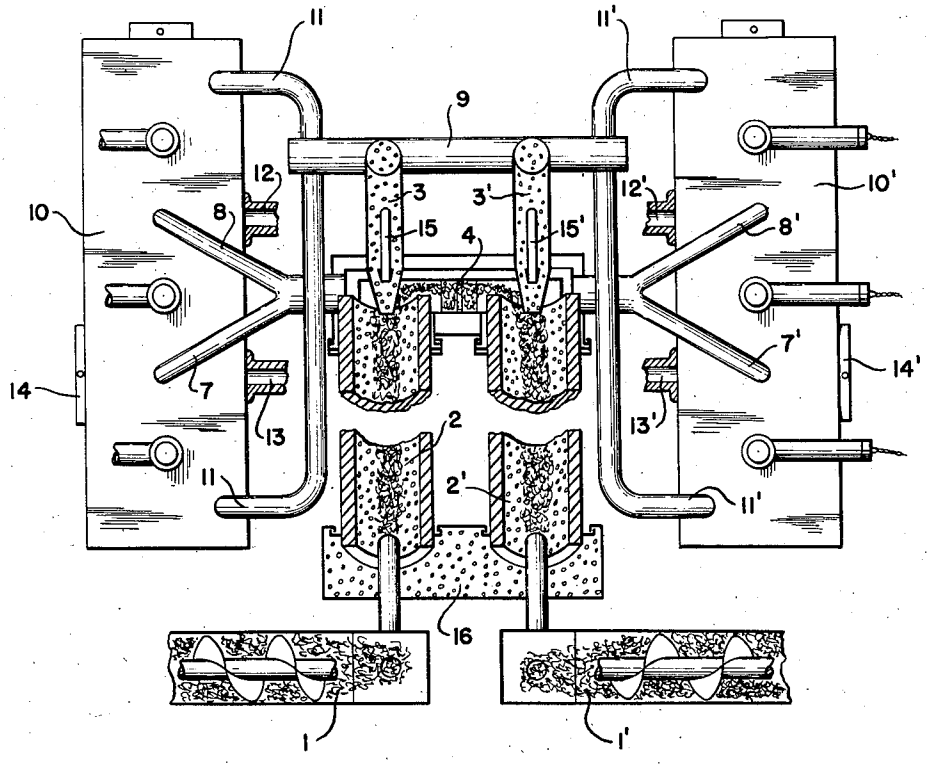
Sept. 3, 1957 V. S. ARATA 2,805,142

METHOD FOR THE PRODUCTION OF PURE IRON, AND IRON CARBON ALLOYS INCLUDING CARBON AND ALLOY STEEL

