquid metal is stirred with a piece of green wood in order to assist the separation of the slag. From time to time sample ingots are taken from the bath, broken and tested. If, too soft, pieces of very high steel are introduced into the molten mass; if too hard, wrought iron is put in, and the process of reduction continued. When the desired point is reached, the metal is drawn out and forged into any given shape. Thus it seems that the direct method of making steel has been known since 1812. The process was not extensively introduced and owing to the difficulty of obtaining a sufficiently high and uniform heat and especially to the poor quality of steel manufactured, the process was abandoned. In 1824 Briant revived the same idea. He treated very gray pig iron with an equal amount of filings of similar metal previously oxydized, and he thus obtained a good product. He mentions the fact that the blackest pig irons are best adapted for steel making, and adds that reverberatory furnace may be advantageously employed, and that natural oxyd of iron may be substituted for oxydized iron filings. From this time until 1845, a period of twenty years, no mention is made of the reverberatory furnace, although crucibles were successfully employed in carrying out the process. August 4th 1845, Josiah Marshall Heath patented a process in England, for the manufacture of cast steel by reaction, in a reverberatory furnace heated by carbonic oxyd gas. Heath's specification was the most elaborate proposition yet brought forward for making steel by reaction, and his ideas embodied all the important principles of the process as it is successfully practised at the present time.

Heath's proposed plant consisted mainly of a cupola furnace, a reverberatory furnace, and a gas generator. In the drawing of the apparatus which accompanies the specification, the cupola is placed at the extreme right, the cast iron when melted is run from it into the reverberatory through a channel in the preliminary heating hearth, which is situated between the cupola and the reverberatory proper. The bottom of the latter is circular and dishing to hold the molten metal, and takes the place of the crucible, the slags which cover the mass answering to the lid. Circular conduits furnished with annular tuyeres surround the circular bottom, and through them, the gas and air blast pass into the furnace, the blast having been previously heated in pipes placed in the chimney. The preliminary hearth is heated by waste heat and upon it, on either side of the canal, is placed the wrought iron used in the process. When the wrought iron is nearly white hot, it is pushed forward into the molten pool of cast iron with hooks worked through a side door suitably situated. The circular reverberatory is furnished with a charging door and a tap hole opposite. The gas used is taken from the top of a blast furnace or from a special generator. Heath further specifies the relative proportion of cast and wrought iron necessary to make hard or soft steel, the neutral or oxydizing character of the flame employed, the form and character of the wrought iron used and the taking of sample ingots from time to time as a direct means of controlling the process. The metallic bath was to be stirred, and protected from oxydation by a vitreous flux. Owing to lack of uniformity and intensity of heat and also to the use of inferior materials Heath never carried his invention into successful commercial practice, and his failure cast great discredit upon the entire process. After ten years, John Davie Stirling claimed a patent in England, in February, 1854, for the manufacture of steel by the reaction of powdered oxyd of iron upon pig iron. One year later Henry Bessemer, in 1855 turned his attention to the same process and took out a patent for the fusion of steel in a reverberatory furnace. Sudre claimed a similar patent in France, in October, 1858, and soon after made experiments. He also undertook a second series of experiments in November 1860, to March 1861, at the forge of Montataire but these first experiments were not very successful. He obtained a sufficiently high degree of heat, but the furnace was not as refractory as was required, and failed after a few operations. About 1860, M. Alexander, manager of the imperial establishment at Villeneuve, near Brest, undertook a systematic investigation of the manufacture of cast steel. He used large crucibles, into which he put mixtures of (1) cast iron and malleable iron. (2) pieces of cast iron and oxydized filings, and (3) filings of cast iron and oxydized filings. Mixtures were made of these various substances in different proportions, and all the various grades of steel from soft to hard were successfully produced. Subsequently in 1861, after the failure of Sudre, Alexandre erected a reverberatory furnace at Villeneuve and formed the bottom of a mixture of graphite and refractory sand. The fusion succeeded and the furnace lasted through twenty to thirty (20-30) operations. Some castings were made, but the metal was of inferior quality. This was owing to the poor quality of the pig iron used and not to the process of fusion itself. The fact, that good steel cannot be made from poor materials was not sufficiently taken into consideration. Owing to the inferior quality of the products, the experiments at Villeneuve were discontinued in 1862, before any satisfactory result was attained. Bessemer was experimenting about this time in a similar way, and although he failed at first, he afterward tried pure Swedish pig irons, and succeeded. The difficulties he met with, led him to give up his research in this direction of making steel by the pneumatic method, the result of which is now known as the "Bessemer Process" of converting cast iron into wrought iron and steel. Martin at Sireuil made similar experiments with substantially the same results as were secured by Bessemer. Soon after this the celebrated Siemens' furnace was introduced and immediately the aspect of steel making was changed. Its high, uniform, and perfectly controlled heat was exactly adapted to utilize the open hearth process and was experimented upon by Martin. He used pure irons, and made very superior steel of different grades, and the reaction process upon the open hearth after so many years of failures and discouragement, was an established success! Martin secured his first patent, July 28th 1865, and additional certificate on December 19th, 1865, and ten of less consequence during the years 1866 and 1867. The Martin steel was first brought into public notice at the late "Exposition" at Paris in 1867. The Messrs. Martin were awarded a "grand prix" for the excellent quality of their steel, and steel makers from different countries took licences to manufacture by their method upon a large scale. The "Martin Process" is extensively practised in France, Prussia, and Austria on the Continent and in Great Britain. Martin procured letters patent from the United States dated December 10th 1867, for "Improved Process for Refining and Converting Cast Iron into Cast Steel and other combinations of Iron and Carbon", which letters were surrendered and canceled and Reissue obtained August 25th 1868, number 3096. Some eight to ten firms in this country are now successfully manufacturing this product. Martin claims no originality in his process. It is simply a utilization of apparatus already perfected to carry into successful practice ideas which, as has already been shown

— Theory of the Process —

have been known for many years. The principles upon which the Siemens=Martin process is founded are quite simple. The object in view is, to attain at will a given point between the limits of wrought iron on the one hand and cast iron on the other, so as to produce steel of any desired grade. Theoretically this object might be attained by adding carbon in some form to wrought iron, which is free from this substance or by taking it away from cast iron which contains an excess. Practically it is impossible to melt wrought iron by itself for the purpose of introducing carbon, but wrought iron readily dissolves in an intensely heated bath of melted cast iron. On the other hand carbon may be removed from molten cast iron by allowing it to burn off, the metal being exposed to an oxydizing flame and stirred from time to time. The Martin process combines the solution of wrought iron with the oxydation of cast iron. For this purpose a bath of suitable pig metal is prepared upon the furnace bottom and into this are thrown pieces of wrought iron previously heated to bright redness. The wrought iron very soon softens, and is incorporated with the bath by thorough stirring. Two modes of manipulation are now presented; one, to proceed with the additions of wrought iron until there is just enough carbon left in the homogeneous mass to make the resulting product of the grade desired. The other method is to decarbonize the mixture by oxydation until there is no carbon left, the steel molten product being simply homogeneous wrought iron, and then to add just enough of a recarbonizing agent to give the entire mass any desired percentage of carbon. The former plan is perfectly practicable, though it does not give such uniform results as the latter, which has come into general use among the manufacturers of this description of steel.

Note. The former has however a restricted use in making very high steel. For if enough of a recarbonizing agent were added to give the entire mass the desired grade, the resulting metal would not be uniform, as a perfect mixture could not be secured, owing to the great difference in the respective specific gravities.

General arrangement of the Siemens'=Martin Plant.

For the purpose of illustrating the principles of the process, we give a somewhat detailed description of the "Steel Works" at Nashua N. H. where the writer is employed, the apparatus used and the methods of working. In the accompanying drawings will be found a plan of the entire steel works, showing the different furnaces and apparatus employed, their actual position upon the ground and their relative positions with regard to each other, and also other drawings, showing upon a larger scale, the construction of the details themselves. The Siemen's open hearth steel melting furnace, and the Gas Producers connected therewith, form the principal part of the "plant", the rest being simply accessory though still absolutely necessary to practical working. The details are more or less numerous and modified in different establishments according to the use for which the product is designed. Drawing No. 1. represents a "General Plan of the Steel Shop."
At the extreme left of the plan is seen a ground section of the building containing the gas producers. This building is so situated, that while the upper floor covering the producers is nearly upon the same

level with the furnace, the lower or grate floor is on the same plane as the lower yard. This avoids the necessity of an excavation, and as will readily be seen, affords great comfort and convenience in cleaning grates and handling ashes. "a" is the flight of steps leading to this lower floor. The main walls of the gas producers are shown by the dotted lines; the producers are numbered from 1 to 6, six being the number contained in this set. 1 and 2 empty into the upright, take=off "d", 3 and 4 into "c" and 5 and 6 into "b". A wrought iron tube connects the three take=offs with the wrought iron "cooling tube", and from this last the gas descends to the main gas flue and thence flows to the necessary points where it is immediately utilized. "E" is a trap door giving access to the main gas flue at the foot of the "cooler." "f" is a similar trap at the point where a branch flue goes to the chimney. This flue is used in "burning out" the various gas flues, and also in starting the producers. At the end of this flue is seen the chimney. The section shows the manner of its construction. The central cone is of the same diameter all the way up, and is connected with the outside stack by piers running the whole height. "g" is another trap door in front of the furnace, at the point where the main flue supplying the furnace is joined by another flue leading to the farther end of the casting pit and supplying the gas for heating the ladle. Through these doors is elevated the cinder which invariably forms after each "burning out". At the lower left hand corner of the "steel shop" is shown the "Ferro-Manganese" furnace. This is simply a crucible furnace with Siemen's regenerators attached in order to burn gas as the fuel. The position of the pot holes is shown by the full lines and of the valves by the dotted lines. Immediately in front of this furnace is shown the large furnace for making the steel. The view shown is a horizontal section through the doors. The position of the four doors, of the two muffles, and of the gas and air ports, are delineated. The two extreme and the large centre ports are for air, the remaining two for gas. The gas valves are shown in front, dotted. On the opposite side is the "casting pit" with all the apparatus for casting. "h" and "i" are slight inclines leading up to the higher level of the furnace "j" is the accumulator used in working the hydraulic cranes. It consists of two cylinders, one of which is fixed; the second slides within the first and is counterbalanced by a very heavy weight beneath the floor, attached by means of several iron rods which also serve the purpose of slide guides. The pump "k" sends the water into "j", where it is kept stored under a great pressure. By working the slide valve "i" the whole amount of water contained in "j" is thrown at once into the crane (1), securing great rapidity and regularity of motion. As the water empties, the steam valve is automatically worked, the pump sends fresh supplies and thus the pressure is constantly continued. "V" operates crane Number "2". The cistern beneath receives the water after being thus used. The blue lines show the radius of the cranes. "n" represents the casting ladle as it stands in position upon the rails over the pit, "o" is a large staple in the frame of the ladle, to which a chain from the windlass "p" is attached, and which draws the ladle along the rails. For convenience in working, the windlass is situated in a rectangular pit. "r" is an iron pipe furnishing a blast of air, and "q" is a wrought iron pipe with damper for the admission of gas. The gas and air blast are used conjointly to form a blow pipe flame for heating the ladle previous to pouring the charge. Opposite crane "Number 2" is situated the "drop" used in breaking up groups of ingots and whose heavy weight is raised by an additional set of "pulleys" affixed to the same crane. On the opposite side is the "moulding floor" and conveniently near it the "drying oven" is situated. This is a simple arched oven, heated by an arched fire-place and into which the moulds are placed to become dry, and also, if necessary the completed castings to become annealed. Along one side of the shop runs a railroad track of the usual guage, used to bring the raw materials and to carry away the completed product.

— The Gas Producers. —

Drawing "No 2" represents the Siemen's Gas Producer, giving a Plan, Side Elevation, Longitudinal Section and Transverse Section, of one of the nest. They are all precisely similar, and are arranged side by side. By refering to drawing "No 1" to the plan of the nest, it will be seen that the pair of producers here delinicated is the end one "Nos. 5 and 6". The first view shown is a longitudinal "section through A.B." looking towards the right. The section passes through one of the "hoppers" (19.33) and the rear "poke-hole" (31). The end view of the "uptake" and "connecting tube", the side view of the "cooling tube" (cooler), the section through the front side wall of the building and the section through the flooring and back side wall are also shown. The "front elevation" shows the front of the producer looking from the grate floor; higher up on the level of the main floor is seen the side view of the "hoppers", and farther back still is seen the front of the "uptake" and the "connecting tube". In order to show the transverse interior, the other producer of the pair is shown in section, the blue line "C.D" indicating the parts cut through. This reveals the interior, showing the hoppers, form of walls, and the middle section of the grate bars, and also their arrangement. Immediately below this view is shown a "plan" of the pair of producers, showing the top of the "uptake" and "connecting tube" the position and number of the different "poke-holes", of the hoppers, and also the planking of the upper floor over the grate floor below. A more extended description will now show the arrangement of the details. "1" is the "cooler" starting from the middle uptake and running out through the side of the building eighteen feet, when it descends into the main gas flue. Its use will be indicated farther on, when the manner of making the gas is considered. "2" shows the end of the "connecting tube" joining the extreme "uptake" with the central one. "3" is a door whose frame is bolted to the end of the connector, and which allows of access to its interior. The other view is shown opposite in the "Front Elevation". The interior of the "connecting tubes" and "cooler" become clogged with the tar and soot which condenses along their inner surfaces and hence a door is provided at the end of each "connector" and one at each end of the larger "cooler". "4" is the uptake of brick, bound by angular pieces of cast iron running its entire height, and provided with "ears" through which bolts run in both directions binding the whole together tightly. This is necessary as it is exposed to extremes of temperature. In the other two views the same binding is plainly shown. The dotted lines indicate the position of the interior brickwork. "5" is a door set into the brick-work and giving access to the interior of the "uptake". Two other views of it are shown at 23 and 34. This gives convenience in cleaning the uptake and removing the accumulated matter. "6" shows the "damper", consisting of a cast iron frame through which passes a moveable piece of sheet iron. This regulates the draught and flow of gas which can thus be entirely cut off. The front view is shown at 22. There is a rectangular flue leading through the arch of each producer in adjacent corners, and these two flues become one just above the dampers. "7" shows the foundation stone wall of the front of the building. "8" is a "poke-hole" at the back of the producer, and is shown at "31" upon the plan view. There is also another similarly situated upon the other side of the "uptake" but covered on the plan by the "connector". These "poke holes" as they are denominated are provided with stoppers fitting loosely, and are used to test the quality of the gas, and also to thrust down a long iron bar into the mass of the coal below.

