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PROCESS FOR THE MANUFACTURE OF STEEL, THE TREATING OF IRON, AND THE PRODUCTION OF PORTLAND CEMENT.

APPLICATION FILED MAR. 23, 1917. RENEWED DEC. 18, 1919.

1,366,383.

Patented Jan. 25, 1921.

3 SHEETS—SHEET 1.

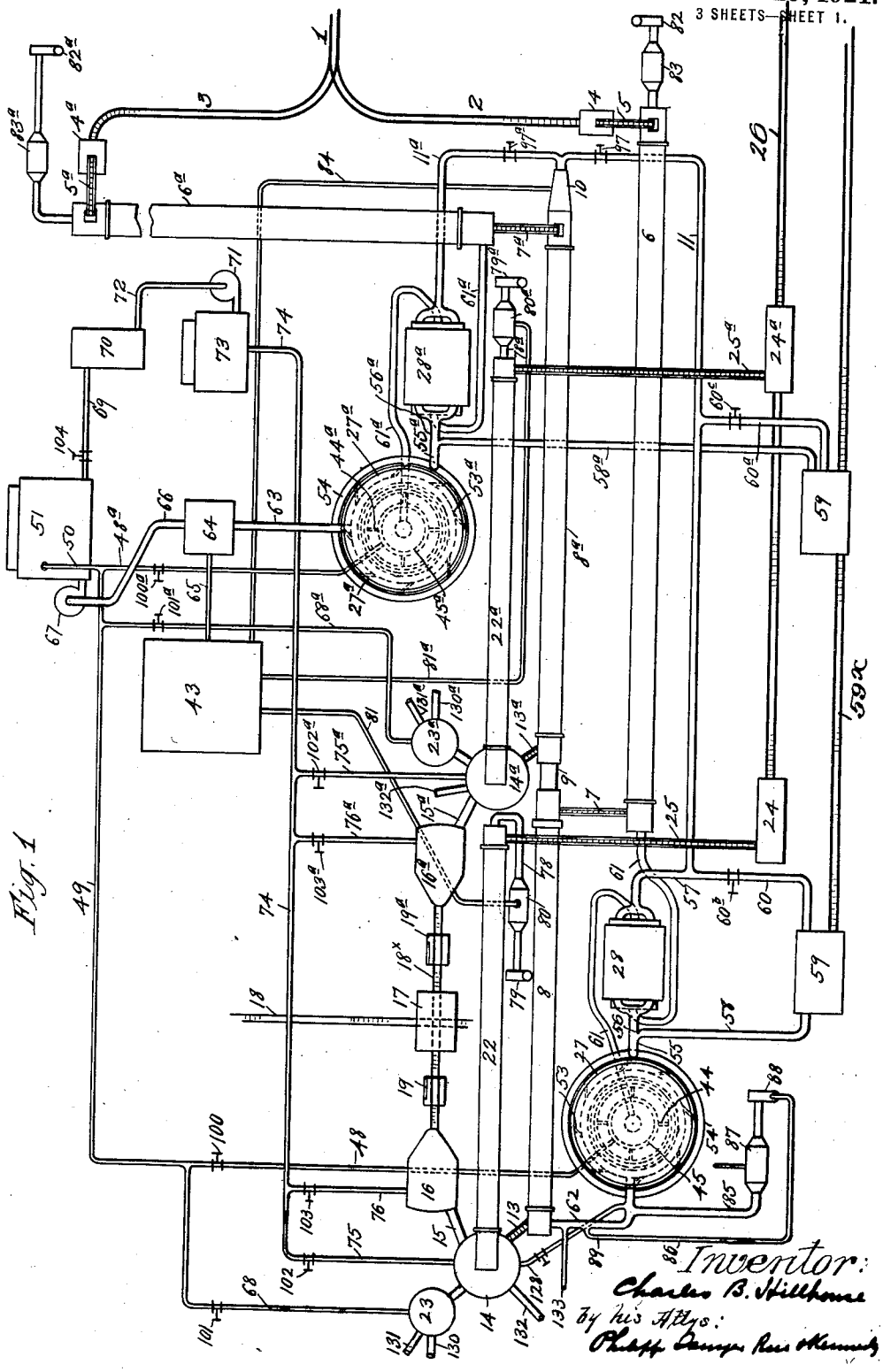


Fig. 1.

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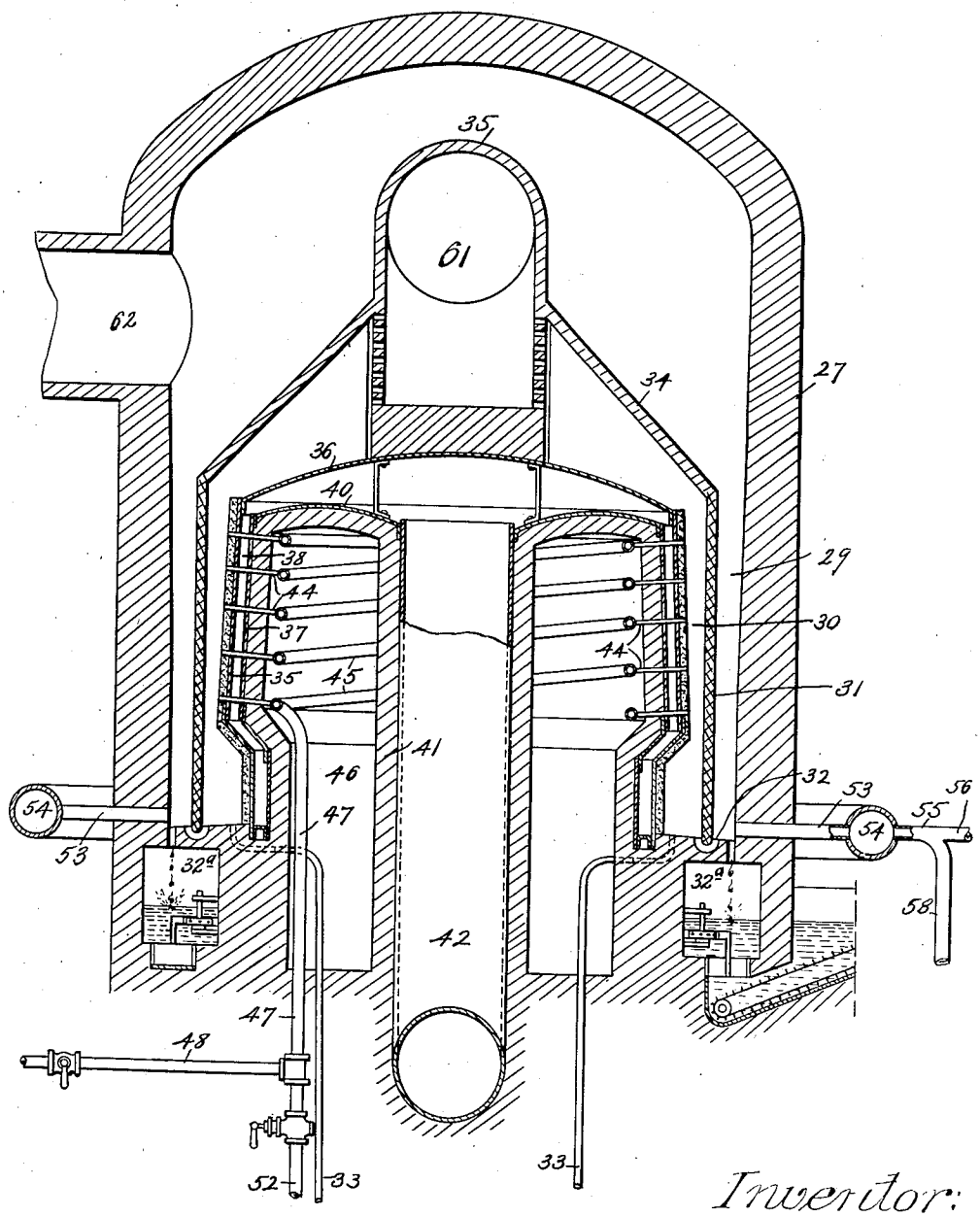
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3 SHEETS—SHEET 2.