Filed Feb. 9, 1954 3 Sheets-Sheet 1

FIG. 1



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FIG. 2

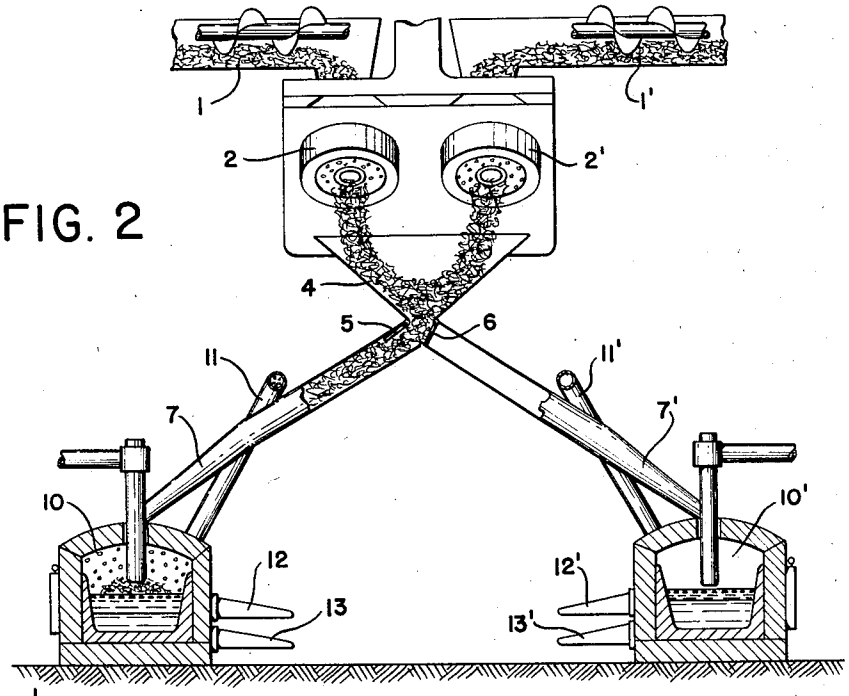
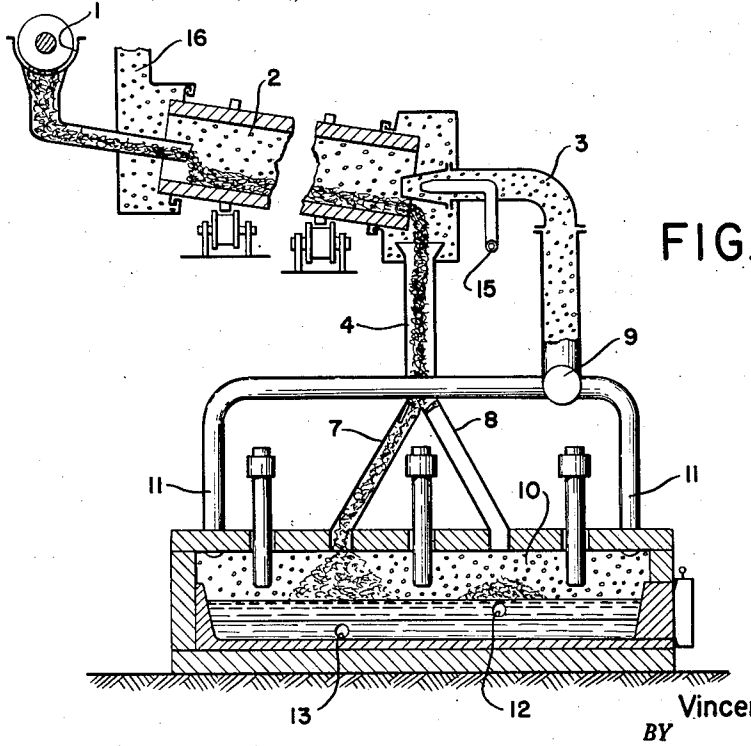