"9" shows the brick work below "8", the red tint indicating common brick, the yellow ordinary fire brick with which the whole interior is lined. "10" shows the position of the middle line of "poke holes," also shown at "32" upon the "Plan." "11" shows the "hopper" into which is charged the coal. "12" is a heavy piece of iron arranged to slide along the handle of the damper "13" and by its weight acting as a lever to keep it closed. When the coal is to be charged into the producer, "12" is brought to a perpendicular position and an opening through is afforded without letting in air which is cut off by the layer of coal still above. The other exterior view is shown at "19" opposite and the interior view at "21", the plan view being seen at "33". The handles are shown in each case in their proper positions. "14" represents the incline upon which the coal is placed. This is composed of fire bricks placed upon a cast iron bed, made up of four plates socketed upon three inclined supports, one in the middle, and one fixed in the wall at each side. At "15" is seen one of the grate bars and its supports. At "16" is seen a support upon which false grate bars are placed in cleaning out the fires and removing ashes and clinkers. Upon the "Front Elevation" these details are also delineated. "28" represents the four supporting cast iron plates referred to at "14." "27" shows the front view of "16". "26" shows the ends of the grate bars, continued, of course, all the way across. The binding of the main walls is shown at "17" and "18". Wrought iron rails, run across the top of the arch and down at the ends of each producer, and are held in place and securely fastened by a large plate at the top and smaller ones below through which bolts pass to the back side of the producer. "20" shows the section of the rails supporting the upper floor. The rear side walls rest upon a heavy joist, which in turn is socketed into and supported by six cast iron pillars. Thus the grate floor is entirely open to the air outside. A water pipe runs along under the upper floor and just over the binding to supply water to the ash-pit, whose surface is a little shelving to retain it in place. Almost any combustible used as fuel may be made to evolve useful gas in a suitable producer, coal, wood, peat and sawdust having been used in different countries. The "Producer" under consideration is suitable for burning bituminous coal of various kinds. The coal used is mostly "slack," so called, being the finely divided refuse of the mine, and containing more or less of impure foreign matters.

When the "Producers" are to be started, the dampers of the "up-take" and "burning-out flue" are opened giving free communication with the chimney, a small fire of wood or coke is kindled upon the grates and coal in blocks is let down upon it from the "hoppers" overhead. When fairly on fire more is let down and this is continued until the coal is heaped some two (2) feet or more above the centre of the grates and back along the incline down which it is delivered. The coal is now on fire at the bottom and burning freely, while a mass of heated coal rests upon it. Under these circumstances gas making proper is begun and the chimney damper is closed, the gas being delivered into the main flue as will be explained later. The upper part of the mass of coal is subjected to almost precisely the same conditions as if it were in a closed retort. The top layer is strongly heated without access of air and a large body of hydrocarbons is evolved, together with tar, steam etc. As the coal descends towards the grate it parts entirely with its volatile constituents and becomes coke in which state it finally burns. The carbonic acid thus evolved passes up through the heated coal and takes on another equivalent of carbon, becoming carbonic oxide, so that for each equivalent of carbonic acid, there are formed two equivalents of carbonic oxide, $CO_2 + C = 2CO$. The oxygen is obtained from the air of course, of which it constitutes only about one fifth part, so that a large volume of nitrogen is unavoidably introduced into the mixed gases, and for every one equivalent of carbonic oxide evolved as above, two equivalents of nitrogen gas are also introduced. Water is kept upon the ash-pit under the grates, and the heat radiated and the hot coals dropping into it, converts it by degrees into steam which passes up through the heated mass. The steam (H_2O) is decomposed, the hydrogen being set free, and the oxygen combining with the carbon to form carbonic oxide (CO). Hydrogen has great heating power. Thus for every volume of steam we have two volumes of valuable gases free from nitrogen. These all combine, and the chimney draught being closed, they pass into the main furnace to be consumed. The composition of the gas is really more complicated than has been indicated above. Besides the main constituents there are formed variable amounts of bihydrides of carbon (CH_2), olefiant gas (C_2H_4), volatile hydrides of carbon (C_nH_{2n}), benzol (C_6H_6), cyanogen ($2CN$), sulphuretted hydrogen (H_2S), ammonia (NH_3).

sulphurous acid (SO_2) and bisulphide of carbon (CS_2), according to the coal used, and the management of the producer. The first four mentioned would form upon heating carbon under the given conditions. All the nitrogen originally present in the coal would go to form cyanogen and ammonia. Iron pyrites frequently found in this coal would form the different sulphur compounds just mentioned. Indeed, sometimes the smell of sulphurous acid is very uncomfortable, when the gas is allowed to escape into the air. In just what proportions these last named various gases exist in the combined mixture, the writer has been unable to determine, either by research or experiment. It is very probable that many exist only as traces. About 35 per cent. of the mixture is available gas and the rest has simply a diluting effect. Much of the tar and soot is carried bodily into the furnace in a finely divided state and there burned with the gas. Most of the tar and all the undecomposed aqueous vapor is deposited along the walls of the flues. Specimen No. 1 is a piece of solid tar taken from the flue at the base of the cooler. This burns with a smoky flame, and might be used again as fuel.

As the coal slowly settles it is replenished from time to time from the hoppers above. Its quality is tested by opening one of the poke-holes, and watching the gas delivered therefrom. If it instantly lights, and possesses a rich coffee brown color, it may be assumed to be of the right composition. If it is bluish white or grey and lights with difficulty or not at all, the coal is not being burned to advantage. Should the fire burn through the top layer of coal, the carbonic oxide is all burned to carbonic acid and lost. In this case a bar of iron is thrust through one of the "poke-holes" most conveniently situated, the air hole filled in, and covered by properly working the long bar. Each hopper will hold about 115 lbs. of coal and about three quarters (3/4) of a ton of slack is consumed in twenty four hours in each pair of producers. Under the most favorable conditions, two (2) tons of good bituminous coal is the limit of working. Three quarters (3/4) of a ton of coal slack will furnish gas sufficient to produce one (1) ton of steel, working the furnace one "shift." One half (or less) (1/2) ton of same will produce one ton of steel working in two (2) "shifts", the reasons being obvious.—

The clinkers etc which invariably form over the grates are removed once in twenty-four hours. For this purpose false wrought iron bars of similar size and shape to fence pickets are entered over the false grate at "16" and driven through the mass of coal to the back wall. This supports the incandescent mass above, while the real grates below can be easily removed and cleaned. They are then replaced and the false bars withdrawn. It is very necessary to be able to deliver the gas at a slight outward pressure to the furnace so as not to be obliged to depend upon the chimney draught, and also to avoid leakage of atmospheric air. The heated gases being much lighter than the air would naturally ascend with considerable upward pressure and if the furnace were on a higher level than the producers, the desired end would be at once attained. In practise, however, the furnace and producers are upon substantially the same level. To overcome the difficulty the "cooler" has been devised. This has been described and consists of an elevated tube of boiler iron, exposed to the air. The heated gases while passing through this horizontal tube, are cooled to a very considerable extent and when they descend to the main flue are very much heavier than the heated gases in the "uptake", and overbalance them forming a syphon in fact, and urging the gases forward into the flue. The height necessary to carry the "cooler" in order to produce any given pressure may be readily calculated. Suppose we wish to ascertain the height necessary to carry the "cooler" in order to produce a pressure equal to that secured by placing the "producers" ten (10) feet deeper in the ground. The heat of the gases in the producer is taken at about 500°c, and would readily cool down to 100°c in the cooling tube. 13.14 s, g, as compared with hydrogen, has been found to be the specific gravity of samples of similar gas, corresponding to a s.g. of 0.91016 as compared with atmospheric air. 1 litre of air at 0°c. and 760 m.m. barometric pressure weighs 1.29366 grammes. 1 litre of air at 30°c and 760 m.m. expands to 1.10995 litres [$1+0.003665\times30=1.10995$.] Weight of 1 litre of air at 30°c and 760 m.m. = 1.16551 grms [$\frac{1}{1.10995}\times1.29366=1.16551$] 1 litre of air at 100°c and 760 m.m. barom. press. expands to 1.3665 litres [$1+0.003665\times100=1.3665$]. Weight of 1 litre of air at 100°c and 760 m.m. = 0.947310 grms [$\frac{1}{1.3665}\times1.29366=0.947316$.] 1 litre of air at 500°c and 760 m.m. expands to 2.8325 litres [1. + 0.003665 × 500 = 2.8325] 1 litre of air at 500°c and 760 m.m. weighs 0.45672 grms. [$\frac{1}{2.8325}$ × 1.29366 = 0.45672].

0.947316 × 0.91016 = 0.86221 grms — 0.45672 × 0.91016 = 0.41569 grs.

1 litre air at 30°c and 760 m.m. = 1.16551 grammes.

" " gases " 100°c " " " " = 0.86221 " .

" " " " 500°c " " " " = 0.41569 " .

The <u>upward</u> pressure = 1.16551 — 0.41569 = 0.74982 grm

" <u>downward</u> " is 0.86221 — 0.41569 = 0.44652 "

Hence the number of feet necessary to produce the required pressure equals $\frac{0.74982}{0.44652}$ × 10 = 16.79 ft. equivalent to 16. ft. 8.48 inches.

The flues after a time become clogged with tar, soot, etc which seriously retard the flow of the gases. To remove these ostructions, the flues are all "burned out" once a week. To accomplish this end the chimney draught is opened and the accumulations in the flues at their "<u>further</u>" extremities are set on fire. The tar and soot gradually burn out along the entire length, leaving a thin scale like residue, which is subsequently removed by hand and collected and hoisted through the various trap doors previously mentioned.

— Ferro = Manganese Furnace. —

This furnace forms no part of the immediate "Plant" as recarbonizing agents can be bought, as well as manufactured at any Steel works. Therefore no detailed description of this furnace will be attempted, nor any drawing of it furnished. It is simply a crucible furnace, accommodating six pots and furnished with "Siemens' Regenerators." Mixtures of suitable combinations of iron, manganese and carbon are charged into these pots, calculated to make about 50 lbs of metal in all, and are heated for a considerable length of time, gradually at first, finally to the most intense heat. When the reaction is completed is completed the product is poured into moulds. The heat produced in this furnace is very great and renders the drawing of the pots a matter of personal endurance to the workmen. The metal thus produced is of a very bright, coarsely crystalline fracture when broken and very hard and brittle. It varies very materially in its composition, the manganese, the principal ingredient varying from about 15% to 35% according to mixture and manner of treatment. The highest amount of manganese ever reached is about 80% and the highest amount of carbon that can be made to combine with the metal is 6.00%. The following analysis of "Binoxide of Manganese ore" used in the above described product was made by the writer and the analysis of N. J. Franklinite Pig Iron also used in same product, was forwarded by the N. J. Zinc Comp'y, who furnish the pig iron. It is really a spiegeisen containing a small and variable amount of manganese as it is smelted from the residues left after the extraction of the zinc from the ore.

Binoxide of Manganese.		Franklinite Pig Iron.	
Mechanical moisture	= 1.250%	Iron	= % 85.10
Hygroscopic " + Organic matter	= 0.457	Manganese	= 8.50
		Combined carbon	= 1.90
Silicic acid	= 7.672	Graphite	= 0.75
Gangue (clay etc)	= 6.130	Sulphur	= trace
Sesquioxide iron + (mostly) " " Aluminium	= 2.250	Phosphorus	= 0.21
		Slag	= 3.30
Lime	= 1.550	Total	= 99.76
Magnesia	= 0.039		
Carbonic acid	= 1.214		
Mang. binoxide	= 42.590	Metallic manganese = 51.78%.	
" oxide + (diff) " sesquioxide	= 36.848		
Total	= 100.000%		

The following analysis of imported "Swedish Spiegeleisen" was made by the writer. The metal may be used in making "Ferro-Manganese" or by itself as a recarbonizer. No attempt was made to ascertain the amount of S and P present and the combined carbon has since the time of the analysis (Aug. 1872) been proved to be rather high. It was done by Eggertz's method. The last remark applies also to the analyses of Ferro-Manganese Nos. 1 and 2 which will presently follow.

– Swedish Spiegeleisen –		German Spiegeleisen –	
Insoluble residue	= % 0.05	Silicon	= 0.568
Combined carbon	= 5.36	Com. carbon	= 4.504
Graphite	= none	Graphite	= none
Manganese	= 10.44	Manganese	= 11.225
Iron (direct)	= 84.60	Iron	= 83.455
	100.45	Nickel	= 0.005
		Copper	= 0.054
		Aluminium	= 0.034
		Calcium	= 0.016
		Phosphorus	= 0.064
		Sulphur	= trace
			99.925

This last analysis is of "German Spiegeleisen" imported by Phillips S. Justice, 42 Cliff St. New York, and is used by N. Washburn Esq. at Worcester, Mass. The analysis was made by Otto Wuth, Phil. Pa. and is placed beside the analysis of "Swedish Spiegeleisen" in order to afford comparison. Samples of the preceding Spiegel-irons and of similar "German" Spiegel iron have been placed by the writer in the cabinet of the Institute. The average of Spiegeleisen of whatever make will contain from 80% to 85% of iron, and from 8% to 12% of manganese. Combined carbon varies from about 3% to between 5–6%. The following three analyses of "Ferro Manganese" were made by the writer, the last (3) being used in charge #465 which will be treated of at length subsequently in this thesis.