Fig. 2.



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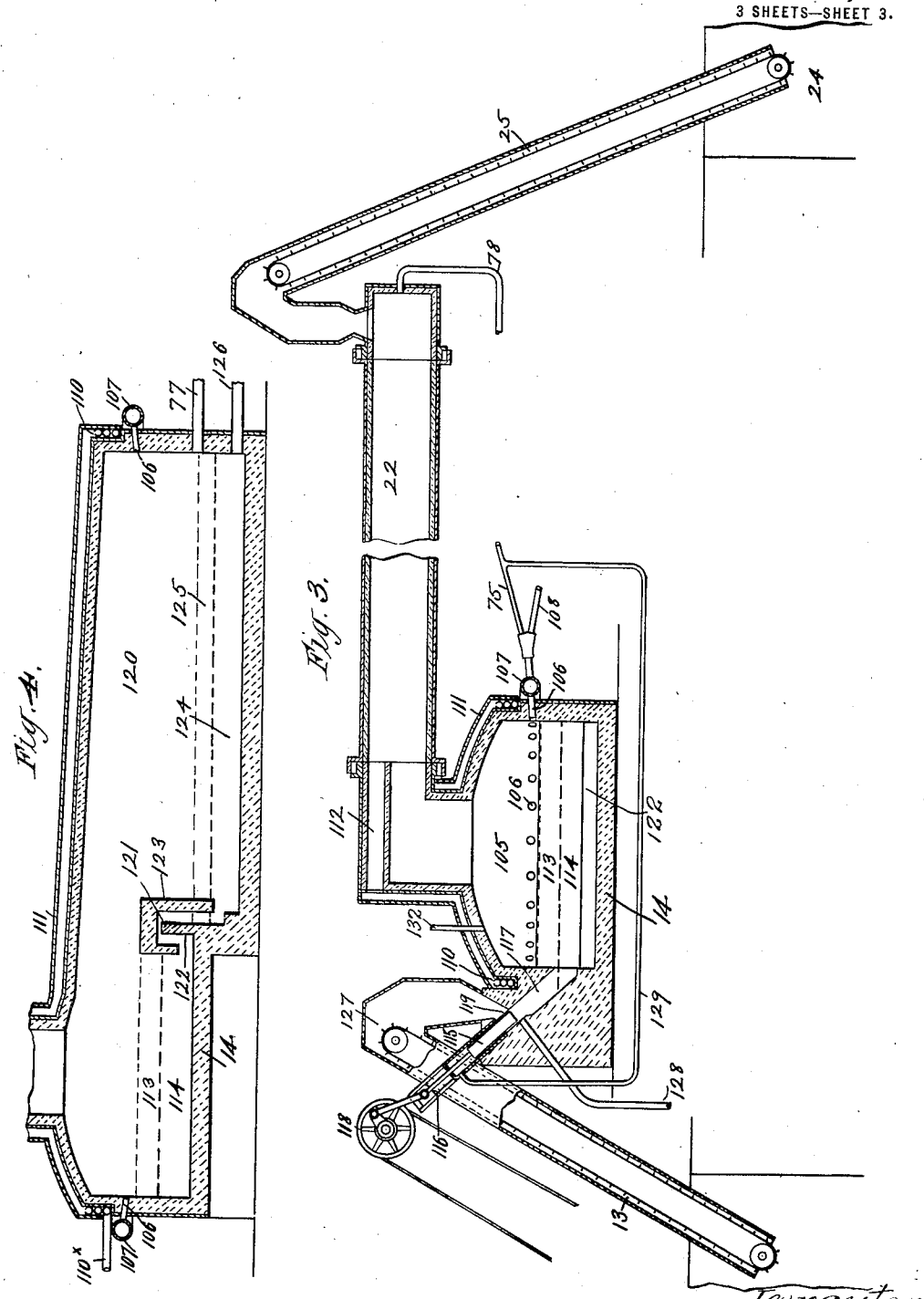
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3 SHEETS—SHEET 3.



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UNITED STATES PATENT OFFICE.

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PROCESS FOR THE MANUFACTURE OF STEEL, THE TREATING OF IRON, AND THE PRODUCTION OF PORTLAND CEMENT.

1,366,383. Specification of Letters Patent. Patented Jan. 25, 1921.

Application filed March 23, 1917, Serial No. 156,818. Renewed December 18, 1919. Serial No. 345,881.

To all whom it may concern:

Be it known that I, CHARLES B. HILLHOUSE, a citizen of the United States, residing at New York, county of New York, and State of New York, have invented certain new and useful Improvements in Processes for the Manufacture of Steel, the Treating of Iron, and the Production of Portland Cement, fully described and represented in the following specification and the accompanying drawings, forming a part of the same.

This invention relates to a process of producing steel and for the treatment of iron ores for use in the production thereof. In this respect it is a continuation of an application filed by me July 3, 1915, Serial No. 37,811. The invention also relates to the additional step, in this process, of simultaneously producing cement.

In the practice of my invention I use two batches of molten iron, preferably prepared as hereinafter described, having relatively different known carbon contents, and by mixing them, in suitable proportions for the purpose, produce a steel having any desired carbon content between those of the two batches of molten iron. In one batch of molten iron the carbon content is, of course, above, and in the other below, the carbon content of any mixture of the two batches, and, within these limits, a steel may be produced having any desired carbon content according to the relative proportions of the two batches used in the mixture. Preferably, one of the two batches of molten iron will be free or substantially free from carbon, while the other will contain the carbon necessary, on the mixture of the proper proportions of the two batches, for the production of steel having the desired quality as to carbon content.

The process also includes the steps of preparing the two batches of molten iron used in producing the steel from two separate lots of ore, not necessarily of the same kind but preferably comminuted, and in subsequent treatment of the two lots of iron sponge produced therefrom; these and all other steps of the process, beginning with the initial treatment of the ores and ending with the production of the two batches of molten iron, being carried on under such conditions, including the exclusion of the atmosphere (by carrying on the process in a closed system), as to insure the production of the two batches of molten iron, and steel resulting from a mixture of the two, free from or with a negligible amount of sulfur and phosphorus.

In this continuous process the lot of ore designed for reduction to carbon-free sponge is preheated in a suitable preheater; the other lot of ore is also preheated, in a second preheater, at a lower temperature, though under some conditions no preheating of it will be necessary; the first lot of ore is reduced to iron sponge, in a suitable reducing kiln, by maintaining the reducing gases therefor and the ore at a sufficiently high temperature to produce a sponge free or substantially free from carbon, and the second lot is also reduced to iron sponge, in another reducing kiln, by maintaining the reducing gases therefor and the ore at a sufficiently low temperature to cause the deposition of carbon on the sponge, which will be retained therein in its subsequent fused state, other carbon being added if the quantity deposited is not sufficient; then the two batches of iron sponge are fused in separate fusing furnaces, to which lime is supplied from suitable lime-preheaters; and, finally, the two batches of fused iron are withdrawn from their respective fusion furnaces and mixed, in the requisite relative quantities for the production of the desired steel as to carbon content. The preheaters and reducing kilns referred to are, as will hereinafter more fully appear, of the rotary type.