FIG. 3



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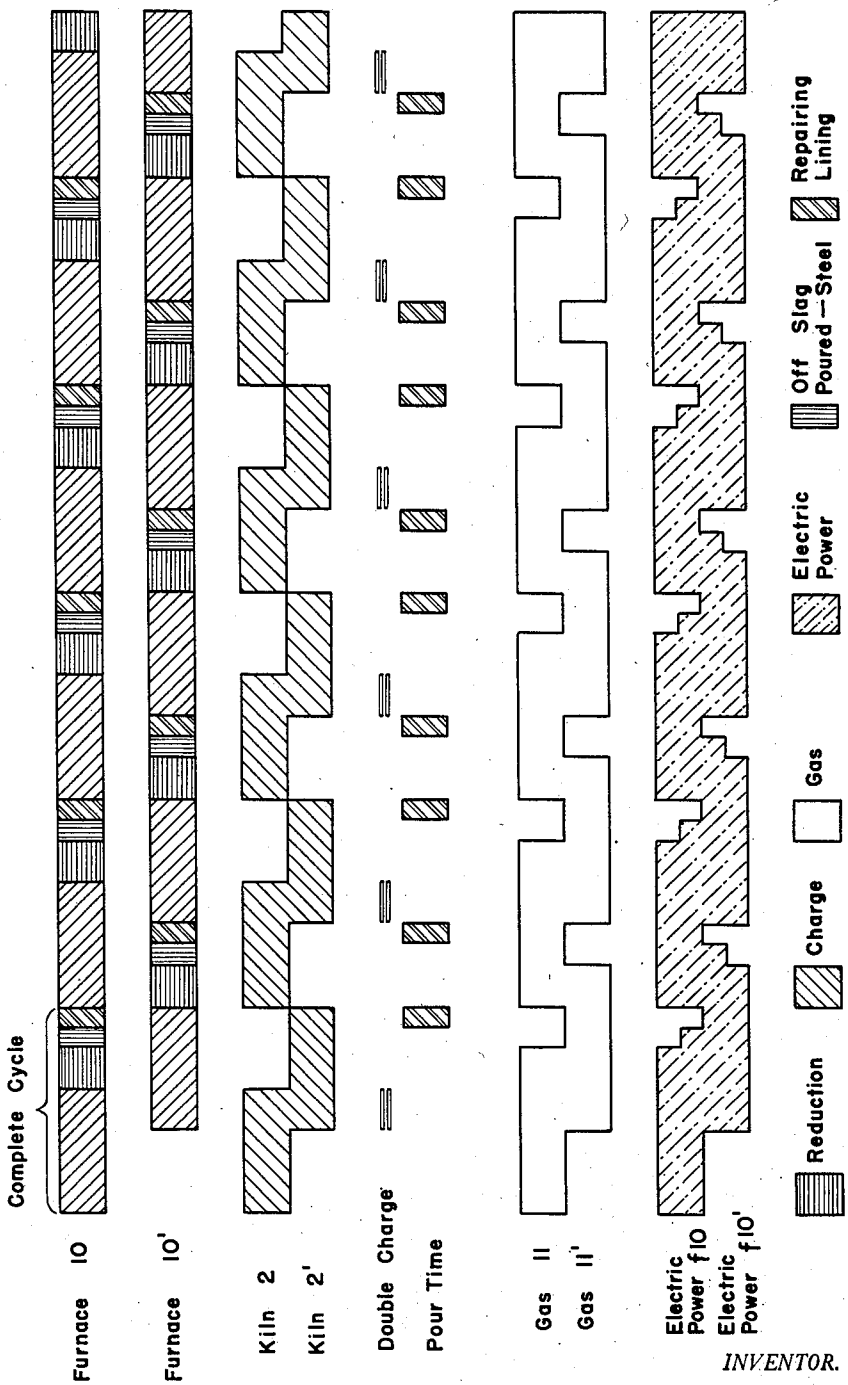
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Filed Feb. 9, 1954 3 Sheets-Sheet 3

FIG. 4



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United States Patent Office 2,805,142 Patented Sept. 3, 1957

2,805,142

METHOD FOR THE PRODUCTION OF PURE IRON, AND IRON CARBON ALLOYS INCLUDING CARBON AND ALLOY STEEL

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Application February 9, 1954, Serial No. 409,217

7 Claims. (Cl. 75—11)

My present invention relates to the commercial production of pure iron and iron-carbon alloys, including carbon and alloy steel, directly from ore and carbonaceous material. In using the terms "directly" or "direct process" in the succeeding text, I mean that the process does not involve the production and handling of intermediate materials such as coke and pig iron, and that the iron or steel is produced directly in the molten state.

In the past, single charges of ore and carbonaceous reducing agent have been converted into steel in the electric furnace, but the methods that have been used up to now have had one of two principal disadvantages which have prevented their coming into general use. The first of these has been the high estimated capital and operating costs of full-scale plants of this type. These high estimated costs have in turn been due to the operation of the plant purely on a batch process. The salient factor contributing to high estimated operating costs has been the high power consumption of 2500 kwh./metric ton or more and similarly the largest factor in capital cost has been the high cost of power-generating facilities for a given annual steel ingot capacity. These factors have tended to discourage the installation of plants employing the direct process in many localities.

My present invention embodies a method of treatment whereby power consumption can be decreased one-third to one-half resulting in a decrease almost as great in total cost, and a proportionate decrease in capital cost of generating facilities. Furthermore, according to my present invention, steels can be produced to the required analyses on a regular basis with a minimum number of off heats.