	No. 1.	No. 2.	No. 3	By combustion
Silicon	= 0.022	0.027	0.0750	4.820
Com. carbon	= 5.100	5.400	4.7400	4.747
Graphite	= —	—	—	4.740
Manganese	= 17.80	23.94	13.6900	4.734
Iron (direct)	= 77.22	70.96	81.6000	
Sulphur	= not sought for	" —	0.0217	
Phosphorus	= " "	" —	0.0713	
	100.142	100.32	100.1980	

Samples accompanying show the structure and general appearance of these several alloys. No. 2 is a piece of "Ferro-manganese." No. 3 the same from a different pouring. No. 4 is a sample of "Swedish" and No. 5 is a sample of "German Spiegeleisen", all used at these "Steel Works" as recarbonizing agents and also for other purposes noticed later in this report.

— Siemens' Open Hearth Furnace. —

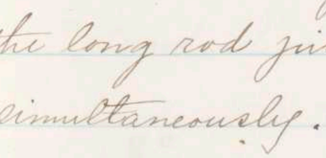
The furnace used in the process under discussion is the well known furnace of the Messrs. Siemens'. The distinctive feature of the Siemens' furnace is the "regenerative" principle, by which the heat mostly lost in the ordinary reverberatory furnace is arrested and returned to the heating chamber to be utilized. This is accomplished by causing the waste gases on their way to the chimney to pass through chambers packed with fire brick, which absorb nearly all the heat. By reversing the incoming current of air and gas, the cool gases on their way to the furnace chamber are heated intensely, nearly to the degree attained by the regenerative chambers, and carry this initial heat with them. So that when they mingle and burn this additional amount of heat is given off besides that due to their immediate combustion. By continued reversing of the incoming cool gases and causing them to pass through the intensely heated regenerators, a very intense degree of heat is finally attained, limited only by the ability of the materials of which the furnace is constructed to withstand it.

Drawing "No. 3" represents several sectional views and a front elevation of the furnace in question. "Section C.D." represents a longitudinal view cutting through a gas "port" on one end, and an air "port" at the other, showing the form and extent of the hearth, the material of which it is constructed, and the manner in which it is supported, the main binding of the furnace, the regenerative chambers, and the flue passages immediately below them. "Section E.F." is a transverse view cut through the centre of the furnace. This view shows the spring of the arch, the central door, the form of the deepest portion of the hearth opposite the tapping hole, the other view of the "air regenerator" and a transverse view of the valve chamber. This last mentioned portion shows the main gas flue, the chimney flue below, and the valves for reversing the directions of the incoming currents of gas and air. In order to save space a transverse view further up the hearth, cutting through the "muffle" is coupled with this sectional view. The dotted lines show the continuation of the hearth, at "E.F." and the door frame upon the opposite side. The position of the "ports" of course is not altered, and to complete this section the colored lower arch should be imagined to extend entirely across. By imagining a line to pass down the "Front Elevation" through the centre of the "muffle" door, it will readily be seen that the section across the furnace at "G.H" would not pass through the valves at all, but would simply pass through the ventilation flue (noticed subsequently) and one branch of the gas flue. The three doors at the back of the furnace are all alike, and thus by imagining the arch and the hearth at "G.H" to extend across to the door as shown, and leaving out the valves and upper (main) gas flue, the entire section is delineated. It is believed by thus looking at the combined view no confusion will arise as to the respective parts delineated. "Section at "A.B" shows a longitudinal view cut through the "furnace chamber". at the height shown by the dotted blue line. The different walls, doors, and number and arrangement of gas and air ports are here delineated.

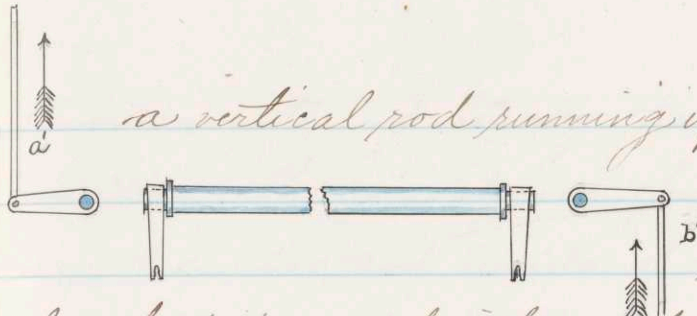
Section "I. K" gives the other longitudinal view through the "valve chamber", the chimney flue and the gas flues, one on either side of the gas valve, the arrangements for reversing currents of air and gas, and regulating the draught to the chimney. A section through the muffle is given, showing the form of the walls and arch, and the sand bottom is also here given. The general form of the furnace having thus been given, a more detailed description of its construction and also the arrangements of its working parts, will now immediately follow. "1" on "Section C. D" shows the form and position of the "arch" over the "fire chamber". This is made curving in order to reflect or "reverberate" the heat directly upon the charge. This roof is also arched in the other direction in order to make it support itself. The other view of "1" is shown at "1" upon section opposite, and of "a" nearer the "ports" at "a", upon the same section. "2" shows the form and thickness of the furnace bottom or "hearth". This is composed of suitable refractory sand filled into the proper thickness upon a bed of firebricks, "3", which is supported by cast iron plates resting upon square elevations of brickwork placed at regular intervals under the furnace bottom.

This gives stability and also space for ventillation. "4" represents one of the gas ports, and the flue leading from the left hand gas "regenerator". "5" shows one of the air ports and the flue at the opposite end of the chamber. These ports are placed alternately, air, gas, air, gas, air, making two of gas to three of air, and the capacity of the two groups of ports (air and gas) being in the same ratio (3 to 2). The horizontal section (A.B.) shows this more plainly, "12" being gas and "13" being air ports. At "4" as above the air port is seen beyond the gas port, while the corresponding flue below is shown dotted. The air, of course, is the heavier and tends to fall when introduced into the furnace, while the gas being much lighter tends to ascend. To make a more intimate mixture of the two before combustion, this fact is taken advantage of; the "gas" port opens on a level nearly with the top of the hearth while the "air" port is built almost to the top of the arch before it is allowed to deliver the air into the furnace chamber. The two thus meet at an angle, at a distance of about two (2) feet from the base of the air port, commingling and burning at just the point where the greatest heat should be thrown down upon the charge.

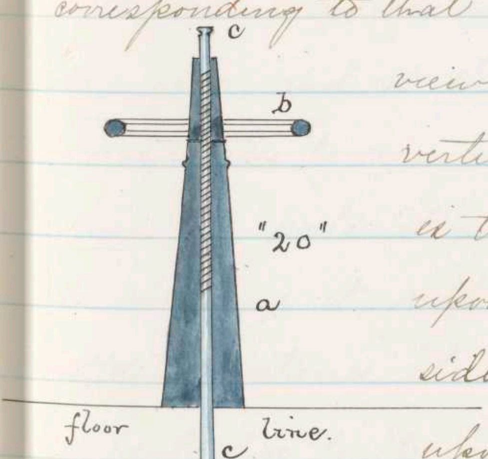
"C" shows the lower bracing on one side, the different walls being similarly braced at convenient points. The "binding" of the furnace is shown above the arch in "Section, C. D." upon the "front elevation", and in section up on the horizontal view at "A. B." It consists of strong plates of cast and wrought iron bound firmly together above and below by long bolts passing across the furnace above in both directions, and through the brick work below in a similar manner. Three (3) grades of firebricks are used in the construction of parts immediately exposed to the heat. The most infusible are put into the furnace chamber proper, and are represented by the bright yellow color, gamboge. The second grade is used in the arches of the regenerators and also partly in their walls, and in filling up their interior spaces, and is indicated by the darker yellow, Indian yellow. The third is placed in the lower half of the regenerators, and the flues immediately below, and is shown by the darker shade, Roman ochre. "I to IV" represent the "regenerator chambers," their walls, arched tops, and the manner in which they are filled. I and IV are for gas, II and III are for air. The proportion 2 to 3 being still observed in their respective sizes. These chambers are filled with firebricks piled cross-wise in regular layers, one above another until the chamber is full. The several layers at the top are composed of 1st quality firebrick as they are the most intensely heated. A space of two inches one way and about six inches the other, is allowed between the bricks in order to give free passage for the gases flowing through the regenerators. "II" shows the other view of one of the air regenerators. The open spaces between the bricks are placed so that no two apertures come together and thus the gases are caused to take a zigzag course, and to come into intimate contact with every brick in the whole regenerator. By this means the heat is absorbed to such a degree that while the upper layers are heated to intense whiteness, the flues below are so cold that one might safely put the hand into them. The brick filling rests upon large bricks, which run the entire length of the bottom of the regenerators and divide them into several flues, 7, 8', 8''. These flues are built up solid at one end and at the other end of the chamber, they unite and empty through an arched cavity into the main gas and air flues. By referring to section below, this will be readily understood. At "7" are seen these cavities coming from the gas regenerators, and emptying into the main gas flue, in whose centre stands the "gas valve," regulating and reversing the current. Just behind it (not seen here) is the air flue and its valve exactly similar. The chimney flue runs transversely under the centre of the two valves, carrying the products of combustion, nearly cold, to the tall chimney stack outside the building. Note_ The position of this chimney, the gas valve and flues are shown on the "General Plan" Drawing No. 1. This is also shown upon section "E. F." The position of the end of the main gas flue from the "producers", the two valves, and the chimney flue below them, are there delineated. "8" are the cavities opening from the air regenerator, shown dotted, as they are behind the gas flues. "9" shows the chimney flues, also seen at "9'", "e and e'" show ends of entering gas flues above the valve; "d and d'" the valve itself, and "c" the air valve opening into the air of the valve chamber. The gas enters through "k" into "e – e'," and then passes down into the valve past the "clapper", which cuts it off from the chimney flue and also from that flue conveying into the chimney flue the waste gases, into the left branch of the gas flue, and through this into "7" (at the left.) under the regenerator I. Passing up through the heated chequerwork of bricks, the gas enters the upper flues "4," "13" and passes into the furnace chamber, meeting the air which has passed into the valve "C", and pursued a precisely similar course through regenerator "II", a little in front of the ports and burning. The course is shown by the blue arrow, the entering air current being shown by the arrow partly dotted. The burning gas flows over the hearth and then when consumed passes down through the similar ports, down through the regenerators III and IV, and heating the brickwork intensely, then passes through "7" and "8", out through "7" and "8" into the gas and air valves and thence into the chimney flue, as shown by the doubly curved blue arrow. In section "E. F." at 9' the consumed gases are represented in a similar way passing into the chimney flue. By reversing the "clappers" of the valves, the air and gas are made to pursue the opposite courses, entering the flues which just served as exit passages; while the exit gases go out by the previous inlet passages. The bottom of the hearth is kept cool by currents of cold air which enter constantly through square holes in the bottom of the iron binding at the back of the furnace. The air then passes under the "hearth", carrying away part of its heat, and out through the sheet iron ventillation tubes 18 and 18' and empties into the flue "19" which proceeds to the chimney and delivers its contents into the open space between the central cone and the exterior of the stack. The ventillation flue could not communicate with the chimney proper, as it would spoil the main draught. It is sometimes necessary to enter the regenerator chambers in order to repair the arches, or replace more or less of the brick chequer work. For this purpose a space sufficiently large for a man to enter, is left in the main front wall of each chamber by making "straight joints" when the wall is first constructed. This is subsequently filled with brick work, which can be readily removed at any time without disturbing the main wall, and ingress thus be obtained. "10" represents this filled aperature in the wall of the gas regenerator, "11" that in the air regenerator. The "tapping hole" is placed under the middle door, abreast of the deepest and hottest portion of the hearth. A sheet iron "trough" lined with clay is bolted to the main frame of the furnace, and out of it leads an aperature through the brickwork, and is ended by the sand bottom which is pierced when the charge is to be poured. This aperature when working, is also filled with a mixture of clay and sand. "17" represents this "trough" and the "tapping hole" beyond. The valves for regulating and reversing the currents of air and gas have been alluded to previously in a general manner, and their construction and manipulation will now be given. — The valves consist of a cylinder open at top, and whose bottom "d" has aperatures in each side, to which another cylinder is connected. These last cylinders are closed at an incline at their farther ends and are open at the bottom. A cast iron "clapper" fitting closely every portion of the centre cylinder, swings upon an axis in the middle, and makes in effect, a simple four way cock of the entire arrangement. Gases coming downwards are deflected through the left hand auxiliary cylinder (when the clapper is in the position indicated) and gases coming upward through the right hand branch are sent downwards through the bottom of the central cylinder. By placing the "clapper" in its other position this direction is exactly reversed, of course. The amount of air and gas admitted is very simply regulated by a seat valve of a cup shape form which shuts down upon the top of the centre cylinder above referred to. This valve can be raised to any desired extent, admitting more or less air or gas. The clapper "27" is reversed, by a simple system of leverage. A long lever bar with a handle at its upper end, "24," passes down through the cast iron flooring over the valve chamber, and swings upon a pivot fastened just above the aperature in the floor. At "25" it is connected with a long straight rod to the handles which operate the clapper itself at "26". The end of the air valve handle is shown beyond. A "clutch" connects the air valve with the long rod just mentioned, so that both valves are reversed simultaneously. This "clutch" is shown at "26'." The figure



shows this still more plainly. The lever is of the 3rd class; — power, fulcrum, weight, and by moving the handle of the lever in one direction, the "clapper" is turned in the other. The seat valves "23 and 23'" are lifted by a vertical rod socketed into a short horizontal one "22 — 22'" which in turn is fastened to a stout iron rod supported from the roof as shown, and running half the length of the chamber to the end wall. Here, "21'", another precisely similar piece of iron is attached to this main shaft and its free end to



a vertical rod running up through "20". The figure will make this plainer. The main shaft is here represented with the short pieces at either end. At one end it is connected with the valve below, at the other with the raising apparatus above. So when "a'" is raised, (as per sketch) "b'" is also elevated to the same extent by the rotary motion of the connecting shaft. "a'" passes up through the "standard" "20," and is raised or lowered by a screw cut upon its other end, and passing through a hand wheel playing upon the top of the "standard" and upon whose inner surface is cut a "thread" corresponding to that upon the rod. The accompanying sectional view shows the manner in which the second vertical rod passes through the standard. "a" is the main standard, "b" is the wheel resting upon its top, a screw thread being cut upon the inside of the hole passing through its centre. "c" is the rod upon whose upper end a screw is cut, and is fastened to the main shaft below. When the wheel is suitably revolved, "c" is raised, "a'" or "21" on the plan, is similarly elevated and consequently "b'" above, or "22" on the plan is moved vertically to the



same amount, and finally the valve "23" is lifted and gas admitted. The air valve is operated in precisely the same way. A similar rod inside of a third "standard" moves another lever, to the farther end of which a chain is fastened. This chain then passes over a pulley at "28", down through the gas flue at "30" and raises the sheet iron chimney damper at "29". The intensity of the heat in the furnace chamber depends of course upon the due amount of air let in with the gas. For getting the highest heat, it has been found best to make the air regenerator much larger than the corresponding gas chamber say as 3:2, or even more. So that when both valves are opened to the same degree, more air enters than does gas, and at the same time the temperature of the air is raised also to a much more intense point. When the gas emerges from its "ports" it meets a maximum amount of air necessary to consume it, and also at a higher heat than it has itself attained. Hence it is instantly burned and the entire amount of heat due to its combustion is delivered when it is most needed. By properly modifying regenerators, flues, form of arches etc, a flame of any desired intensity, length or character may be obtained. The amount of brickwork in the regenerators necessary to absorb the waste heat of any given furnace may be simply calculated. Taking an analysis of hard coal in Watts' "Dictionary of Chemistry," Vol I. page 1081, the calculation is as follows.