The necessary reducing and fuel gases or other heat for use in carrying out the process may be of any kind and used in any way suitable for the purposes indicated.

As to the reducing gas, however, I prefer that it should be CO with hydrocarbons and that it should be used as follows: A quantity thereof, with the CO largely in excess of that required for reducing the ore therein, is supplied to the kiln in which the ore is reduced to carbon-free sponge, so that the gases leaving this kiln shall still contain a large proportion of CO which has remained inactive and unoxidized during the reducing operation in this kiln. These gases are then passed into the other kiln where, at the lower temperature therein of the iron ore, this CO becomes active and reduces the ore therein to carbon-con-

taining sponge. The gases leaving this kiln, consisting of CO_2, CO and hydrogen or hydrocarbons, are again utilized for producing reducing and fuel gases. The hydrocarbon element of the reducing gases greatly facilitates the reducing operation.

The reducing gas is produced, as part of the contiuous process preferred by me, from a portion of these gases emerging from this second kiln, with the addition of pulverized carbon and steam. The mixture thus made passes into a converting chamber (under suitable temperature for the purpose) where the CO_2 is re-converted into CO, and the steam into CO and hydrogen or hydrocarbons, again used as a reducing gas, successively in the two reducing kilns, referred to, the partly oxidized gases from which are again returned to the converting chamber, and so on; there being a continuous cycle or circulation of reducing and oxidized gases, respectively, from and to the converting chamber.

As to the gas used as fuel in the gas-converting step just referred to, as well as in other parts of the process, it is preferably of the same composition and initially from the same source as the reducing gas, being produced as part of the general process and by utilizing the balance of the gases emerging from the reducing kilns and not utilized for producing reducing gas. These gases have steam and carbon added to them, as before, and the mixture thus made is passed into another converting chamber (like that before referred to) where the CO_2 is re-converted into CO and the steam into CO and hydrogen or hydrocarbons. This gas then passes, as fuel, from this converting chamber to the combustion chambers of the two converting chambers, the two fusion furnaces, and the two mixers for the fused iron, as well as to any other parts of the system used that may need such fuel, as, for example, slag containers. The waste gases therefrom then pass out of the system into the atmosphere after preheating ore, making and preheating lime and producing steam or being utilized for other purposes.

While the fuel gas from my process, used in the converting chambers and elsewhere, will have a very high temperature flame, owing to the large proportion of CO present, yet, to further add to the temperature, the gas may be burned hot and the air used for combustion may be heated air where circumstances will permit.

Steam used in the different stages or steps of the process, other than for power purposes, may be the exhaust steam of the engine used in connection with the process or from any other suitable source, as steam produced in shotting slag.

Volatile matters in the ores, including sulfur and phosphorus, are removed therefrom partly in the ore preheaters, whence they pass into the atmosphere; partly in the reducing kiln or its connecting passages whence they pass off, with the gases emerging therefrom, to the converting chambers where such gases are re-converted into reducing or fuel gases. Any organic sulfur with the carbon introduced into the reaction chambers is eliminated from the system by passing off in the liquid coal ash. Basic slag in the fusion furnaces which is maintained therein in a highly heated liquid condition will finally remove any remaining sulfur and phosphorus.

As a further safeguard against sulfur the gases to be used as fuel in the fusion furnaces and mixers may be passed through a desulfurizer after leaving the converting chamber.

The basic slag in the fusion furnaces, before referred to as in a highly-heated liquid condition, is maintained in that condition by burning in the furnaces a portion of the fuel gases produced in the system and by highly heating the lime entering the furnace by waste gases from the latter, these gases also having the effect of dissociating CO_2 from the limestone used.

The maintenance of the slag in this condition and its regulatable character makes it capable of being given the composition of Portland cement. Any lacking ingredients for the purpose of giving it this composition will be added to it before "shotting."

This slag is maintained in the form of a layer superposed on the layer of fused iron which it therefore protects against oxidizing and other deleterious agencies and the iron sponge enters this mass of superposed layers of molten material at a point below its surface and through a trap so that it also is protected against oxidizing gases. As it enters the fusion furnace after its immersion most of the danger of reoxidation has passed. Whatever sponge remains unfused, being lighter than the fused iron, will rise and meet the fresh intensely heated lime or extra basic slag at or near the top, when the gangue accompanying the sponge will be slagged and fused completed.

As a further precaution against oxidation or for further purification, the sponge before immersion in this mass is passed through an atmosphere of purer CO, etc., gas and having a temperature higher than its own, as hereinafter more fully explained.

As indicated, the heated lime and the iron sponge, with its accompanying silica, meet for the first time in the highly heated fusion furnace. One advantage of this is that the "heat of formation" of the slag is added at the highly important period of the critical temperature of fusion, thereby adding greatly to its heat value.

A very high temperature is required in the fusion furnace for fusion purposes. In

order to attain this a large excess of heat units are required, only about 10% of the heat units supplied being utilized for the generation of this temperature. The balance (90%) of these heat units pass off in the waste gases. These waste gases are utilized by me for the preheating of the lime, as more fully described later on. The lime as it enters the fusion furnace is highly preheated, its temperature being only a few hundred degrees below that of slagging and fusion. Therefore the additional heat required to raise the lime to the temperature of slagging, and the latent heat of fusion of the slag, is all the heat that has to be provided for on account of the lime, and as the heat of formation of the slag more than offsets these two heats, a double quantity of lime can be used in my fusion furnace without providing additional high temperature heat, thereby enabling me to fuse with highly basic slag as is done in an electric furnace.

The process has other features of novelty and realizes other advantages which will hereinafter appear.

It will be understood that while I have referred to two batches of molten iron, additional batches, with or without a carbon content, may be used, and that while I prefer to prepare the batches of molten iron in the continuous process above referred to, either or both may be replaced by molten iron from other suitable sources. It will also be understood that, while I have referred to one fusion furnace for each batch of molten iron, two or more may be used in multiple arrangement.

In the accompanying drawings—

Figure 1 is a diagrammatic view of a system for practising the process in the preferred way above outlined.

Fig. 2 is a sectional elevation, on an enlarged scale, of one of the reaction furnaces of the system, each of which comprises a reaction chamber and a combustion chamber therefor.

Fig. 3 is a sectional elevation, also on an enlarged scale, of one of the fusion furnaces, showing also means by which it is supplied with heating fuel, with the reduced ore and with lime, and, if desired, other materials; and

Fig. 4 is a transverse vertical section thereof on the line 4 Fig. 3.

Referring to Fig. 1, 1 represents a main track leading from an ore crushing mill or other suitable source of ore supply. Whatever the source it is preferred that the ore should be in a comminuted condition, although this is not essential to the present invention; ore in a comminuted condition being preferred because in such condition it is more speedily and uniformly reduced. From main track 1, ore conveyers pass, by tracks 2, 3, to ore pits 4, 4ª respectively. From the pits 4, 4ª the ores are conveyed through two separate sets of apparatus and, after reduction and fusion, finally discharged from the system into a common receptacle, as will hereinafter appear.