According to one method for the production of pure iron, of my invention as disclosed in United States Patent No. 2,747,985, the ore is finely crushed and intimately mixed with the required flux and with a determined quantity of finely divided carbonaceous reducing material. This quantity is determined so that after allowing for carbon lost in the flue dust escaping with the top gases, sufficient carbon is left in the charge to reduce between 60 and 90 percent of the iron content of the charge as calculated stoichiometrically. I normally use the following equations for this type of stoichiometric calculation:

$$Fe_2O_3+3C=2Fe+3CO$$
$$Fe_3O_4+4C=3Fe+4CO$$

In the production of steel in contrast to the production of pure iron, I determine the quantity of carbon charged analogously, except that I provide sufficient carbon to reduce approximately 85–100 percent of the iron content of the charge. According to my previous method of operation, all of the materials were charged, melted, and refined batchwise in the electric furnace, and the manner of accomplishing this together with a physical and chemical description of the process is described for the case of pure iron in the above-mentioned patent application. The production of steel is analogous except for the differences in carbon content of the charge noted above.

Numerous attempts have been made in the past to make the direct process fully continuous, in order to reduce capital and operating costs. I have found in many years of practice that fully continuous production is inconsistent with regular analysis and reliable quality of steel produced. Therefore the present process can be considered to be a batch process with respect to the refining period and to the cycle of a single electric furnace, but it can be considered to be continuous with respect to the charging of raw materials and the production of steel in the plant as a whole, as well as with respect to the utilization of gas from each individual furnace. The elements of the plant are connected in such a way that the operation of the preheating chambers is continuous, and the effect of the preheating (and partial reduction) step is to decrease power consumption from 2500 kwh./metric ton to 2000 kwh./metric ton or less. My process therefore involves a number of electric furnaces and a number of preheating chambers. With respect to the flow of solid materials, each electric furnace is connected in parallel with at least one other electric furnace and in series with at least one preheating chamber. With respect to the flow of gas, the same is true, except that in the majority of cases all of the electric furnaces will be in parallel with each other and in series with all of the preheating chambers, which in turn will be parallel with each other.

Before describing the operation of my process by a concrete example, it may be advisable to point out several ways in which the carrying out of my process will deviate from and represent an improvement upon past methods of conducting the direct process.

First, in the making of steel from ore and carbonaceous material by the direct process, the most critical period is the refining period during which the heat is adjusted with respect to its final carbon content, and the sulphur and phosphorous contents are brought down to the correct levels. Most coals contain appreciable sulphur and this element is always the most difficult to eliminate in the direct process. This is due to the fact that the direct process employs a slag high in FeO and the elimination of sulphur requires a strongly basic slag low in FeO. Therefore, frequently it is necessary to remove the first slag and replace it by a strongly basic slag rather low in FeO. This procedure cannot be efficiently or reliably carried out while excess carbonaceous material (usually coal or coke) remains on top of the slag, as has been attempted in the past, since the removal of the first slag would bring the carbon of the coal in contact with the metal and carburize it so that the steel would not show the correct tapping analysis in carbon. Therefore it is not feasible to charge excess carbon to the furnace and still maintain a regular and controlled analysis of the steel produced. Accordingly, in my process, after allowing for carbon lost in the flue dust and for carbon going into the steel, I only charge sufficient carbon to reduce 80–100 percent of the iron content of the raw materials, and I conduct the refining process batchwise so as to provide the opportunity to charge a second slag for removal of impurities, including sulphur and phosphorous.

Second, if it is attempted to produce steel continuously in the electric furnace by continuously charging fresh materials, it will be impossible to refine the molten metal into steel in the same furnace; this is due to the difficulty of separating the metal being refined from the incoming material. The incoming, impure materials tend to increase the oxygen and sulphur contents of the metal bath, to introduce dirt and other contaminants, and to vary the analysis of the product. Such continuous operation has been tried in the past, and has resulted in irregular analysis of the steel produced. Therefore, in the present invention the charging cycle of

each furnace is discontinuous and represents only a portion of the total heat time, and the refining is carried out batchwise.