—Composition of the Coal—		—Oxygen required—
Carbon	.7857	× 8/3 = 2.0952
Hydrogen	.0529	× 8 = 0.4232
Sulphur	.0039	× 1 = 0.0039
Nitrogen	.0184	2.5223
Oxygen	.1288	less 0.1288
Ash	.0103	Net oxygen = 2.3935
	1.0000	20% excess = 0.4787
		Total oxygen = 2.8721.

Corresponding Nitrogen — — — — — — — — — — — 9.616.
Nitrogen in fuel — — — — — — — — — — — 0.018.
Total = 9.634

Gases produced from one lbs. of coal.	Specific heats	Equiv. wt. water.
Carbonic acid = 2.881	.217	.625
Water (steam) = 0.476	.480	.228
Sulphurous acid = 0.004	.154	.001.
Oxygen in excess = 0.479	.218	.104
Nitrogen = 9.634	.244	2.350
Total equivalent weight of water — — — — — — — —		3.308 lbs
" " " " firebricks (specific heat = 0.2) =		16.540 " .

Thus it would appear that about 17 lbs. of firebrick at each end of the furnace per lb. of coal burned per hour would be theoretically sufficient to absorb all the waste heat of any given furnace, the current of gas and air being reversed every hour. Practically only the top of the chequerwork is intensely heated for only about one fourth (1/4) of the way down, the bottom of the mass being quite cool, comparatively, so that three or four (3–4) times as much would be required. The "regenerators" are always placed immediately below the furnace proper, in order to create a draught and thereby force the gases into the furnace chamber. The saving in the cost of fuel by converting it into gas and consuming it in the way above described, is about one half (1/2) when using good coal. But as inferior kinds, otherwise useless, may be converted into a good quality of gas, the saving effected amounts frequently from 70–80 per. cent. A most intense degree of heat is necessary in order to melt steel on the open hearth. In melting steel in crucibles, the pots rest in burning coke, and are completely surrounded by the flame, while upon the hearth only the top of the mass receives the direct heat, the bottom being purposely cooled. The late Prof. Faraday while speaking of the Siemens' Furnace in his last public lecture before the "Royal Institution", says:—

"Carbon burnt perfectly into carbonic acid in a gas=producer would evolve about 4,000 °of heat: (The exact calculation will be found immediately following this quotation). but, if burnt into carbonic oxide, it would only evolve 1,200°. The carbonic oxide, in its fuel form, carries in with it the 2,800° in chemical force, which evolves when burning in the real furnace with a sufficient supply of air. The remaining 1,200° are employed in the "gas=producer" in distilling hydro=carbons, decomposing water etc. The whole mixed gaseous fuel can evolve about 4,000 in the furnace, to which the regenerators can return about 3,000° more!" The perfect combustion of 1 lb. of carbon requires about 12 lbs. of air, — hence the weight = 12 + 1 = 13. The total heat of combustion of 1 lb. of carbon is 14,500 thermal units; the mean specific heat of the products of combustion is 238, which multiplied by 13 = 3094. — 14,500 divided by 3094 = 4,689°, theoretical temperature of a furnace, assuming every atom of oxygen that was ignited in the furnace, entered into combination. (but this is impossible.) In an ordinary furnace twice the volume of air enters, and the temperature is reduced nearly one half. But in the furnace under consideration just enough air is introduced to supply the required amount of oxygen, so that the above figures may approximate to the truth. But for the want of two desiderata the Siemen's furnace as now operated, would be practically perfect. 1st. — A material sufficiently refractory to permanently withstand the intense heat which is developed, and 2nd. — some simple instrument to accurately measure its intensity; — so that the heat can be kept at any desired point for an indefinite length of time. With regard to the first point mentioned, the "Mt. Savage clay" answers the requirements better than any other material yet discovered. The flame to which the bricks are exposed is so entirely free from fine ashes that they are not fluxed and cut away but fail from simple fusion throughout their entire mass. The alkalis (potash & soda) add most to the fusibility of slags. The alkaline earths, oxide of manganese and protoxide of iron increase the fusibility, but in a less degree. Hence a refractory substance must contain little or none of these constituents. The composition of the hard "Mt. Savage" clay of which they use 5/6ths in making the brick is as follows: —

Water	13.02
Protoxide of iron	0.07
Lime	0.18
Magnesia	0.11
Silicic acid	56.21
Alumina	31.18
Organic matter and loss	0.23
	100.00

This analysis was made by Otto Wutte, Pittsburg, Pa. An analysis of similar clay by Prof. Ordway, gives more alumina and less silica than the above and about the same percentage of the other ingredients, with the exception of the protoxide of iron. The soft clay which they use to cement the rest together, contains a little more lime and magnesia, than the above. Note.

The statements made in reference to the degree of fusibility of the different elements named were based upon a report of Prof. Ordway to the Mt. Savage Fire-brick Co. in 1872. The bricks made from the above clay are put in all the more exposed portions of the furnace. So far as the writer is informed no instrument has as yet been perfected for measuring the highest heats of the Siemens' furnace, though one has been invented by Mr. Siemens', with which he has been moderately successful in measuring the temperature of ordinary reheating furnaces.

— The Process —

It has been stated previously that when the producers are first "fired up", the products of combustion are thrown into the tall chimney in order to give a proper draught. And that when the gas is of a sufficiently good quality, the chimney damper is closed and the gas is sent through the main flue (see drawing No. 1.) to the furnace proper. Here as has been stated, it enters "E", passes through "d", and the reversing damper "27" being in the position indicated, goes under the regenerator I, and finally comes up through the ports as shown by the arrows. A fire of wood having been kindled upon this (left) bank of the hearth, the gas on entering is fired and burns, the products of combustion going down the opposite ports and out into the chimney flue as previously described. After several hours the current is reversed and the heat consequently raised. This is continued, reversals taking place every hour, then more frequently, finally every twenty (20) minutes. It takes several days to heat up a Siemens' furnace to a sufficiently high degree to melt iron and steel, supposing the furnace to have been already used, and to be in good order. If the fires were started early Monday morning (1–2 A.M.) the furnace would generally be ready to receive a charge by Wednesday morning following. A quantity of cold pig metal is first thrown in and melted, the molten mass collecting at the lowest portion of the hearth in a pool several inches deep and forming what is technically called the "bath". Then wrought iron in the form of scrap, rail crop ends, rerolled scrap iron, and blooms together with scrap steel in various forms, is charged into the "bath" from time to time. The heavy pieces are placed in the "muffles" and heated to a bright redness, and then pushed over into the "bath". The small is charged in cold at the back doors of the furnace in small portions at a time in order not to chill the furnace. Instead of the muffles, there is in most establishments a preparatory simple heating furnace in which the wrought iron etc. is heated to the right intensity before being charged into the furnace. The waste heat from this small furnace also furnishes the necessary supply of steam for the pump which throws the water into the cranes drop lift, and for any mechanical power which may be necessary. This latter arrangement is specified in the Messrs. Martin's patents, and is more generally used than the "muffles" for previously heating the iron etc. —— ——

The arguments for an accessory furnace are the facts, that the cold iron takes up enough heat to diminish the intensity very perceptibly, some authorities maintaining that enough heat is thus taken up to more than run the secondary furnace, that the time of melting is increased by one to two hours, and sometimes even more: — that the temperature of the "bath" cannot so readily be brought to a very high point and so evenly kept there; that the "bottom" of the furnace cannot so readily be renewed after each charge, as the workman must work up hill, and finally that the surface of the large iron next to the "bath" in the muffles melts under the intense heat, and trickling down the "muffle" floor, gets into the sand composing the hearth and solidifies there. This mass is removed entire several times in a year. The silicon etc in the pig metal forms a vitreous slag of sufficient thickness to protect the molten mass from the action of the air. When the additions of wrought iron have been continued for some time, sample ingots are taken from the bath, broken and tested. This is accomplished by dipping an iron ladle into the molten mass and pouring the metal withdrawn, into a small mould. The fracture gives very good indications of the state of the charge.

The carbon burns off by degrees, the surface of the metal being in a state of constant and mild ebullition. There is no violent action, no "using" of the entire mass as in puddling iron. The wrought iron introduced also diminishes the amount of carbon by simple dilutation. The oxidation is continued either until the sample ingots indicate a proper state for the pouring of the charge; or else until the metal is completely deprived of carbon. In the latter case there is added to the decarbonized iron a sufficient quantity of previously heated spiegeleisen or ferro-manganese to supply exactly the desired amount of carbon and then the whole mass is well-stirred, and is now ready for pouring. The latter is the course pursued here excepting high metal for particular uses. Rich ores in a natural state, or more or less reduced, can also be employed to replace a portion of the wrought iron used. Steel has been made by this last modification of the process, but an excessive amount of the slag is produced, the furnace being more attacked, while comparatively little metallic iron is added to the "bath". The scoria ordinarily formed over the molten metal is now oxydizing, but a little rich ore added to it would make it oxydizing in its effects, and would cause a more certain and direct "fining" to take place.

In order to make the above more intelligible, the different times at which the iron of a particular charge was added, the precise amounts used, and the amount of the recarburizer employed are here appended. Charge "No. 465" was the one experimented upon and was made Jan. 20, 1874, for boiler plate stock.

Time	Material added	
7 – 40. a.m.	1,200 lbs	Workington Pig Iron.
8 – 40	686 "	Furnace Scrap.
9 – 0	1,040 "	Blooms, marked "λ" (crowfoot)
9 – 52	1,076 "	" " "
10 – 30	1,166 "	" " "
11 – 10	1,070 "	" " "
11 – 50	1,142 "	" " "
12 – 35	1,060 "	" " "
1 – 22	1,170 "	" " "
2 – 10	886 "	" " "
2 – 46	150 "	Ferro-manganese.
2 – 55 Tapped.		

Weight of Pig Iron used	= 1,200	Percentage	= 11.336
" " Scrap "	= 686	" "	= 6,480
" " Blooms	= 8550	" "	= 80.767
" " F.M.	= 150	" "	= 1.417
Total	= 10,586	Total %	100.000

Total weight of charge = 10.586 — Percents.
" " " Ingots = 7.699 ---- 72.728
" " " Scrap = 1.170 ---- 11.052
" " " Waste = 1.717 ---- 16.220
100.000 %

The per. cent, of ingots is quite low as will be seen from statistics given further on in the "process."

Total weight of coal for 24 hours = 68 Hoppers = 7,820 lbs. nearly.

Percentage of carbon = 0.13 (by combustion method)

— Notes taken in connection with charge No. 465 —

The melt was commenced by addition of Workington Pig Iron at 7–40 a.m. At 8.00 the lever of the valves was reversed. All the pig metal was melted in about 55 minutes, the furnace not being fully heated. Mass was then in a state of calm ebullition, and covered with slags. At 8–20 the lever was again reversed, and so on at every 20 mins, during the entire melt. Test ingot "No 1" was taken at 8–35 just before the first addition of metal, consisting of steel furnace scrap of similar composition to the charge under consideration – The moulds were then taken from the pit and the ingots of the preceding charge broken apart. At 8–40, 686 lbs, furnace scrap charged into the "bath," and first weight of blooms (1) laid into the muffles.