As both sets of apparatus for the ores from the two pits 4, 4ª are largely duplicates of each other in construction, the same reference numerals will be applied to corresponding parts in both, followed, however, for convenience of description, by the reference letter "a" in one set of apparatus. Here it may be noted that the system shown is made up of two sets of apparatus or divisions because, in the preferred practice of the present invention it is, as before stated, designed to produce in these two divisions two iron sponges, different as to carbon content, and to unite these ultimately in a fused state in proper relative proportions to produce steel having any desired carbon content,

From the pit 4, an elevator 5 conveys the ore to a preheater 6 of ordinary construction; another elevator 5ª conveying the ore from pit 4ª to a similar preheater 6ª. An elevator 7 in turn conveys the preheated ore from preheater 6 to a reduction kiln 8 of ordinary form; while another elevator 7ª conveys the preheated ore from preheater 6ª to a similar reduction kiln 8ª. The preheaters 6, 6ª and kilns 8, 8ª, are all of the rotary type. Preheating of the ore by means of preheaters, 6, 6ª is preferable, as part of the reduction operation, but not essential, particularly in the case of the ore reduced in kiln 8ª, the preheater 6ª for which may under certain conditions be dispensed with and the ores from 4ª be led direct to 8ª, without preheating. These two kilns 8, 8ª communicate with each other, at 9, so that, as will hereinafter more fully appear, the gases used for reducing the iron ore in these kilns will first traverse kiln 8 and then kiln 8ª. A steam jet exhaust blower 10 circulates the gases through the kilns and discharges them into pipes 11, 11ª, whence the gases pass to certain parts of the apparatus where they are regenerated and then are again utilized for reducing purposes and fuel, as will appear later on.

The preheaters 6, 6ª and reduction kilns 8, 8ª, as well as the elevators 7, 7ª, are closed to the atmosphere, and the reducing gas enters the preheaters and kilns at their ore-discharging ends and circulates from the latter, through the ore in the preheaters and kilns, to the ore-receiving ends of the preheaters and kilns, whence it is discharged. The result of this is that the ore and resulting sponge are during reduction protected from the atmosphere and other oxidizing agencies. Furthermore, the preheating or reducing gases are of such temperature that they will release the sulfur and other volatile matters in the ore, and in their passage through the

kilns or preheaters, or both, expel such volatile matters from the ore, the resulting sponge, and therefore the final steel product, as well as the cement slag produced by the present invention, being therefore free of such sulfur.

The ore reduced in kiln 8 is conveyed therefrom by an elevator 13 (also closed to the atmosphere) to a fusion furnace 14 (see Fig. 3) and thence by a passage 15 to a mixer 16, while the ore reduced in kiln 8^a is conveyed by an elevator 13^a to a fusion furnace 14^a and thence by a passage 15^a to a mixer 16. These fusion furnaces (which are shown in Figs. 3 and 4) will be hereinafter described in detail. The fused ores in mixers 16, 16^a are mixed or united, as desired, in selected relative proportions, in a ladle 17 traveling on track 18, 18^x; scales 19, 19^a being preferably provided for accurately weighing out the required quantities of molten material from the two mixers to produce desired qualities of steel, as to carbon content.

For each fusion furnace there are provided a lime preheater (closed to the atmosphere) and a slag container, designated 22, 23, for fusion furnace 14, and 22^a, 23^a for fusion furnace 14^a. These two lime preheaters, (see Fig. 3) which are of the ordinary rotary type, open at their discharge ends into their respective fusion furnaces and are supplied at their other or receiving ends with crushed limestone from pits 24, 24^a, respectively, from which the limestone is conveyed to the preheaters by elevators 25, 25^a, respectively; the two pits 24, 24^a in turn receiving their supplies of limestone by carriers traversing a track 26 leading from a limestone crusher.

One branch of my invention includes the utilization of the slag in the fusion furnaces for the production of cement, preferably Portland cement and this I accomplish by the use of lime very largely in excess of the quantity required in the fusion operation. This results in the production, in the fusion furnace, of a fluid slag of a cement character, when suitable ingredients have been added to the gangue of the ore, as alumina, the production of the cement itself being accomplished by subsequent grinding.

If it should be desired to maintain in the fusion furnace a more fluid slag than that having a Portland cement character, ores or beneficiated ores will be selected and used which will carry less silica than that required for Portland cement and the percentage of silica needed will be added (preferably pre-heated) to the slag (having excess lime) *en route* to or in the slag container, so that the result will be a true Portland cement slag.

Each of the two sets of apparatus includes also a reaction furnace 27 or 27^a, and a duplex checker fire brick pre-heater 28 or 28^a of ordinary construction. The construction and method of operation of these two reaction furnaces (shown in detail in Fig. 2) is substantially the same.

Here it should be noted that two reaction furnaces are not essential to the present invention, in its broadest aspects. Two such furnaces are, however, preferably provided (one for each of the two sets of apparatus) for the purpose of increasing the efficiency of the system as a whole, such an arrangement permitting the location of each reaction furnace to be in close proximity to the parts of the apparatus supplied by it with hot reducing or fuel gases with the result that the loss of heat, in the gases passing from the reaction furnace to such parts, will be reduced to the minimum. The invention is not limited to the use of a single reaction furnace for each set of apparatus, as two or more may be provided for each.

As shown in Fig. 2, which is applicable to each of the reaction furnaces but will for convenience be described with particular reference to the reaction furnace designated 27, the reaction furnace 27 comprises a converting chamber 29 and a combustion chamber 30 separated therefrom by a dividing wall or partition 31, of carborundum brick or other suitable material, at the lower end of which is provided a liquid ash seal 32, in case other material than a gas (as pulverized coal) is used for fuel. In such case the liquid ash overflows into the liquid ash outlet 32^a and is shotted in the water seal below and (as indicated) taken away by a circular chain scraper. The liquid ash from the reaction chamber 29 carries away with it all the fixed sulfur, iron and phosphorus in the coal and so removes it from the system. The importance of this is that the reducing and fuel gases do not carry into the system organic sulfur, being freed from such sulfur, and therefore the resulting sponge and final steel product, as well as the cement slag produced by the present invention, will also be free of this objectionable element; the volatile sulfur in the ore being eliminated by the preheating and reducing gases, as before stated. The coal ash also carries away the iron and phosphorus in the coal and so prevents them from entering the cement slag. Part of the gas made in the reaction chamber 29 is burned in the combustion chamber 30 and preferably hot. Where coal is used as the fuel in the combustion chamber, it may be supplied thereto in any suitable way, as by means of pipes 33 (Fig. 2) from any source of pulverized coal supply. Upward extensions 34 of the partition 31, converg-

ing toward each other, terminate in a dome 34^a for the combustion chamber at a point below the dome of the reaction furnace.

The partition 31 incloses a cylindrical shell 35, having a dome 36, and an inner cylindrical shell 37 suitably distanced therefrom to provide a space 38 for the reception of a cooling medium (as air or water) between the two, such cooling medium being introduced into the cooling space 38 in any suitable manner. The shell 37 is provided with an annular head 40 suitably spaced from the dome 36 of the combustion chamber to provide for the passage between the two of the heated air or steam escaping from the cooling space 38. The shell 35 is suitably supported, as shown, from the base of the reaction chamber, while the shell 37, and its annular head 40, are supported by a hollow cylindrical portion or hub 41 rising from the base of the reaction chamber, and provided with a central opening containing a pipe 42 through which the heated air or steam entering said opening from the cooling space 38 may pass out to be utilized for combustion purposes, if air, or to the power house 43 of the system, if steam.