Third, those furnaces, which have operated continuously to produce steel by the direct process have been required to hold high temperature slags and iron continuously and this has resulted in high refractory losses and frequent breakouts, which have seriously interrupted operations and in many actual cases rendered the process impractical. According to my cycle of operation, a portion of every cycle of each furnace after each heat is allocated for repairing the walls and the bottom of the furnace, as is normally done in a batch process; this gives the operator time to anticipate and prevent costly breakouts and to maintain a satisfactory furnace lining. Furthermore, in my cycle of operations, which lasts normally five hours, the reduction operation requires approximately four hours, and during this period only the locations adjacent to the arcs are at high temperature. Accordingly, reduction proceeds throughout the greater part of the charge at temperatures less than 1200° C., and the walls and roof remain cool. Only during the refining period, which requires about half an hour of the total cycle, is the temperature of the materials adjacent to the walls raised above the melting temperature of steel. This factor has such an important bearing on the life of the lining as to spell the difference between feasibility and non-practicability of the direct steel process, and it is a basic feature of my present invention.

I will now give a description of a typical plant in which the electric furnaces are operated in parallel and according to a definite cycle, in order to give a clear picture of its operation.

Such a plant will consist of a number of "units," as hereinafter more specifically defined, each unit including as elements electric furnaces connected in series with one or more preheating chambers. The purpose of the preheating chambers is to preheat and in most cases also to partially reduce the ore. In all cases, the electric furnaces of each unit will be connected in parallel with each other with respect to the flow of gas and of solid materials, and the preheating chambers of each unit will be similarly connected in parallel with each other. The preheating (partial reduction) chambers in each unit may be of various types (for example, rotary kiln or shaft furnace) and may function differently with respect to their physical and chemical treatment of the raw materials. For example, each unit may include two parallel sets of kilns of which each set is made up of two kilns in series so that preheating and roasting of the ore and a degree of coking of the carbonaceous material (by which a large portion of the volatile materials is rapidly eliminated) take place in the first kilns of the series, while partial reduction and additional preheating take place in the second kilns of the series. However, partial reduction and preheating in the second kilns should never go so far as to result in sintering of the iron-containing materials, i. e., in practice the temperature of the material leaving the second kilns should be 600–1000° C. In other plants operating with different types of carbonaceous reducing agent, the individual units may consist simply of one or two parallel kilns into which are charged properly prepared iron ore and carbonaceous material and which discharge in parallel into a battery consisting of at least two electric furnaces.

The preheating chambers should preferably be so designed as to permit regulation of the residence time of the charge materials passing through them so that the discharge cycle of materials from the preheating chambers into the electric furnace is not rigidly determined by the charge cycle of the same materials into the chambers. This feature enables the charging and discharging of the several preheating chambers to be relatively independent of one another and more flexibly adaptable to the electric furnace cycle.

For example, in case the preheating chambers consist of rotary kilns, such regulation can be accomplished by providing control of either the degree of tilt of the kilns or of their rate of rotation, or both.

The number of units in a large plant is of course adapted to the production requirements of the entire plant without departing from the principles followed in a small plant or in an individual unit. It should also be stated that although, with respect to the flow of materials, only the furnaces and preheat chambers in a single unit may be in parallel with each other, with respect to the flow of gas, all of the furnaces in the entire plant are preferably connected in parallel, and the same holds true for all of the preheat units with respect to the flow of gas.

Each individual unit may consist of at least two and possibly more electric arc furnaces with carbon or graphite electrodes preferably of the Soderberg type. The furnaces may be either of the conventional cylindrical type or rectangular or of any convenient shape; they may be either tilting or stationary. They need not be arc furnaces since I may also perform my present invention with other types of electric furnace.

I shall now explain my invention in detail with respect to one specific embodiment thereof selected by way of example and with reference to the accompanying drawings in which:

Fig. 1 is a schematic plan view, partly in section, of a "unit" for carrying out my process;

Fig. 2 is a schematic end view, partly in section, of the unit shown in Fig. 1;

Fig. 3 is a schematic side view, partly in section, of the unit shown in Fig. 1; and

Fig. 4 is a graphical representation of timing relationships between different phases of the operation of the unit shown in Fig. 1.