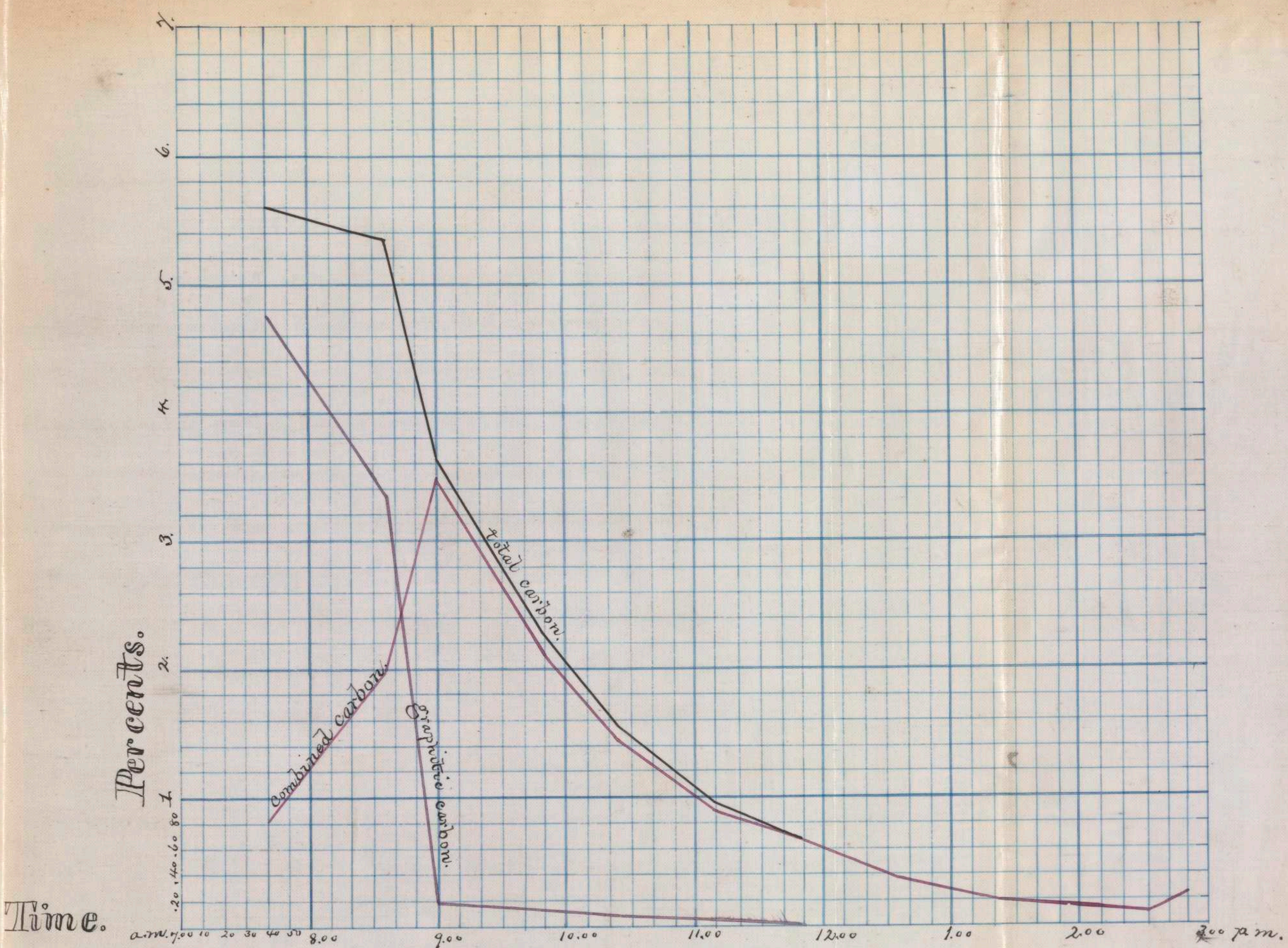
In 20 minutes, 9-00, test ingot "No. 2" was taken and (1) blooms pushed over into the bath, and the second weight of blooms (2) "laid in." Metal was in full ebullition and the blooms were gradually dissolved. 9.20, the furnace was growing hotter, the gas was shut off a little and more air admitted; the chimney drought was opened more at the same time, as the flame was somewhat smoky. At 9.50 test ingot "No. 3" taken, then blooms (2) nearly white hot were pushed into the bath. Third weight of blooms (3) were then laid into the muffles. The metal was calmly boiling, and furnace running a trifle hotter. Blooms do not dissolve as readily now as after their first addition to the bath, as the per cent of carbon diminishes. Blooms weigh from 200 – 250 lbs. apiece. At 10-25 test "No. 4" was taken. The moulds were smoked with burning resin and tapping hole "snout" lined and baked. At 10-30 blooms (3) charged and fourth weight of blooms (4) laid in. Note – It took 32 mins. to melt 1076 lbs - (2) blooms. Gas was middling fair, though made from poor slack. At 10-45 a fire was started in the ladle, by gas flame and air blast. Metal was calm excepting around the remains of the blooms mostly dissolved. The flow of gas not being so free, the "fires" were hurried up, and a little more gas let into the furnace chamber. At 11-10 test "No. 5" was taken, the blooms (4) charged in and the fifth weight of blooms laid in the muffles. The metal now began to resemble steel. Furnace was at almost full heat. Valves not altered since 10-45. 11-50, test "No. 6" taken, and blooms (5) charged. Violent ebullition took place. Furnace was now at full white heat. The moulds were set in the pit for casting, and at same time, sixth weight of blooms (6) "laid in". Ladle becoming quite hot, valves unaltered. At 12-35 test ingot "No. 7" was taken and blooms (6) charged, and then seventh weight of blooms laid into the muffles. At 1-20, test ingot "No. 8" taken (7) blooms charged and the eighth weight of blooms laid in. At 2-10 test "No. 9" was taken (8) blooms pushed into the bath. Furnace at full heat, chimney damper was closed a trifle more, and gas valve opened more. 2-32 test ingot "No. 10" taken. The stopper to the ladle was then heated in the small front door. 2-46, the tapping hole was "dug", and the superfluous sand removed, in readiness for casting. Metal was in a very calm state, there being almost no boiling whatsoever. Ferro-manganese laid into muffles and in a few moments charged. The entire mass was then thoroughly stirred with hooks, and the last test "No. 11" taken after its completion. The gas was now shut off from the ladle, the heated stopper adjusted & the whole run up to the "spout". Gas shut off, tapping bar driven in, metal drawn, drained and poured at 2-55 P.M. As soon as the "pouring" is completed the "melter" cleans the furnace bottom of any metal or slag which may remain, and repairs it with fresh sand. The producer "fires" are also "banked up" until 12.00 M. following, when the grates are cleaned, the fires renewed and the furnace heated in readiness for the next charge. A table will now be given showing the number of ingots taken, the various times, the per. cent. of carbon in each, and the diminution of carbon from ingot to ingot.

Number	Time	Graphite	Combined Carbon	Total Carbon	Difference
	Work Pig Iron	3.178 —	0.552 —	3.7300 —	
1.	8-35	2.2498 —	1.3240 —	3.5738 —	0.1562
2.	9-00	0.0958	2.3340 —	2.4298	1.1440
3.	9-50	0.0830	1.4220	1.5050	0.9248
4.	10-25	0.0650	0.9587	1.0237	0.4813
5.	11-10	0.0560	0.5557	0.6117	0.4120
6.	11-50	traces	0.4379	0.4379	0.1738
7.	12-35	——	0.2491	0.2491	0.1888
8.	1-20	——	0.1346	0.1346	0.1145
9.	2-10	——	0.0950 —	0.0950	0.0396
10.	2-32	——	0.0749 —	0.0749	0.0201
11.	2-50		0.1470	0.1470	0.0721 more

Rolled steel of same charge — 0.1320 —

Total carbon in all these ingots was obtained by the chloride of copper method, Graphite in usual way by solution in HCl acid.

59 continued. — In order to more plainly set forth the results of these carbon determinations, "Curves showing graphically, amts and condition of carbon in the Bath" have been subsequently constructed, and are here appended. Vertical distances indicate Per Cents. the distances being shown double the actual value in order to more plainly show the real differences during the progress of the heat. Horizontal distances indicate times of taking the tests.
The "black" line indicates the "total carbon", the "crimson lake" the "graphitic carbon", and the "Carmine" line, the "combined carbon". The point where the "total carbon" becomes all "combined" and the "graphite" disappears is very marked. Also the rise of carbon after the final additions of "Ferro=manganese" to the "bath" is sharply indicated.
A similar series of tests for the "Sulphur" and "Phosphorus" would be very instructive but have been reluctantly omitted by the author for want of time.



Curves showing graphically amt's. and condition of carbon in the Bath.

It will be seen that after the addition of Ferro-manganese, the metal was immediately poured, as if left standing for even 20 minutes or less, the beneficial effects of the recarbonizer would be entirely lost. Upon examination of these carbon determinations it will be seen that although the absolute loss of carbon in the original pig iron charged is quite small, yet a large part of the Graphite is taken up by the iron and chemically combined with it during the hour in which it is heated by itself. This accounts partly for the large amount of carbon which disappears when "No. 2" is taken. The combined carbon burns off, very rapidly, and the introduction of the low similar scrap (below 0.20% probably) steel keeps along the reaction. With the exception of the break between "1 and 2" the series of differences is a pretty uniform one. By the time "No. 6" is taken the carbon has mainly disappeared. "No. 10" was taken just before the addition of Ferro-manganese and represents the lowest amount of carbon reached in the descending series. The Ferro-manganese contains 4.74% carbon. 150 lbs. of it would consequently raise 10.586 lbs. of metal containing 0.0749% carbon to 0.1420% carbon, a very close agreement with that actually found. It will also be noted that the metal after having been re-heated twice and rolled into plates loses a small amount of its carbon. These ingots were taken just before every fresh addition to the bath, so that the previous addition might have its full effect. Inasmuch as the metal was taken from the "bath" at a very high heat, and cooled suddenly in a small iron mould for the various test pieces, it may be the small amounts of Graphite found in "Nos. 3 to 7," may be partly owing to the chill the metal experienced in the manner of handling it. When such ingots are drilled and broken an examination of the cavity and fracture will give an approximate idea of the state of the metal at any one time during the process. "No. 1" was simply re melted cast iron. It was solid, easily broken and had the characteristic fracture peculiar to this metal. It was not quite as black as the original "No. 1 Foundry Pig" first used for the "bath". No II was also solid. It was harder and tougher than "No. 1". The crystalline structure was better developed. It cuts a little harder than "No 1". No. III. was nearly solid; the crystals were larger and brighter than ingot No. II. The metal was also brighter and tougher in cutting. Ingot No. IV, was cavernous and showed larger crystals than No. III. It was quite tough and hard to drill. Ingot No. V, was considerably cavernous, showed larger crystals than any of the previous ingots. It was very bright and tough. Ingots Nos. VI, VII, VIII, IX. X, were similar to No. V, each successive

Pg. 61 continued. In order to more plainly show the differences between the various tests in density, a "Curve showing diff.ce in sp. grs. of the diff. tests" is appended. Vertical distances indicate "Specific Gravities" with real values attached, while horizontal distances show the number of the particular tests, begining with No 7, which is simply remelted pig iron.

sample approximating more nearly to the condition of wrought iron, and becoming more and more cavernous and brighter and larger in its crystalline structure. No. XI, the finished product, was tougher than any of the rest. In cutting, the metal seemed almost to tear apart, it was very malleable and bright. It looked fibrous and did not cast solid. These indications are of considerable importance in judging the state of the charge at any stage of the process. Excepting in very high steel, containing over 1.00 percent or even more of carbon, the absolute amount of carbon throughout the mass is very uniformly distributed. The top and bottom of a number of ingots in the same "group" and also in other groups of the same charge, have been carefully tested and no appreciable variations found. In order to show the density of the metal at different stages of the process, the specific gravity of each "sample ingot" as well as the rolled steel of same charge was taken:—

Density	No. 1	7.380
"	" 2	7.557
"	" 3	7.816
"	" 4	7.849
"	" 5	7.864
"	" 6	7.812
"	" 7	7.734
"	" 8	7.764
"	" 9	7.723
	No. 10	7.763
	" 11	7.763
	R.S.	7.899

10.586 lbs. of metal were put into this charge of which 1.717 lbs. were lost, and the remainder was in the form of "sprews", "runners" and "ingots". This gives a loss per cent of 16.22. Annexed will be found several per cents, showing the entire waste for different recent quarters. Per cent of waste for the quarter ending Mar. 31. 1874 = 10.497

" " " " " " " " June 30. " = 10 +

" " " " " " " " Dec. 31. 1873 = 10.567

" " " " " " " " Sept. 30. " = 11.08

Thus it will be seen that the average loss per cent is something over 10%, and that the above per cent is exceptionally high. The metal may be kept in the melted state, as homogeneous wrought iron, for a moderate length of time before the recarbonizer is added. This affords a good opportunity to add reagents to improve the quality of the steel produced, and to eliminate the impurities. Some experiments have been made in this direction. Note — The "Eggertz method" is the one most generally used for the determination of combined carbon in steel. The per centage of carbon thus present is indicated by the comparative intensity of color. Under certain conditions this method is apt to fail for the "extremes" of the series. In samples containing over 1.00% carbon, the color is so deep that excessive dilutation must be resorted to, to bring down its intensity to the standard color with which it is compared. Below

Analysis of Swedish Pig Iron, branded [Amf / 2T].

Silicon	0.5088	
Combined Carbon	1.0076	
Graphite	3.1286	3.022 (incidental)
Sulphur	0.01966	0.01999
Phosphorus	0.01659	0.01934
		0.01699
Manganese	0.73000	0.01620
Iron (diff)	94.58875	4.1174 Total
Total	100.00000	4.1550 Carbon

This iron is used entirely for the bath at the Norway Iron Works, South Boston, and to a considerable extent at Nashua N.H. The analysis was made by the writer July. 1874.

0.15% so little carbon is present that no more intensity of color is obtained, than would be secured by a <u>similar</u> solution of piano wire in nitric acid. The paragraphs on the "Quality of the Metal" will be found by themselves further along in this report, and the various substances which improve or deteriorate the same will be noticed at the same place. The cast iron used for making the bath should be very pure and carefully selected. It must also melt easily. "Grey" pig iron of superior quality is therefore taken. The "Cleator," "Carnforth" and "Workington" brands of <u>No. 1. Foundry Pig Iron</u> from West Cumberland, England have been successively used at Nashua. They are all made from the best of Hematite ores and are smelted with "<u>coke</u>". These same brands and numbers are very much used in the "Bessemer" process. Annexed will be found some analyses of these irons.

	(1.)		(2)	(3)		
Silicon	1.96	1.98	1.51	0.360		
Com. carbon	0.55	0.53	.60	0.552	3.7300	Total
Graphite	3.25	3.24	2.98	3.178	3.7287	Carbon
Sulphur	none	0.005	—	0.052		
Phosphorus	0.008	0.005	trace	0.016		
Manganese	(prob. a little present)			0.080		
Iron	94.232	94.24 (diff)		92.962 (By diff.)		
				Slag 2.80		
	100.000	100.000		100.000		

(1) "Cleator" pig iron by J. Dods Esq. formerly at Bay State Iron Works.
(2) " " " " Mr. Williams M. I. T. out of a different lot.
(3) Workington " " " the writer " " " This iron was used in charge #465.