In the normal operation of the system the combustion chamber 30 is supplied with fuel gas by means of burners 44 extending horizontally from a coil 45 in the hollow chamber 46 of hub 41 and in turn connected at its lower end 47 with pipes 48, 49, 50, leading from a gas holder 51 or supplied with hot gas from combustion chamber 29; the corresponding burners 44^a and gas supply coil 45^a of combustion chamber 30^a of reaction furnace 27^a being supplied with gas from said holder by pipes 48^a, 50, as shown in Fig. 1. Air or heated air may be supplied with the gas to chamber 30 in any of the well known ways. Pipe 47 should also be connected (as by a pipe 52) with any suitable source of fuel gas supply outside the system for temporary use on starting the system, to warm up its different parts. This pipe 52 is provided with a valve which may be opened (as shown) for this purpose, pipe 48 being then also temporarily closed, as shown.

The converting chamber 29 of the reaction furnace 27 is supplied, with the mixture before referred to, of CO, CO_2 gas, hydrogen or hydrocarbons and steam, and also pulverized carbon, by nozzles 53 extending into said chamber from a supply pipe 54 surrounding the reaction furnace. This supply pipe is connected by pipes 55, 56, preheater 28, and pipes 57, 11, with steam exhaust blower 10, at the gas discharging end of kiln 8^a. It is also connected by pipes 55, 58 with an ordinary form of fan-controlled carbon pulverizer and mixer 59, which is in turn connected by pipes 60, 11 with blower 10, and is supplied with carbon from any suitable source by means of conveyers traveling from such source on track 59^x. The result of this construction is that a portion of the gases emerging from kiln 8^a, and with them steam from blower 10, pass through preheater 28, and a portion thereof through carbon pulverizer and mixer 59. These gases become thoroughly mixed with the powdered carbon and then pass, with the carbon, by pipe 58, to pipe 55 where it blends with the gases which have passed through and been heated in preheater 28. The combined gases, with accompanying pulverized carbon, pass thence to pipe 54 and through the nozzles 53 thereof into the converting chamber 29. These nozzles preferably extend into the lower end of the converting chamber and in the angular or tangential direction indicated in Fig. 1. The intimate mixture of gases and carbon entering the highly heated converting chamber carries the pulverized carbon in suspension with the result that the powerful radiant heat from the wall 31 of the combustion chamber 30 acts upon the minute solid particles and produces almost instantaneous combination. This process of producing the reducing gases is not claimed herein but will be made the subject of a separate application.

Similar connections, and for the same purpose, are provided between another carbon pulverizer and mixer 59^a and reducing kiln 8^a, and the converting chamber 29^a of reaction furnace 27^a.

Combustion chamber 30 of reaction furnace 27 is connected by pipe 61 with the checker fire brick preheater 28 and thence with the ore discharging end of ore preheater 6, while the converting chamber 29 of said reaction furnace is connected by a pipe 62, with the ore discharging end of ore reducing kiln 8.

Combustion chamber 30^a of the reaction furnace 27^a is connected by pipe 61^a with the checker fire brick preheater 28^a and thence with the ore discharging end of ore preheater 6^a and by pipe 63 with a steam boiler or cooler 64, the steam from which discharges into power house 43 by a pipe 65. Cooler 64 is, in turn, connected by a pipe 66 with gas holder 51, a suction fan 67 being provided for drawing the gases through pipe 63, cooler 64, and pipe 66, and forcing them into the gas holder 51. Part of the gases in the holder 51 are forced therefrom by the fan 67 through pipes 50, 49, 48 (Fig. 1) and pipes 47, 45, and burners 44, into the combustion chamber 30 of reaction furnace 27 and, through pipes 50, 48^a, 45^a and burners 44^a into the combustion chamber 30^a of the reaction furnace

27ª. Part of the gases traversing pipe 49 also pass, by branch pipes 68, 68ª, to slag containers 23, 23ª, respectively.

The remaining gases in gas holder 51 are forced therefrom, by fan 67, through pipe 69 into a desulfurizer 70, where they are desulfurized, if that be necessary, and whence they are withdrawn, by a fan 71, through a pipe 72, and forced into a second gas holder 73. From gas holder 73 these desulfurized gases may pass, by a main pipe 74 and branch pipes 75, 75ª, to the fusion furnaces 14, 14ª, respectively, and, by branch pipes 76, 76ª, to mixers 16, 16ª, respectively. The waste gases from the slag container 23 and mixer 16, and the slag container 23ª and mixer 16ª, pass off into the atmosphere. The waste gases from the fusion furnaces 14 and 14ª and other sources heating the lime preheaters 22, 22ª, respectively, are circulated therethrough by pipes 78, 78ª, and suction fans 79, 79ª, and discharged into the atmosphere. Each of the pipes 78, 78ª includes an ordinary form of cooler 80, 80ª, through which said gases pass. The steam generated in these coolers passes, by pipes 81, 81ª to power house 43.

On starting to use the system the combustion chambers 30, 30ª of reaction furnaces 27, 27ª will, for the purpose of warming up the system, be supplied temporarily, by pipe 52, which fuel gas from any suitable outside source of supply through main pipes 47, 47ª and their branches 45, 45ª and burners 44, 44ª or the converting chambers 29, 29ª of reaction furnaces 27, 27ª, may be supplied with heat by burning the powdered carbon mixed with air from carbon pulverizers 59, 59ª through pipes 58, 55, 54 and nozzles 53 (for chamber 29), and pipes 58ª, 55ª, 54ª and nozzles 53ª (for chamber 29ª). This warming up operation will be continued until the different parts of the system have reached the required temperature for its normal operation when main pipes 47, 47ª will be disconnected from such outside source of fuel gas supply. Then the system will operate in the manner now to be described.

As heretofore stated, the process of the present invention includes the step of producing two iron sponges having relatively different carbon contents, and these are fused separately and are thereafter mixed together in certain proportions according to the quality of steel desired, as to carbon content. These results may be attained in various ways, as to carbon contents of the two sponges, but, when operating in accordance with the way I prefer and which will now be described, one of the iron sponges is produced with carbon and the other substantially free of carbon.

Under this normal operation, the CO_2 gas, in association with other unoxidized gases and steam entering converting chamber 29 of reaction furnaces 27, through pipe 54 and its connections, from reducing kiln 8ª and carbon pulverizer 59 (in which a suitable quantity of powdered carbon is added to the mixture), will be converted into CO gas, and the steam into CO gas and hydrogen or hydrocarbons, by the heat of the fuel gases in combustion chamber 30.

The waste gases of combustion from combustion chambers 30, 30ª will pass therefrom by pipe 61, 61ª through duplex checker fire brick preheaters 28, 28ª, and ore preheaters 6, 6ª, respectively. Preheaters 6, 6ª are provided with fans 82, 82ª for circulating these gases through the preheaters 28, 28ª and 6, 6ª, and then withdrawing them through coolers 83, 83ª and finally discharging them into the atmosphere.

Sufficient gases from converting chamber 29 will pass by pipe 62 into the ore discharging end of ore reducing kiln 8, and then pass on to kiln 8ª by passage 9. These kilns are suitably rotated to feed the comminuted ore and also toss it about so that the reducing gases will circulate through the mass and contact with all the particles thereof. The circulation of the gases through these kilns is effected by the exhaust blower 10, actuated by steam from the power house 43 through pipe 54, which steam enters the system with the gases from kiln 8ª and carbon from pulverizer and mixer 59, described, and becomes converted into CO and hydrocarbons in the converting chamber 29. An increase of steam and powdered carbon makes an increase of gas, and as the amount of steam required for the mixture entering converting chambers 29, 29ª, is greatly in excess of that required for the opeartion of the blowers 10, for withdrawing the gases from kilns 8, 8ª, the necessary additional amount may be supplied, as shown, through said blowers or in any other way, as from the exhaust of the engine used for operating the system, such steam being preferably preheated many hundred degrees in any suitable way.