Figs. 1–3, inc., show a single pair of rotary kilns, **2** and **2'**, operating in parallel with each other and in series with a single pair of electric furnaces, **10** and **10'**. This combination represents one of the simplest methods of carrying out my process. In Fig. 1, horizontal screw conveyors **1** and **1'** charge the material continuously into chutes and from these chutes through passageways into kilns **2** and **2'**. Such passageways should always be kept full of charge material so as to maintain a seal preventing the escape of the gases which pass through the kilns. After partial reduction and preheating in the kilns **2** and **2'** are complete, the materials pass into a common hopper **4** which, as shown in Fig. 2 has two exits, **5** and **6**, each with it own valve. The chute passing out of exit **5** in turn diverges, as shown in Fig. 3 into two chutes, **7** and **8**, also provided with individual valves, and through these chutes the materials fall into furnace **10**. The passage of materials through exit **6** into furnace **10'** is entirely analogous, through chutes **7'** and **8'**.

With respect to the flow of gas, uptakes **11**, provided with appropriate valves convey the gas evolving from reduction taking place within furnace **10** into collector main **9**. Uptakes **11'** similarly connect furnace **10'** to collector main **9** which is common to both of the furnaces. (In case there are more than two furnaces in the unit or in the plant as a whole, collector main **9** should be common to all of the furnaces. In any case the furnaces are operated in cycle so as to maintain as nearly as possible a steady flow of gas for use elsewhere in the plant.) According to my process it must be possible to shut off the discharge of gas from either furnace **10** or furnace **10'** by means such as valves in uptakes **11** and **11'** as well as to stop the flow of gas into either preheating chambers **2** and **2'** by means of valves in the passageways **3** and **3'** between collector main **9** and the chambers. This arrangement of the equipment illustrates the functioning

of my process, which permits operating a number of preheating (and partial reduction) chambers in parallel with each other and in series with a number of electric furnaces also operating in parallel with each other. Any chamber or furnace unit should be separable at will from all of the other units comprising the whole, with respect to the flow of both solids and gases. All of the units of the plant should operate under a slight superpressure which is maintained by valves in passages **11**, **11'**, **3**, **3'**, or by equivalent valves located, for example, in collector main **9**.

In certain cases it might be desirable to maintain combustion in the kilns by adding air. Such air injection is carried out by means of injectors **15** and **15'** which conduct air to act as a combustion medium for the gases in passages **3**, **3'**; the flame can of course be regulated to be more or less oxidizing. The gases are exhausted from the rotary kilns **2**, **2'** through a common passageway **16**, and part of the gases may be recycled into collector main **9**. Because of the high temperature of the gases leaving the electric furnaces **10** and **10'**, passageways **11** and **11'**, **9**, **3** and **3'** must be provided with suitable refractory linings.

Fig. 4 is a diagram illustrating a particular method of operating a plant according to my process. The diagram refers to a plant unit having two electric arc furnaces in parallel with each other which are fed by two kilns, also in parallel with each other, and it illustrates the normal cycle of operation of each of the two kilns and each of the two furnaces. Each furnace operates according to the following approximate cycle:

	Hours
(*a*) Total reduction period	4
(*b*) Total charge period (part of reduction period)	3
(*c*) Refining, tapping and preparing furnace for succeeding charge	1
(*d*) Total cycle	5