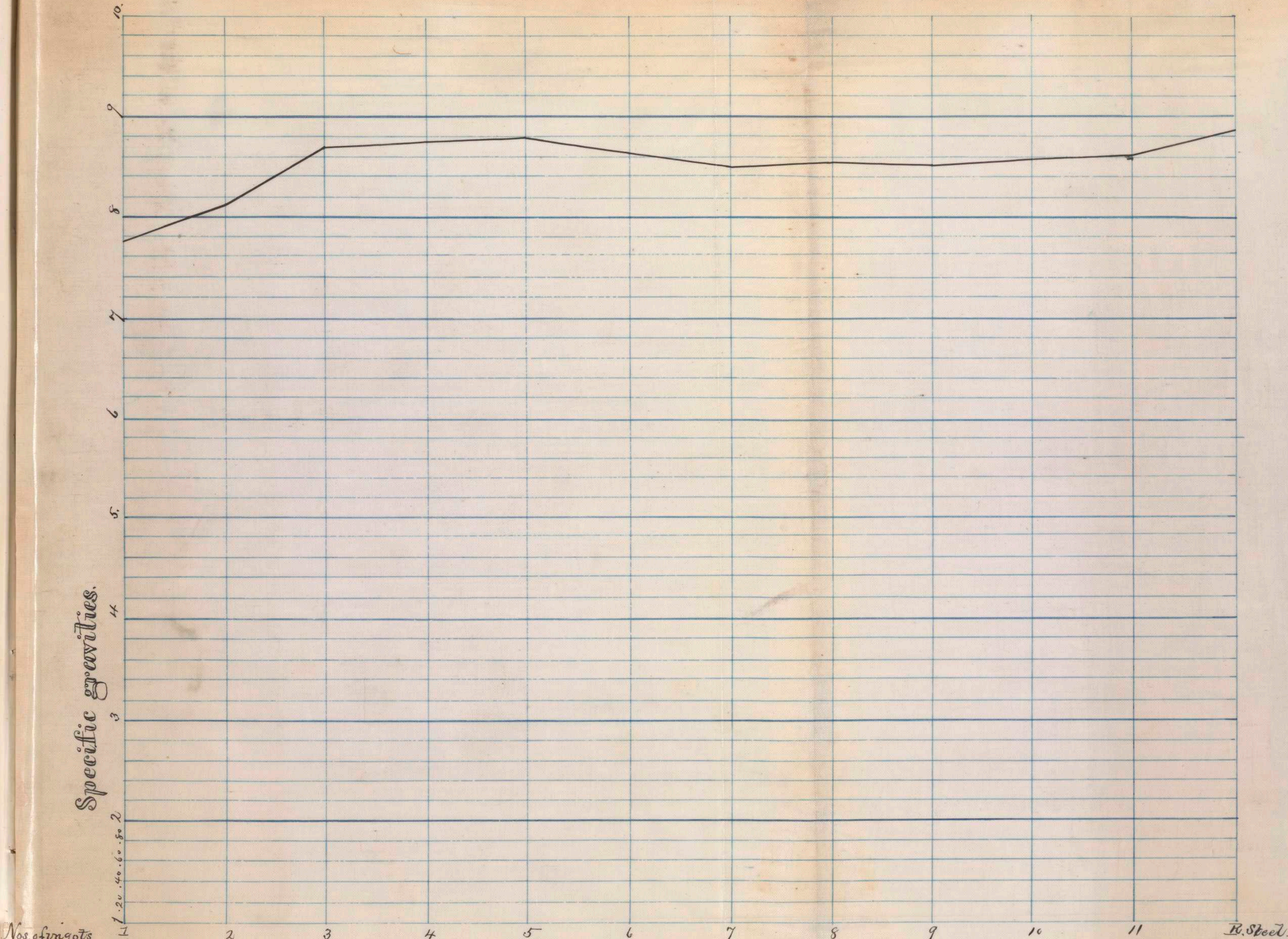
Note. (continued) — Between these limits the "Eggertz" method affords a very valuable and rapid, though comparative process of obtaining the combined carbon in steel. J. Blodgett Brittain Esq. has proposed a modification of this method and it has been largely adopted by the iron chemists of the United States. (No. 465,) the one under discussion. The silicon in this charge is probably a little low and the slag proportionately high. The per centage of total carbon in all three is very nearly alike, viz. — "Cleator" = 3.78%. "Carnforth" = 3.61% and "Workington" = 3.73%. The ingots from charge No. 465 were reheated and rolled into boiler plates. An analysis of some of the "clippings" of these plates gave the following results.

Graphite	———	
Combined carbon	0.130	{ 0.1820 / 0.1297
Manganese	———	
Sulphur	0.028	
Phosphorus	0.011	
Slag	0.071	
Iron (by diff)	99.760	
	100.000	

The writer has made no analysis of the "blooms" used in this same charge, but inasmuch as they constitute 80.767 per centage of the entire charge, it must be inferred from the above analysis that they are very pure and almost entirely free from Sulphur and Phosphorus. These "blooms" are made from the best magnetic iron ore, taken from the "Rodger's Bed," Lion Mountain on Chatauguee Lake. Northern New York. The writer visited it July 4th 1873 and collected specimens. The "blooms" are smelted with charcoal in a Catalan forge of the usual form employed in the Adirondacks. In order to give an idea of these wrought iron "blooms", an analysis of similar iron, furnished by the Jefferson Iron Co. and smelted from Jefferson magnetic ore will be given here - These blooms are marked "PC", and are used for making boiler plate steel at Nashua. The analysis is by Otto Wuth Esq. Pittsburg Pa.

Silicon	0.014
Sulphur	slight trace
Phosphorus	0.027
Carbon	0.280
Slag	0.260
Iron	99.412
	100.000

In making high steel, ferro-manganese cannot be used alone as a recarburizer, for as it is lighter than the mass to which it is added, it rises and floats upon the surface and cannot be made to combine intimately and uniformly with the main body of metal. Hence cast iron or low spiegel is used with the ferro-manganese. Pig metal made from Franklinite iron ore and containing considerable manganese is very suitable for this purpose. A description of this iron which is made by the N. J. Zinc Co, and an analysis of the same have already been given on page 28. — From 30 to 40 charges can be made under ordinary circumstances without material repairs. Then the "roof" must be replaced and sometimes the top of the "ports", and even the sides above the hearth level. 64 charges have been made at Nashua without repairs but that is the best ever done by the furnace there, although the Mt. Savage bricks are very refractory, still they fail after a time. Frequently the sides of the ports become so much softened that portions can be removed by iron hooks when the furnace is at a very high heat. Specimen No. 6 shows how the under surface of the arch is eaten away. No. 7 is a part of the ports. Some of this last specimen is a true igneous rock, showing no trace of the sand from which it was formed. When the arch needs replacing a temporary scaffold is built over the hearth, of a form similar to the final shape of the roof; — sand is heaped up on this, to the required height and form, and the bricks are cemented together resting on this sand. This gives the required shape and when dry, the supports are removed. While the "direct process" has been progressing, other arrangements preparatory to casting have been simultaneously going on. A slight reference has been made to these operations on the 55–57th pages, and they will now be elaborated in full. The "ingot moulds" must be dried and arranged in "groups" at the bottom of the casting pit and the "ladle", into which the steel is first poured, must be heated to bright redness. In order to give a clear idea of the form and position of the moulds whether simply ingot or miscellaneous, reference will now be made to drawing "No. 6" and also to the wooden model accompanying it. The molten metal when allowed to run from the "ladle," falls into an erect, hollow column, and thence by channels radiating from its base, runs into the bottom of ingot molds placed equidistant from the central supplying column. The drawing gives a central section and also a plan view of a group of moulds, showing their position on the "group plate", and the way in which the whole is put together and handled. The centre column, called a "runner" is composed of three parts firmly fastened together when in position for pouring. 1, 2, 3, in section "A, B." represents these parts. They are made of cast iron, and have a "rib" on each side to strengthen them. Each piece is lined with a mixture of fireclay, sand and yellow loam to protect it against the molten steel. They are lined separately, the lining hardened by fire and when the group plate is ready to receive the "runner", they are placed in proper position and securely fastened. "No 1" is flaring at its top in order to better receive the molten metal. "2" is a simple cylinder and "3" is shorter than the other two, and is rounded out at the bottom to give free egress to the fluid material. The several parts are fastened at "f" and "f'". The "runner" is made higher than the ingots in order to give the mass a pressure upwards and make it more solid. "e" in 1 shows the position of a round, projecting piece of iron by which the whole column is lowered. "c" shows its form upon the plan view. "d" and "d'" show the "group plate" itself. This consists of a plate of cast iron about $1\frac{1}{2}$ inches thick, of 16 sides, having a circular depression in its centre and from which radiate eight (8) channels, square in their form and extending and extending nearly to the rim of the "plate". These are filled with fire brick shapes, hollow in the centre to allow the passage of the melted steel. "c" and "c'" show these bricks and the way in which they are placed in position. "Section through C. D", show the view transversely and also the square of firebrick under each ingot mould, in order that the steel may not come in contact with any part of the iron of the plate. "b". "b'" shows a section of two opposite ingot moulds, cut on a line at right angles to the main section line "A. B." These are made of cast iron and are slightly tapering in order to give a pressure to the molten mass as it rises in them, and to remove the moulds readily when cold. "k" is a wrought iron staple, cast in, and is used as a support for the crane when handling them and also to hold a key driven through the top of the "stopper", which closes the mould. The ingot moulds rest firmly without being fastened to the bed plate, "the runner" not being perfectly stable is secured by the arrangement figured in the two views. "p" is a flat piece of wrought iron bent at right angles at one end, the other extrem



Curve showing diffᵉ in sp. grs. of the diff tests.

J.A.H.

ity passing over the lower lip of the bottom piece "3." "g" passes through "h" and also down through the plate, where it is fastened by nut "j." The key "i" passes in turn through "g" and when firmly driven in holds the whole in place. The other view is shown upon the "plan", the same letters indexed indicating similar parts. "4," "5" "6" in sectional view show 4,' 5' and 6' in perspective. "l" is a wrought iron pin, cast in, and is used as a point of attachment for the crane. The "runners" are first lined, baked, and then keyed together. The "plate" is filled with firebricks, accurately fitted to each other, heated, and lowered into the casting pit to final position for pouring. Previously the ingots are washed over on the inside surface with black lead, and thoroughly dried, and heated by placing red hot pieces of iron in their interiors. Sometimes the smaller ingot moulds are coated over with soot, deposited by burning resin under them as they are swung from the crane over the pit. When the "plate" is adjusted the "runner" is lowered and fastened into position as described above and lastly the ingot moulds are lowered one by one and placed in position, and the "group" is ready for the molten metal. It is very essential that the moulds should be absolutely dry, for the least dampness will cause the steel to fly and serious accidents may occur. The moulds should also be "quite warm" so as not to chill the steel and prevent its rising. In regular working, the ingots are not removed until the day following, a short time before the "pouring," so that they retain a sufficient amount of heat for this purpose, the plate, of course, as well as the "runner" being duplicated and ready. The way just described has been found to be the best arrangement for the purpose though several other forms of "group plates" are in use. Latterly a "reservoir" has been added to the top of the "runner" and greatly facilitates the operation of pouring. In making castings the same general form of apparatus is used, the channels not used being "plugged" up at the centre. In making large castings the metal is poured directly into the top of the mould. The bottom cast ingots are always firmer and cleaner as the molten mass rises steadily and uniformly, and also under pressure, along the sides of the moulds. After the main process is well inaugurated, the "ladle" is placed upon the rails at the end of the casting pit, and its interior heated to a bright redness, as it is very necessary that it should be quite hot in order not to chill the steel when it is poured into it from the furnace. To accomplish this purpose, a sheet iron cover fitting loosely is placed over the ladle, a sheet iron pipe bent twice at right angles is attached to the gas pipe by one end, and its other extremity dips nearly to the bottom of the ladle. Gas by the side flue is then let on by turning the damper ("g" in No. 1) ignited at the bottom of the ladle and a blast of air is sent into the delivery tube at the point where the tube dips into the ladle making a "blow-pipe" flame and thoroughly heating its interior.

— The Ladle —

This consists of a truncated sheet iron cone of small inclination, closed at the small end, and securely fastened together, and lined with a refractory plastic material. The ladle is provided with an orifice in the bottom, which is closed at will by a "stopper", appropriately hung and is mounted upon an iron carriage in order that it may be moved from place to place over the pit. Drawing "No. 4," shows a plan, front elevation, side elevation and longitudinal section of the "ladle". The sides are made of one piece of boiler plate, and the bottom is also constructed from a single plate. The lower piece is flanged several inches around its edges and riveted to the sides, as shown in Section "A. B". "b," being the iron exterior. "a" is the lining of same materials as were used in lining the runners. This lining is tapering upon the sides in order to strengthen it, and the bottom is thickest nearest the sides and slopes toward a common centre where the orifice for pouring is located. The bottom lining is finish ed first and then the sides are built up little by little in concentric layers, the top of the plastic material being kept moist that the next layer may adhere firmly. The orifice for casting is composed of a round perforated block of fireclay. "f", set in a cast iron frame which projects through the bottom. The main frame of the ladle is stayed by two bands of wrought iron which pass "under the bottom, and connect half-way up the sides with the trunions upon which the ladle revolves, and also by a broad band "b" riveted to the sides. "A" shows the "stopper" which cuts off the molten mass from the orifice "f" and which can be raised or lowered at will. It consists of a piece of round iron bent twice at its upper extremity and having the part within the ladle protected by a refractory covering. The fire clay "shape" "c" is fastened to "d" by a bolt "e", which passes up through its centre and is secured by a key driven across "d" through its top. The hollow in the bottom of "c" is then closed with a little fireclay. The blue color should go the entire length of "d" but is broken off in order not to confuse the drawing. A cast iron frame "k" is bolted to the front of the ladle. This frame is provided with "~~grooves~~ grooves" in which the wrought iron piece "j" plays. "d" is let into the top of "j" and is fastened in place there by a key. The arm "m-m" is fastened to "k" (see front elevation) and is also connected to "j" and when moved, by its leverage, it moves "j" and thus raises