The gases discharged from kiln 8ª, which are a mixture of CO_2 and inert reducing gases, enter pipes 11, 11ª. The gases entering pipe 11 pass, by pipe 57, heater 28, and pipes 56, 55, 54, and by pipes 11, 60, carbon mixer 59, and pipes 58, 55, 54, into the converting chamber 29 of the reaction furnace 27, where they are reconverted into CO and other reducing gases; while those entering pipe 11ª pass through duplex checker fire brick heater 28ª, and thence, by pipe 56ª, 55ª, 54ª, and by pipes 11ª, 60ª, carbon mixer 59ª, and pipes 58ª, 55ª, 54ª, to the converting chamber 29ª

of the reaction furnace 27ª. It will thus be seen that the gases heated by preheaters 28, 28ª meet the carbon and gases from mixers 59, 59ª, at the pipes 55, 55ª, where they are intimately mixed, with the result that the powdered carbon and gases will be intimately blended before their entrance into the converting chambers 29, 29ª. In warming up the system, waste gases will pass off into atmosphere by pipes 60, 60ª through temporarily opened valves 60ᵇ, 60ᶜ.

The temperature of the gas as it leaves converting chamber 29 is higher than is desired to enter kiln 8. The reduction in its temperature to the point desired may be effected in any suitable way, as by the provision of a by-pass, 85, 86, around pipe 62, containing a cooler 87, and a suction fan 88, for drawing part of the gas from pipe 62 and cooling it and then, after cooling, mixing it (at 89) with the gas in the pipe 62 leading to the reducing kiln 8. Other means of lowering the temperature of the reducing gas may be employed, as mixing cool reducing gas from another reaction furnace.

The ore from preheater 6 enters kiln 8 at a temperature high enough to avoid any substantial deposition of carbon in its reduction by the hot reducing gases. On the other hand the ore in kiln 8ª will have a low enough temperature when subjected to the partly oxidized gases from kiln 8, to be reduced to iron sponge with more or less carbon deposition. The gas as it enters kiln 8 is substantially CO with a smaller amount of hydrogen or hydrocarbons, and is in excess of the quantity required for the reduction of the ore in said kiln at the higher temperature and will be sufficient to provide for the additional ore-reduction in kiln 8ª at a lower temperature, as before stated. The gases used in each of these two reduction operations will be sufficiently high also for the separation and removal in the preheaters or kilns or both, of sulfur and other volatile matters from the ores.

The two iron sponges thus reduced into kilns 8, 8ª are conveyed by elevators 13, 13ª respectively, to fusion furnaces 14, 14ª, respectively, supplied with lime from lime preheaters 22, 22ª, respectively. The iron sponge in the two fusion furnaces are separately fused and pass into mixers 16, 16ª respectively. When it is desired to produce a steel having a certain percentage of carbon, all that is necessary to do is first to ascertain the carbon content of the fused iron in each mixer and then to weigh out from the two mixers, by means of scales 19, 19ª, the necessary quantity of each to produce such a steel, depositing the same in the ladle 17, where they are blended together.

The fusion furnaces 14, 14ª, lime preheaters 22, 22ª and mixers 16, 16ª, as well as other parts of the system, may be heated, and fuel gas be supplied to the combustion chambers 29, 29ª of the reaction furnaces 27, 27ª, in any suitable way but preferably in the following manner:

Fusion furnaces 14, 14ª are heated by desulfurized gases supplied from gas-holder 73, through pipes 74, 75 and 74ª, 75ª, respectively.

Mixers 16, 16ª are also heated by such gases supplied from gas-holder 73, through pipes 74, 76, and 74, 76ª, respectively.

Slag containers, 23, 23ª are heated by CO etc. gases supplied from gas-holder 51 through pipes 50, 49, 68, to container 23, and pipes 50, 49, 68ª, to container 23ª.

Lime preheaters 22, 22ª are heated by the hot waste gases from fusion furnaces 14, 14ª into which they respectively open, and by heated steam from the fusion furnaces, as hereinafter described. Other or additional heating means may be provided.

The waste heating gases entering lime preheaters 22, 22ª are drawn therethrough by the suction fans, 79, 79ª, and discharged into the atmosphere after passing through cooler 80, 80ª.

As before described, the fuel gases for the combustion chambers 30, 30ª come from gas-holder 51, by pipes 50, 49, 48, to the former, and pipes 50, 48ª to the latter.

Pipes 48, 48ª are provided with valves 100, 100ª for regulating the quantity of these gases passing from gas holder 51 to the combustion chambers 30, 30ª. Branch pipes 68, 75, 76 and 68ª, 75ª, 76ª, are also provided with similar regulating valves 101, 102, 103, and 101ª, 102ª, 103ª, respectively. Pipe 69 also has a valve 104 for regulating the quantity of gas from gas holder 51 to desulfurizer 70.

These valves, together with valves 97, 97ª in pipes 11, 11ª, from kilns 8, 8ª, and the valves and other regulating means in other parts of the system, including those usually employed in carbon pulverizers and mixers, ore preheaters, reducing kilns, lime preheaters, etc., such as are embodied in the present system, provide for ready regulation of every step of the process.

From the foregoing it will be observed that the converting chamber 29 of reaction furnace 27 may supply all the gas for ore-reducing purposes, to kiln 8, 8ª; that some of the oxidized and unoxidized gases from these kilns are reconverted into reducing gases and again utilized for ore-reducing purposes in kilns 8, 8ª, and so on, there being thus a constant gas-circulation, between reaction chamber 29 and kilns 8, 8ª; that the remainder of these oxidized and unoxidized gases pass from kilns 8, 8ª, with steam and carbon, into converting chamber 29ª of reaction furnace 27ª, where they are also reconverted

into CO and hydrocarbons; and that the waste gases of combustion chamber 30 of reaction furnace 27 pass, as a source of heat into ore preheater 6, and thence into the atmosphere, through cooler 83.

It will also be observed, as just indicated, that the CO gas, with accompanying hydrocarbons, from converting chamber 29ª of reaction furnace 27ª, is not utilized for ore-reducing purposes, but solely as heat-supplying fuel, part of it (direct from gas holder 51) in its own combustion chamber 30ª, in the combustion chamber 30 of reaction furnace 27, and in the slag containers 23, 23ª, and the balance of it (in a desulfurized condition, direct from gas holder 73) in the fusion furnaces 14, 14ª, and mixers 16, 16ª. The waste gases from the fusion furnace, etc., pass into the atmosphere, after circulating therethrough and through lime preheaters 22, 22ª, as before noted.

Although I prefer, as fuel, the gases produced, as described, in the system, any other suitable kind of fuel may be substituted for it.

Referring now particularly to Figs. 3 and 4, the fusion furnace, with its connections, shown therein, will be described in detail. This furnace, which, as a whole, is designated as 14, is the same as the furnace 14ª. It comprises a chamber 105, heated from burners 106, extending from a manifold 107, inclosing the chamber and connecting with gas-supply pipe 75 (Fig. 1), which has connected with it (near manifold 107) an air pipe 108, provided with a fan (not shown) for mixing air with the gas entering burners 106, the air and gas being preferably hot. Chamber 105 is cooled by means of steam ejected from perforated pipes 110 connected by pipe 110ˣ with any suitable source of steam supply, and preferably the exhaust of the engine used for operating the system. These pipes 110 are inclosed in a casing 111 which in turn incloses the upper side of chamber 105 and communicates, by passage 112, with the interior of lime preheater 22, so that the steam in said casing 111 may escape with the waste gases from chamber 105 into the said preheater. Preheater 22, as will be observed, opens into chamber 105 at the top thereof, so that the highly heated lime therefrom will drop downwardly onto the layer of slag 113, above the layer 114 of fused iron sponge therein. The lime entering the fusion furnace will be at all times largely in excess of sulfur requirements, for all the organic sulfur and most of the volatile sulfur has been eliminated or removed in other parts of the process.

The iron sponge is deposited in fusion chamber 105 by a plunger 115 which is reciprocated, in its casing 116 and in an opening 117 in the furnace wall, by a suitably driven pulley 118, past the discharge hopper opening 119 of elevator 13, which conveys the iron sponge from ore-reducing kiln 8, to chamber 105 of fusion furnace 14. At each downward reciprocation, the plunger 115 forces the iron sponge which has fallen in front or below it downwardly into the mass of molten iron 114 and slag 113 in chamber 105. Unfused sponge being lighter than the molten iron will rise up and meet the hot lime and fusion will take place. The sponge in chamber 105, as well as that added thereto from time to time, is thus always out of contact with any oxidizing or other deleterious agent.

Moreover the opening 117 by reason of the formation of its discharge end and its relation to the slag level, provides a trap which the sponge must pass as it enters the fusion furnace and which therefore excludes oxidizing gases.

It will be noted that the iron sponge and highly heated lime meet for the first time in chamber 105. This has the advantage, before noted, that the "heat of formation" of slag is added at the highly important period of the critical temperature of fusion, thereby adding greatly to its heat value.

Chamber 105 is provided with an extension 120 having a lower level and between the two there is trapped passage 121 (Fig. 4) for the iron to pass through on its way from chamber 105 to extension 120. The upper portions of these two chambers open into each other, and they are both heated from the same source, the more intense heat being in the fusion section 105, as the other section requires only enough heat to maintain the slag and iron in a liquid state. At or near their lower ends they also communicate with each other by means of the trapped passage 121, formed by barrier 122 and dam 123, which are so arranged relatively to each other that the molten iron 114 and superposed body of slag 113, will be maintained at about the levels indicated, any excess of molten iron passing gently through trap 121 into chamber 120 as indicated at 124, beneath a body 125 of slag. Excess of slag passes over the top of dam 123 into chamber 120. As the molten iron and slag spill gently into it the chamber 120 constitutes, in effect, a settling chamber, with the molten mass of superposed layers of iron and slag quiescent, so that any impurities or foreign materials in the iron will have an opportunity to pass upwardly through it and be taken up by the slag.

The molten iron is withdrawn from chamber 120 and deposited in mixer 16 through outlet 126, and thence by passage 15 to mixer 16, in any suitable way; while surplus slag is withdrawn therefrom through pipe 77 to slag-container 23.

The gases at the upper end of the discharge hopper 127 of elevator 13 are in

equilibrium, with the CO in excess of the CO_2. At the lower end or discharge opening 119, however, of the hopper, this equilibrium may be disturbed, by an increase of temperature or additions of CO_2. To overcome this, and maintain the necessary equilibrium between the CO and CO_2, additional hotter and purer CO etc. gas is supplied at this point directly from the converting chamber 29 of reaction furnace 27 by a pipe 128.

Also, to provide for the escape of the gases confined with the sponge in the opening 117 in which the plunger 115 reciprocates, and thus permit said plunger to operate properly, said plunger has a loose fit in its casing 116, so that, on the downward or upward movement of the plunger, such gases may pass it and escape from the fusion furnace. The gases thus escaping are preferably conducted by a pipe 129 to the pipe 75 and thence to manifold 107 for re-use as heating fuel in the chambers 105, 120.

The foregoing description, though directed, in terms, to fusion furnace 14, is equally applicable to fusion furnace 14^a.

Referring now to the slag containers 23, 23^a (Fig. 1), it will be observed that each of them is provided with two pipes 130, 131 and 130^a and 131^a, respectively. The pipes 130, 130^a are for use in "shotting" the slag if desired, that is to say, by putting the hot slag into water, where the slag disintegrates into sand-like particles, and pipes 131, 131^a may furnish suitable materials for refining the molten slag, as for instance carbon to remove iron brought in by the limestone, or these pipes may be used for other purposes. The slag may be removed from the fusion furnace or slag container in any other suitable way.

Fusion furnaces 14, 14^a are also provided with pipes 132, 132^a, respectively, for use in adding to the contents thereof any ingredient for the improvement of the quality of the steel to be produced from the iron therein, or to add suitable ingredients, to those present in the slag, to produce an approximately true Portland cement slag, as for example, alumina and a constant small and regulatable stream or percentage of iron oxids, a portion of which will pick up any phosphorus in the molten iron. The phosphoric acid in the fusion furnaces will be taken away from the iron oxids and held by the highly-heated basic slag permanently.

It will thus be observed that while the process is producing steel it is also simultaneously producing Portland cement. Also with but a single unit as shown in the drawings, in using certain ores, it will produce a larger quantity of steel than can be made in any blast furnace together with its secondary operations, and in addition to the steel my process will produce a quantity of Portland cement nearly equal to the full capacity of the same number and size of rotary kilns.

Pipe 62, leading from converting chamber 29 to ore-reducing kiln 8 is also provided with a branch pipe 133 for the introduction of hydrogen, or other gases in case it is desired for purifying sponge in passing through said kiln or its connecting passages.

Nitrogen is largely excluded from the system except for purposes of combustion and then only one half as much nitrogen has to be heated up in burning CO gas as fuel as in burning coal or coke because only half as much oxygen in the air is required for chemical combination with CO gas as with solid carbon.

What I claim is:

1. A steel manufacturing process comprising the passing of a plurality of batches of iron ore through separate rotary kilns, reducing the separate batches of ore therein to sponge by passing therethrough a reducing agent at temperatures determined by the carbon contents desired in the batches of sponge, and uniting the final products of the batches of sponge in certain relative proportions determined by the carbon content desired in the steel.

2. A steel manufacturing process comprising the passing of a plurality of batches of iron ore through separate rotary kilns, reducing the separate batches of ore therein to sponge by passing therethrough a reducing agent at temperatures determined by the carbon contents desired in the batches of sponge, conducting the batches of sponge from the kilns, out of contact with oxidizing agencies, into separate fusion furnaces, and uniting the resulting batches of fused iron in certain relative proportions determined by the carbon content desired in the steel.

3. A steel manufacturing process comprising the passing of iron ore through a rotary kiln, reducing the ore therein to sponge by passing therethrough a reducing agent at a temperature determined by the carbon content desired in the sponge, and adding suitable material to the final product to produce steel having a desired carbon content.

4. A steel manufacturing process comprising the passing of iron ore through a rotary kiln, reducing the ore therein to sponge by passing therethrough a reducing agent at a temperature determined by the carbon content desired in the sponge, conducting the sponge from the kiln, out of contact with oxidizing agencies, into a fusion furnace, and adding suitable material to the resulting fused iron to produce steel having a desired carbon content.

5. An ore-treating process comprising the passing of ore through a rotary kiln, re-

ducing the ore therein to sponge by passing therethrough a reducing agent at a temperature determined by the carbon content desired in the sponge, conducting the sponge from the kiln, out of contact with oxidizing agencies, into a fusion furnace, and subjecting the sponge to the action of a hot purifying gas, contacting therewith, prior to fusion.

6. An ore-treating process comprising the passing of ore through a rotary kiln, reducing the ore therein to sponge by passing therethrough a reducing agent at a temperature determined by the carbon content desired in the sponge, conducting the sponge from the kiln, out of contact with oxidizing agencies, into a fusion furnace, and subjecting the sponge to the action of a hot purifying gas contacting therewith while in transit to the fusion furnace.