*. The writer encloses a paper on "Improvements in ladles &c" read at the "Chattanooga Meeting of Mining Engineers" and showing improvements in manner of operating the ladle, designed by the writer for the new steel shop of the N. I. & S. Co built by the Compy in 1877.

the stopper "A". "j" is prevented from dropping out by a pin at "n" (or "n'") fastened to "k" and projecting through a long slot in "j". A thread is cut upon the projecting part of this pin, and a similar one upon the inside of the "clamp" n – n'. Hence the stopper can be readily held at any one place by turning the clamp until it binds "j" in the grooves. "g" shows a section through the frame of the carriage, the exterior being shown in plan at "g'" above i – i'. are the wheels supporting the frame. "O" is a large toothed wheel, fastened to the "axle" or "trunion", and plays into an endless screw below. This screw, "q" is fastened to an inclined rod "p" at whose farther extremity a crank is adjusted. By turning this crank "o" is revolved and the ladle turned over. "o" and "q" are shown in blue lines in order not to confuse the drawing and the right hand wheel is represented cut away, in order to show the way "p'" is supported. "S" is the support in which the trunion "r" rests. The ladle is drawn along by a chain fastened to the link "h – h'". The stopper "A" is heated separately at the same time as the main ladle, by placing its end "c" just inside the small front door of the furnace*. While working, a large sheet iron platform is placed over the end of the casting pit, and when the process is completed and all is ready for pouring, this is swung off by the crane "1", drawing No 1. The cover of the ladle is also removed and the iron heating pipes and the gas and air shut off. The capstan "p" is manned and the heated ladle, with adjusted "stopper", is run up under the "spout" of the furnace. A piece of joist is slid under the frame work of the carriage on either side and rests in an iron socket there, planks are placed across the staging and a temporary platform thus formed upon which the workmen stand while driving the "tapping bar" through the furnace bottom. This is done by placing the iron bar in the end of the trough, and striking its extremity with a heavy iron billet swung on a chain fastened overhead. The hearth is quite hard and often the operation of piercing it, is by no means an easy one. When the bar is driven through, it is twisted around several times and then withdrawn and the fluid metal follows. The hole is then enlarged by a smaller bar to the full extent, and while the metal is flowing into the ladle, the planking is removed. When the steel is nearly removed from the furnace, the handle of the ladle "m–m" is depressed and the metal allowed to run out of the ladle into the first group of moulds below it. When these are filled and the furnace entirely emptied, the orifice in the bottom of the ladle is closed and the chain drawn in until the ladle is just over the "runner" of the second group, when the handle is again depressed, and the group filled, and so on until the pouring is finished. Sometimes the top of the ingot moulds are "stoppered" with pieces of cast iron, keyed in place. This prevents the steel from overflowing, boiling over, or "spirting". The same effect may be produced by placing a shovelful of damp yellow loam over the top and "tamping" it down with the shovel. This chills the steel which immediately hardens at that point and prevents the metal from "boiling over" although it leaves the ends of the ingots more ragged than in the first instance. It is necessary that the ladle and moulds should be very warm else the steel will chill on the outer surface and cause much trouble. No dampness can be allowed as steam would instantly be formed and a violent scattering of the molten mass result. After the steel is all poured, the ladle is run to the farther end of the pit, reversed by the crank above described, and the "slag" is allowed to run into a sheet iron vessel placed below to receive it. The slag should be of a vitreous, transparent nature. Opaqueness is caused either by the hearth material becoming fused, and mingling with it or by the iron combining with it, as silicate of iron. These cases can be distinguished by comparing the physical aspects of the slags. As soon as the metal has fairly solidified, the first two joints of the runner are unclamped and broken off, one after the other, the third being fastened to the plate itself. This is done for convenience as they are more easily separated while red hot.

The "runner" steel is always remelted. The main plate and the ingots are left until the following morning, partly in order to keep the moulds hot for the succeeding charge. The moulds are then drawn off one by one from the ingots themselves and the plate finally lifted from the casting pit and reversed to free it from the remains of the bricks and clay. It is then repaired for a subsequent charge. The ingots connected together by the small runners ("spruers") at the bottom, are placed under the "Drop" (drawing No. 1) and broken apart by a heavy iron ball which is allowed to fall upon them. The furnace hearth is repaired after each charge by filling all the depressions with sand of a proper nature which is filled in through the doors in a large iron "spoon", put in place, smoothed over and rammed in firmly. As before stated moulds at the time of casting must be dry and quite warm. Hence when moulds for miscellaneous castings are constructed, they must be heated gradually for some time, until thoroughly dry, before they can be used. A separate furnace or "oven" is used for this end. Its location is indicated upon the "General Plan" and a complete drawing, No. 6. shows its construction. This "oven" consists of a brick chamber arched at the top, having cast iron plates upon its bottom, and provided with swinging wrought iron doors in front. It is heated by a regular arched fireplace and the flame produced goes over the bridge and circulates among the moulds put therein. Small moulds are carried in, but the larger ones are placed upon cast iron carriages and rolled in. Three sections are given. That through "C.D" shows the interior longitudinally. "A" is the oven chamber in which the moulds and castings are placed. "B" is the firechamber, enclosed in refractory brick. The grate bars are here shown, as also the charging door for the fuel which is hard coal or coke; "C" represents the ash pit, closed by an iron door as usual. The products of combustion pass forward and enter by square holes into flues in the main wall, thence upward and over the main arch through a special flue to the chimney, which is located in the centre in the position indicated at "d". "d" shows this top flue and the manner in which the bricks composing it are supported on the upper side. The other two sections show different views of these same parts. The arrows show the course of the escaping gases. The manner in which the doors are hung, and the walls braced and securely held in place is plainly indicated on the several sections. When the drying is completed the moulds are cleaned and immediately transfered to the casting pit. The same furnace can also be used for annealing castings.

— Quality of Metal produced —

One great imperfection of the process is the difficulty of making perfectly sound, homogeneous ingots. In low steel these are always more or less cavernous. This difficulty is partially overcome however, when the product is to be reworked, by reheating and putting the ingots under a heavy hammer or through a large train of rolls. By increasing the height of the "runner" and "stoppering" the moulds, a pressure can be brought to bear upon the fluid steel and the metal made more dense. During the last two years ('72–'74) experiments have been made to demonstrate the feasibility of absolutely compressing the fluid metal and thereby made it dense and free from "blowholes". These have in the main succeeded, and promise good results on a larger scale in regular working. When castings are made, the steel is highly charged with carbon and becomes more mobile, and the excess of carbon subsequently removed by annealing. For this purpose the castings are brought to a red heat in some auxiliary furnace, then buried up in ashes, the fire is kept burning slowly all night, and is then allowed to go out, while the castings are left several days in the furnace to cool. A considerable amount of combined carbon is thus eliminated and the product made correspondingly tougher. Several grades of metal are produced for different uses, the percentage of combined carbon ranging from 0.15 ~~to~~ .18 to 2.00 per cent. From 0.15 to 0.20% of carbon the steel is very tough and malleable and is used mostly for plates, though some descriptions of forgings are also made from this grade. From .20 to .26% the steel is very tough and a trifle more rigid and is used for car axles, piston rods and some kinds of rolled bar or merchant steel. These two grades constitute what is called technically, "mild steel". From 0.27 to .39% causes the resulting metal to become a little harder and suitable for crank pins, slide bars, and some varieties of merchant steel. From 0.40% to 0.69 causes increased hardness and rigidity and makes metal suitable for chisel points for drills, and more especially for blooms for locomotive tyres. From 0.70 to .90 quite hard and technically termed "high steel". This steel may be tempered and can be made into "spring" steel. Up to 1.00 per cent of combined carbon, when manganese is added just before the pouring, the metal can be rolled and hammered. Beyond this point from 1.00 to 2.00 per cent, the metal is made into castings and annealed as above stated. It is very tough and hard and makes very excellent hammer dies, blocks, railroad frogs, hydraulic cylinders and any casting where great strength and endurance is desired, and where comparatively little "tool" finishing is required. This high steel cuts with great difficulty and hence cannot be worked to any considerable extent. A very fair grade of steel can be made from scrap iron and steel, but when the very best quality is desired, charcoal blooms with one of the cast irons above described should alone be employed. The writer has had no opportunity to personally test the strength of this description of steel but will give a few statements in reference to its tensile strength. A sample from charge #61 made from the best materials and containing 0.73% of combined carbon was tested. The tensile breaking strain of one inch square section = 119.440 lbs. A sample of charge #64, containing 0.30% carbon, of one inch square section gave a breaking strain = 80,264 lbs. A sample of charge #32, containing 0.66% carbon of one inch square section, gave a breaking strain = 88,608 lbs. These two last were made from poorer stock. Two samples of best "Nashua Steel" were afterwards tested, one of "No. 2", the other of "No. 3" steel. These test pieces were drilled and analysed by the chloride of copper method by the writer. "No. 2" contained 0.6528% carbon. "No. 3" contained 0.245% carbon. Tensile breaking strain of "No. 2" = 127.510 lbs, Density = 7.8552. " " " " "3" = 84.249 " . " = 7.8528. The tensile strength of the best English

The writer encloses a copy of the "Report of the Naval Constructor" from the Boston Navy Yard to the Commandant of the Yard of tests made of boiler plate mild steel made by himself at Nashua. The tests were all taken from the regular manufacture of such metal, & were not especially selected for testing purposes. They were at that time esteemed remarkably good tests though since then every standard maker of plate metal has reached similar results. The recommendation of the "Constructor" has been followed & with good results. Metal has been made up to 0.33% of carbon with 40 – 45 tons breaking strain and 53 per. ct. elasticity (Gov. tests) with the grain, & 50 per. ct. at right angles with the grain. This is an extra test & metal was used for gun blocks for howitzers. It will be seen that the elasticity of Nashua plate metal runs from 25 to 30 per. ct. and this is the regular average result.

[COPY.]

United States Navy Yard, Boston.

NAVAL CONSTRUCTOR'S OFFICE,
November 4th, 1873.

In compliance with the order of the Commandant to test certain samples of steel, which have been furnished by the NASHUA IRON AND STEEL COMPANY for that purpose, We would respectfully report that we have attended to that duty, and beg leave to submit the results of the tests.

The first test was made with reference to the tensile strength, and for that purpose two (2) pieces were selected from plates having a thickness of nine-sixteenths (9–16), ten-sixteenths (10–16), and eleven-sixteenths (11–16), respectively. These six pieces gave a mean tensile strain of twenty-seven and eighty-two one-hundredth (27.82) tons per square inch, of original section, sixty-five and thirty one-hundredth (65.30) tons per square inch of fractional section, an elongation of two and one-sixteenth (2 1–16) inches in a length of eight (8) inches, and a mean strain of nineteen and six one-hundredth (19.06) tons per square inch without stretch, or sixty-five (65) per cent. of breaking strain. The elongation was the same in all the samples and the strength was remarkably uniform.

The cold forge tests were made with plates nine-sixteenths (9–16) and five-eighths (5–8) inches in thickness. It was found that the samples could be folded over until the surfaces met, without any perceptible evidences of fracture. A nine-sixteenth (9–16) plate was placed over a hole nine by nine (9x9) inches square in a piece of wrought iron, a six (6) inch cast iron shot was then driven down by a two thousand (2000) lb. steam hammer having a mean stroke of twenty-four (24) inches, until the calotte or cup thus formed had a depth of four and three-eighths (4 3–8) inches. The lower surface was then thoroughly examined and no signs of fracture could be detected. A second trial was then similarly made upon a plate eleven-sixteenths (11–16) inches thick, with a view to ascertain to what extent this test could be carried without fracture. After breaking three (3) shot, a wrought iron cylinder with a spherical end was substituted, and at about the sixtieth blow disintegration took place along one side of the cup at a distance of two (2) inches from its bottom. The thickness of the plate at the point of fracture was reduced to one-quarter (1–4) of an inch, the depth of the cup being four and seven-eighths (4 7–8) inches.

When heated it was found that the plate could be folded over until the surfaces met, and then bent in the opposite direction to a similar position without fracture, and after repeating this operation four times only a slight fracture took place. Hot tests were made also in the following manner.

A three-quarter (3–4) hole was punched in a cold plate; the plate was then several times heated and the hole pinned out until a cylinder was formed five (5) inches in diameter and five (5) inches long. After it was thoroughly cold a flange was turned down all around the end, the surface remaining perfectly free from cracks and other defects.

Right angled, inside and outside corner flanges were formed with the greatest ease; no amount of heating appeared to affect the malleability in the least. With a view to ascertain if the scrap which would be made in building a ship could be utilized, about sixty (60) lbs. of samples were made into three-quarter (3–4) round bar in precisely the same manner as ordinary iron.

The tensile strength of this bar was found to be twenty-nine and sixty-two one-hundredths (29.62) tons per square inch, or one and eight-tenths (1.8) tons more than from the original plate. Several rivets were made from the bar which stood a double shearing strain of twenty-one and fifty-five one-hundredths (21.55) tons, or forty-eight and seventy-six one-hundredths (48.76) tons per square inch. After carefully examining the results of these tests, we are of an opinion that the metal is admirably adapted to ship building purposes, more especially for armor plates, but think its value would be increased if its tensile strength was brought up to about thirty-five (35) tons per square inch, its malleability being in its present condition unnecessarily great for the above purposes, as the very great difference between the breaking strain per square inch of the original section and that of its fractured section would seem to indicate. Being homogeneous, no lamination or surface defects, such as are often found in iron, need be expected, and there is reason to believe that as there is a smaller proportion of impurities in the metal than in iron, it would prove less liable to corrosion.

Very respectfully,

[Signed] SAMUEL H. POOK,
Naval Constructor, U. S. N.