7. An ore-treating and cement-slag-producing process comprising the passing of iron ore through a rotary kiln, reducing it therein to sponge by passing therethrough a reducing agent at a temperature determined by the carbon content desired in the sponge, conducting the sponge thence, out of contact with oxidizing agencies, into a fusion furnace, feeding highly heated lime to the fusion furnace in quantities largely in excess of fusion requirements, maintaining the lime and slag therein in a highly heated layer above the sponge, and withdrawing the resulting fused iron and molten slag from the fusion furnace.

8. An ore-treating and cement-slag-producing process comprising the passing of iron ore through a rotary kiln, reducing it therein to sponge by passing therethrough a reducing agent at a temperature determined by the carbon content desired in the sponge, conducting the sponge thence, out of contact with oxidizing agencies, into a fusion furnace, passing limestone through and highly heating it in a rotary kiln, conducting the resulting highly heated lime from the kiln into the fusion furnace in quantities largely in excess of fusion requirements, maintaining the lime and slag therein in a highly heated layer above the sponge, and withdrawing the resulting fused iron and molten slag from the fusion furnace.

9. An ore-treating and cement-slag-producing process comprising the passing of iron ore through a rotary kiln, reducing it therein to sponge by passing therethrough a reducing agent at a temperature determined by the carbon content desired in the sponge, conducting the sponge thence, out of contact with oxidizing agencies, into a fusion furnace, passing limestone through a rotary kiln, highly heating the limestone therein by means of the waste heat from the fusion furnace, conducting the resulting highly heated lime to the fusion furnace in quantities largely in excess of fusion requirements, maintaining the lime and slag therein in a highly heated layer above the sponge, and withdrawing the resulting fused iron and molten slag from the fusing furnace.

10. An ore-treating and cement-slag-producing process comprising the passing of iron ore through a rotary kiln, reducing it therein to sponge by passing therethrough a reducing agent at a temperature determined by the carbon content desired in the sponge, conducting the sponge thence, out of contact with oxidizing agencies, into a fusion furnace, feeding highly heated lime and other cement ingredients to the fusion furnace with the lime largely in excess of fusion requirements, maintaining the lime and slag therein in a highly heated layer above the sponge, and withdrawing the resulting fused iron and molten slag from the fusion furnace.

11. An ore-treating and cement-slag-producing process comprising the passing of iron ore through a rotary kiln, reducing it therein to sponge by passing therethrough a reducing agent at a temperature determined by the carbon content desired in the sponge, conducting the sponge thence, out of contact with oxidizing agencies, into a fusion furnace, heating such furnace by means of a heating agent containing no organic sulfur, feeding highly heated lime into the fusion furnace in quantities largely in excess of fusion requirements, maintaining the lime and slag therein in a highly heated layer above the sponge, and withdrawing the resulting fused iron and molten slag from the fusion furnace.

12. A steel manufacturing process comprising the reduction separately of a plurality of batches of iron ore to iron sponge having relatively different percentages of carbon, by applying an excess of reducing gas to one batch at a high temperature of gas and ore, and the residue thereof to the next batch at a reduced temperature of ore, then separately fusing the batches of sponge, and then uniting the resulting batches of fused iron in proper relative proportions for securing the carbon content desired in the steel.

13. A steel manufacturing process comprising the reduction separately of a plurality of batches of iron ore to iron sponge, one substantially without and another with carbon, by applying an excess of reducing gas to one batch at a temperature of gas and ore avoiding the deposition of carbon in the ore, and the residue thereof to the next batch at a temperature of gas and ore producing such deposition, then separately fusing the batches of sponge, and then uniting the resulting batches of fused iron in proper

relative proportions for securing the carbon content desired in the steel.

14. A steel manufacturing process comprising the fusing separately, in suitable fusion furnaces, of a plurality of batches of iron sponge having relatively different percentages of carbon below the point of saturation, maintaining in each of said furnaces, above the sponge, a layer of highly heated liquid slag, introducing the sponge into the furnace beneath the slag, then permitting the batches of fused iron to settle in other compartments of their respective fusion furnaces, maintaining in each of the fusion furnaces and said other compartments, above the fused iron therein, a layer of the same highly heated liquid slag, and subsequently uniting the batches of fused iron in proper relative proportions for securing the carbon content desired in the steel.

15. A steel manufacturing process comprising the reduction separately, by currents of reducing gas, of a plurality of batches of iron ore to iron sponge, having relatively different percentages of carbon, then separately fusing the batches of sponge in suitable fusion furnaces, then permitting the batches of fused iron to settle in other compartments of their respective furnaces, maintaining in each of said furnaces and other compartments, above the fused iron therein, a layer of highly heated liquid slag, and subsequently uniting the batches of fused iron in proper relative proportions for securing the carbon content desired in the steel.

16. An ore-treating proces comprising the reduction of the ore to sponge, the fusing of such sponge under a highly heated liquid layer of slag maintained above it, the entrance of subsequent batches of sponge, before fusing, into the molten mass of superposed layers of fused iron and slag at a point below the layer of slag, and the maintenance around the sponge, as it approaches such entrance point, of a reducing atmosphere of greater purity than the ore-reducing gases behind it and of a higher temperature than the sponge.

17. An ore-treating process comprising the reduction of the ore to sponge, the fusing of such sponge under a highly heated liquid layer of slag maintained above it, the entrance of subsequent batches of sponge, before fusing, into the molten mass of superposed layers of fused iron and slag at a point below the layer of slag, trapping the mass at the entrance point of the sponge, and the maintenance around the sponge, as it approaches such entrance point, of a reducing atmosphere of greater purity than the ore-reducing gases behind it and of a higher temperature than the sponge.

18. An ore-treating process comprising the reduction separately of a plurality of batches of iron ore to iron sponge having relatively different percentages of carbon, by applying an excess of reducing gas to one batch at a high temperature of gas and ore, and the residue thereof to the next batch at a reduced temperature of the ore, and then separately fusing the batches of sponge.

19. An ore-treating process comprising the reduction separately of a plurality of batches of iron ore to iron sponge, one substantially without and another with carbon, by applying an excess of reducing gas to one batch at a temperature of gas and ore avoiding the deposition of carbon in the ore, and the residue thereof to the next batch at a temperature of the ore producing such deposition, and then separately fusing the batches of sponge.

20. A steel manufacturing and cement-slag-producing process comprising the passing of iron ore through a rotary kiln, reducing it therein to sponge by passing therethrough a reducing agent at a temperature determined by the carbon content desired in the sponge, conducting the sponge thence, out of contact with oxidizing agencies, into a fusion furnace, feeding highly heated lime to the fusion furnace in quantities largely in excess of fusion requirements, maintaining the lime and slag therein in a highly heated layer above the sponge, and adding suitable material to the resulting fused iron to produce steel having a desired carbon content.

21. A steel manufacturing and cement-slag-producing process comprising the passing of a plurality of batches of iron ore through separate rotary kilns, reducing the separate batches of ore therein to sponge by passing therethrough a reducing agent at temperatures determined by the carbon contents desired in the batches of sponge, conducting the sponge thence, out of contact with oxidizing agencies, into separate fusion furnaces, feeding highly heated lime to each of the fusion furnaces in quantities largely in excess of fusion requirements, maintaining the lime and slag in the fusion furnaces in highly heated layers above the sponge, and uniting the resulting batches of fused iron in certain relative proportions determined by the carbon content desired in the steel.

In testimony whereof, I have hereunto set my hand.

CHARLES B. HILLHOUSE.