[Signed] F. L. FERNALD,
Ass't Naval Constructor, U. S. N.

refined wrought iron = about 76,000 lbs. In order to show the strength of Nashua steel as compared with the very best cast iron, several averages of the strength of "Richmond Pig Iron" will be given. This pig iron is the strongest known and is used exclusively by the "Government" in its ordinance department. Remelted Richmond pig iron, four (4) samples of 1 square inch in section gave an average breaking strain of = 39,989 lbs. Five (5) samples of ordinary Richmond pig iron (not remelted) of 1 square inch in section, gave an average breaking strain = 25,441 lbs. Specimen No. 8, shows a piece of best charcoal bloom, "low steel". It is from charge No. 465, the one treated of at length above. "I" is bent cold, "II" is bent at an orange heat, "III", bent at a bright red heat. Best wrought iron can only be bent once upon itself when cold and even then often cracks when hammered flatly back upon itself. Nos. 1. 2. 3. 4. 5. are pieces of steel of all the different grades from IIIII to I and vary from 0.18% to 0.80% of combined carbon. They are added to make the list complete. Various impurities affect steel in different degrees as with any variety of metallic iron, and to a far greater extent. The principal of these are Sulphur, Phosphorus, Silicon, and Manganese; also when present, Titanium, Arsenic, Tin, copper etc, though

Pg. 82 continued –

* "Copper" is always, or with very few exceptions, present in "Spiegels" of almost every grade and variety. The writer has found it present even to the extent of nearly (0.40%) 4/10 of one per. ct. In "hard" steel of every grade where such spiegels are used, Copper is found in the resulting steels. (.04%) 4/100 of one per. ct. was found by the writer and the steel was uniform and good everyway, for "tire" steel. Copper if present to any extent beyond that amt. (0.04%) would be likely to render the steel very "red short" and likely to work "shelly" under the hammer. "Copper" in excess is even worse than same amt. of "Sulphur". Steel contaminated with Copper in excess will not weld even with the best fluxes used. It is the writers idea that it will also render steel unsound & somewhat brittle in cold working.

†. These remarks apply still to "mild" steels of extra quality as also to fine steels of higher grades where great elasticity cold is required. 2/10ths per. ct. & even more when Mn. is sufficiently present does not affect the rolling & hammering of steel. Irons very impure in "Phosphorus" are now used in making cheap steels of many kinds & when rightly treated and combined with increased amts. of Mn. give better results than were formerly thot possible. "Phosphorus Steels" are a regular manufacture to a large extent especially in France and are now extensively made in this country. For this purpose the Carbon is run as low (or small amts.) as possible say 0.10 – 0.15% the Phosphorus is run from 2/10ths to 5/10ths per. ct. or even more & the Mn. added to extent of 1/2 to 2 per. ct. in finished steel. Phos. thus replaces Carbon, abt 3/5 P. being esteemed equal to 2/5 Carbon. P. makes steel very solid & free from defects when worked.

* these last are less frequently present. Sulphur makes steel "red short",
†. Phosphorus "cold short". 0.1% Phosphorus makes steel, "cold short"; and about 0.05% is the limit practically allowed. Phosphorus is very difficult to eliminate and is perhaps the worst enemy the steel maker has to encounter. 0.2% Sulphur makes steel "hot short", but nothing like that amount can be allowed in practice. Sulphur imparts, when not in great excess, increased fluidity when hot and toughness when cold to "castings". Manganese counteracts the effect of "Sulphur" in steel. Heath obtained a patent for its use as oxide in 1839. Robert Mushet obtained patent No. 2168 Sept. 16th 1856 for "Improvements in the manufacture of Iron". He employed a mixture of black oxide of manganese mixed in certain proportions with pitch, charcoal, tar or coal for purifying steel and obtaining the desired amount of carbon. The steel was melted in crucibles. He also obtained an additional patent, No. 2219, Sept. 22. 1856, for the "Improvements in the manufacture of iron and steel", by the use of spiegeleisen or ferro-manganese, and he furthermore specifies the mode of its manufacture and manner of use, as has been shown in previous pages of this report. Oxide of manganese is much used in making crucible steel and as an ingredient in making "physic" for the purification of puddled iron and steel. $MnO_2 + S = Mn + SO_2$ may be the reaction, SO_2 going off as gas. Steel as

Pg. 83. continued — ¶ Improved working has largely corrected oxydation through the "bath," and hence tests can now be worked and hammered when the charge is sufficiently "worked"! If the tests hammer badly thro' the last part of charge it is a sure indication of oxydation & should be corrected by proper additions of Manganese.

* More delicate methods have since shown #465, to contain about (0.10) 1/10 of one per ct. of Manganese. Dr. Witte has also found substantially the same quantity in similar steel made by Nashua men at "Otis Iron & Steel Co" at Cleveland Ohio.

†. This statement needs to be qualified. As better methods of steel making have since been devised no trouble is experienced in combining almost any desired amount of Mn. with the "bath" especially in case of "high" steels or steels of large amts. of contained, combined carbon.

☆ "Silica" in any appreciable amt. renders steel brittle &c. & the less present the better. "Silicon" combined with iron as an alloy renders the resulting steel more hard and tough and at same time gives it increased solidity & elasticity in "high" steels. "Silicon" as such is now commercially used in making "Silicon Steel" & with good results. For "mild" steels it is not useful as it would harden the metal if worked cold or put in water

made by the process above described (Siemen's Martin) is "cold short" naturally and cannot be hammered. This is entirely corrected by addition of manganese in suitable quantity. Hence the alloys "spiegeleisen" and "ferro-manganese" are employed in the way previously described. The exact function of manganese is not clearly understood, but it is generally believed now that the manganese deoxidizes the steel, as none a very little is found in the resulting steel, and most of it is found in the remaining slag. Thus enough manganese was added to charge *465 to give it 0.20%, but careful search revealed not even a trace.
*
An excess of manganese, so that the steel should contain an appreciable amount does not improve the metal in the least. There is no manganese
† in "high" steel, either "tool" or otherwise, as it will not combine with it. "Silicon" in small quantity renders steel harder, though more than 0.2–0.30% can
☆ not be allowed, as it would make the metal brittle, 0.05% is about the ordinary amount present in "mild steel". "Titanium" gives increased hardness and renders the iron more refractory in melting and working. Too much titanium unfits iron for steel melting. A little improves the quality. "Tungsten" has the remarkable property of giving increased power of magnetism to tempered steel. A magnet made from "tungsten" steel will hold up 13–20 times as much as an ordinary magnet from its armature. Copper in appreciable quantity renders steel "red short." See pg 82 continued. The writer knows nothing definite about the effects of arsenic, tin, antimony etc except that they impart increased hardness. It is very difficult to experiment upon the effects of these substances, as many of them are almost always simultaneously present.

— Steel directly from the Ore. —

The last modification necessary to complete the "reaction process of making steel upon the open hearth" is a method of producing it directly from the ore itself. For many years (since 1855) experiments have been made from time to time in this direction. Some very promising researches were made, but were, one by one, abandoned. Up to the year 1868, the only method of making steel upon the open hearth was by the fusion of wrought iron in cast iron in the manner already described. So much however has been accomplished since that time, that although no improvements have yet been generally introduced into our manufactories, steel of a very superior quality has been made directly from the ore. Hence a brief notice of the various improvements will be given up to the present time (1874). The first promising way of producing steel "directly," was indicated by Mr. Siemens in his lecture before the "Chemical Society of Great Britain;" May 7th 1868. He adds some vertical hoppers to his ordinary regenerative melting furnace. These are cast iron pipes lined with fire clay and set in the roof of the furnace. The ore etc, is filled into these from wagons running on tramways overhead. These "hoppers" are heated by the flame from the chamber, and the intensity is regulated by dampers at the top of the hoppers. Ordinary producer gas is forced in among the heated ore.

The ore is reduced to a sponge by the heated reducing gases, and falls down into the bath, where it is soon melted. As the ore falls in the "hoppers" more is added at the top and the process is continuous. Accumulations of slag are removed through aperatures for the purpose or through the doors. The "bath" having sufficiently increased, the supply of ores is stopped and the charge completed in the usual way. Dr. Siemen's experimented for several years upon the form of furnace, and obtained some good results, but becoming discouraged by the obstacles he encountered and which he enumerates at length in one of his later lectures, he abandoned his research in this direction, convinced "that the successful application of reduced ores could not be accomplished through their conversion into "spongy" metal" and that this explained "the want of success which has attended the previous efforts of others to produce iron direct from the ore". In his latest lecture upon the subject, delivered to the "Chemical Society," London March 20. 1873, Dr. Siemen's begins in his new process by fusing the oxide. His apparatus consists of a regenerative gas rotative furnace, the rotator being lined with bricks made in a special manner from bauxite, with some ferric oxide mixed with about 5 per. cent of plumbago and some silicate of soda. The furnace is heated to a high temperature, and charged with, say one ton iron ore, with fluxes or admixtures of other ores to form a liquid slag under the influence of heat. Rotator set in motion, intense flame directed into it in order to heat ore thoroughly, carbon (20 per cent of the whole) is introduced to reduce the charge to the state of magnetic oxide, when the ore is on the point of smelting. Upon this a violent reaction sets in and carbonic oxide (Co) is freely liberated, to utilize which a blast of air is admitted through one of the regenerators into the furnace, gas at the same time being reduced. Metallic iron is soon precipitated from the molten ore on which the slags are tapped off and a great speed of motion is given to the rotator to ball up the iron, which balls may be melted with addition of spiegel if cast steel is desired. 12 cwt. of steel may be made in 2½ hours with consumption of 30 cwt. coal to the ton of steel, which is about one half the weight of coal required for making a ton of pig iron in a blast furnace. Pure ores yield good results, poor ones very fair as it is possible to make better iron by sacrificing some of the iron as phosphoric acid is not precipitated so easily as iron. Stop operation before complete reduction, and phosphoric acid almost entirely goes off with the slag. The samples produced looked very well indeed. 51 per cent iron out of 58 per cent iron in the ore was obtained at Dr. Siemen's sample works in Birmingham, England, though the average yield was somewhat less. This includes the important part of researches made in England upon this subject. It is a well known fact that in the blast furnace iron is reduced to the metallic state as a sponge long before its subsequent carburization and fusion. This fact has been very clearly demonstrated by Dr. T. Sterry Hunt of the Mass. Institute of Technology, in a report addressed to Sir W. Logan, Director of the Geological Survey of Canada in 1869. Starting with the production of iron "sponge" as a basis, Mr. Thomas S. Blair of Pittsburg Pa. has made a series of investigations in the direction of the direct process, and has met with very promising results. In a paper read before the American Institute of Mining Engineers, at the meeting in New York on the 26th of Feb. 1874. Mr Blair gives a complete account of his experiments to that date. In order to make true iron sponge, it is obvious that several conditions must be observed.

1st There must be contact of the iron oxide with carbon.

2nd There must be isolation from the free oxygen of the air.

3rd The materials must be brought to a bright red heat.

4th A certain duration of time must be observed.

5th The reduced metal must be isolated for the air until cold.

In order to meet these several requirements, Blair uses an open cylinder, 40 feet in height and 3 feet in diameter. This is sealed from the air above by the ingoing material and gases percolating through it and below by the cooled material. This tube is divided into three parts or zones;

viz.— The heating zone, the reducing zone, and the cooling zone. In the mouth of the reducing cylinder is suspended a cast iron cylinder or "thimble" having an outside diameter of 28 inches and a length of six (6) feet. This leaves an opening or "annulus" of four (4) inches across. The ore broken into pieces of suitable size is charged into this annulus and heated. Below the annulus is the reducing zone, set in a brick chamber and heated by common producer gas, let in by jets at different heights, and with an air inlet opposite each stream of gas, all arranged, so as to have the gas under convenient control. This fire chamber is supported upon iron pillars, thus leaving the "cooling zone" accessible below. The "cooling" chamber is simply a prolongation of the reducing cylinder, surrounded by a water jacket through which a current of water is continually flowing. This "cooler" reaches to within 18 inches of the floor, whence it is prolonged in a telescopic sleeve, which shuts down upon the floor, and is raised when the material is to be withdrawn. The annulus is heated partly by the carbonic oxide (CO) which escapes from the reducing zone, and meeting the air burns there, and partly by a stream of gas which is delivered at the bottom of the annulus by an iron pipe and there fired. The process is continuous and as fast as the completed sponge is withdrawn fresh materials are charged at the top. The limit of working is simply the time which is necessary to keep the material in the "annulus" at a bright red heat to insure complete reduction. The reduction of the ore is very perfect as numerous experiments and chemical analyses have demonstrated. In the process of reduction the sesquioxide first becomes magnetic oxide, then prot-oxide, then metallic and this seems to be borne out by the facts. A very important fact is, that at a bright red heat no carbon is taken up by the metallic iron. There need be no fear of air excess as the air is so perfectly excluded, it is regained at the bottom. Charcoal is at present used as the reducing agent though coal etc may be employed. The sponge iron can be made at less than half the cost of charcoal blooms and it is even proposed to do away with pig iron eventually by the use of carburized sponge. The carbon may be mechanically or chemically combined. This same idea of sponge metal has been taken up by several American inventors and carried to some degree of success but the process of Mr. Blair includes all the main principles. When the sponge is completed it is taken and compressed into blocks of about the size of blooms. The second step in the direct process is the fusion of the iron sponge. This is used in precisely the same way as "blooms"; only the iron is very readily fused, and the uncombined materials enter into the slag. These sponge blocks were experimented upon at the Bay State Works and steel of a very superior grade readily made and with no excess of slag or corroding of the furnace bottom. Blair, not succeeding in obtaining a license for Siemen's furnace was obliged to look elsewhere for a substitute and is now engaged in experimenting upon the gas furnace of Mr Herman Frank of Pittsburg. The success thus far is not as great as might be wished. The sponge seems to be perfect and exactly adapted for use in the open hearth process, but a suitable furnace has not yet been perfected. If the Siemen's' furnace could be utilized the "direct process" would seem to be completed. From this brief account it will be seen that "the direct process' proposes to accomplish nothing less than the making homogeneous wrought iron cheaper than pig, by extracting the former directly from the ore by simpler and more economical means than are now employed for the first stages of iron manufacture in the ordinary blast furnace. If Mr. Blair's application of the direct process be as simple and easy of general adoption as would appear from his very clear exposition of it, it will help to revolutionize the whole iron trade!" It is the writer's firm conviction that this last modification will sooner or later be perfected and thus the "reaction process" carried along from stage to stage through so long a period will be finally practiced in its completion.

Respectfully Submitted,

J. Amory Herrick.