It is understood that the following description is applicable also to a plant having more chambers and furnaces than illustrated and in which the total period and the relation of the various cycles may vary in accordance with the characteristics of the charge and the number of chambers and furnaces comprising the plant. At the beginning of a campaign furnaces are brought up to temperature by melting in them several successive scrap charges. Afterwards they are ready to receive the first ore-containing charge. The charge proceeds as follows: several shovelfuls of coal are first introduced, for example, into furnace **10**, through open door **14** (the valves in passages **11**, **7** and **8** being closed). The introduction of coal serves the purpose of absorbing and eliminating the oxygen of the air which is present in the interior of the furnace prior to opening chutes **7** and **8**, and thereby avoiding the slight explosion which might otherwise occur when the considerable amounts of carbon contained in the entering charge are suddenly brought into contact with the air within the furnace. The appearance of flames at the door **14** of the furnace indicates that gas is present within and, upon this observation, the charge controlling valves in passages **7** and **8** are opened (valve **5** being open and valve **6** closed). Passages **7** and **8** are kept open until charge has been deposited beneath the electrodes to a thickness of at least one foot, after which they are again closed. Since the charge coming from above is deposited somewhat unevenly, the surface of the charge is then raked to form a smooth bed beneath the electrodes. On top of this bed a layer of iron scrap several inches thick is charged through the door. Subsequently the electrodes are lowered and as soon as all three of the electrodes touch the surface of the scrap, power at maximum voltage and minimum amperage is supplied to start the arc. It is necessary to employ maximum voltage to increase the power absorption during the initial period when the conductivity of the charge and therefore flow of current are low. The reason it is necessary to maintain a high initial power consumption is that normally the electrodes are regulated so that they are raised and lowered by increases and decreases of both amperage and total power and it is necessary to avoid that the electrodes should sink into the charge due to the small amount of current passing them and the low power consumed. It should be emphasized that it is impossible to start the arc unless use is made of the high conductivity of the scrap layer; this layer permits the current to flow and a small bath of molten material is rapidly formed. However, it should be noted that in some cases the partial reduction operation may have produced sufficient metallic iron or may have sufficiently raised the temperature of the charge so that, due to the high conductivity of the charge entering the electric furnace the arc will start spontaneously; in this case the charging of the scrap layer can be dispensed with. Normally no difficulties present themselves in this phase, but in case one of the electrodes should tend to sink into the charge, a small amount of scrap or reduced iron should be added through door **14** in such a way as to make a good contact. After the proper steps have been taken to insure that the current and power are balanced between the three electrodes the ore begins to be reduced in quantity and the gases appear at door **14**. At this point door **14** is closed and passages **7** and **8** and **11** are opened. From time to time the amperage is increased in the normal manner and the voltage decreased to the minimum point consistent with good operation since it is advisable to transfer to the charge as much heat as possible (this transfer being represented according to Joule's equation $W=I^2R$).

From time to time either of passages **7** or **8** can be closed for a while to equalize the level of the charge in both ends of the furnace and to permit observing the operation of the furnace through peepholes.

After completion of two hours of the charge cycle of furnace **10**, charging of furnace **10'** is commenced by opening valve **6** and in this manner kilns **2** and **2'** will be supplying the entire charge requirements of both furnaces **10** and **10'** for a period of one hour. Three hours after the beginning of the charge cycle of furnace **10**, valve **5** is closed so that the charge proceeds through valve **6** only into furnace **10'** so as to complete the charge cycle of furnace **10'**. After stopping the charging of furnace **10**, reduction continues in this furnace for approximately one hour. Then gas uptake passage **11** is closed and door **14** may be opened slightly permitting the gases to blow out. The bath is then agitated with a stirrer. When no further gas appears the reduction cycle is complete. Door **14** can now be fully opened, if necessary, in order to determine whether pieces of the charge are adhering to the walls, in which case they can be put back into the bath. At this time a test sample is taken to determine the carbon content of the melt. The taking of this test sample is very important at the beginning of the campaign when it is desired in succeeding heats to obtain a steel of a definite carbon content without adjusting the bath by adding a second slag. By charging the furnace in accordance with my patent application U. S. Serial No. 286,213, or in accordance with those modifications of this patent application which are described above as applying to steel manufacture, it is possible to produce a bath containing a regularly constant content of carbon. When operating with high-grade ores of low P and S content, and with ores containing MnO and of low P and S content, it is recommended that several shovelfuls of 75% or 90% ferro-silicon be added on top of the slag in order to reduce part of the FeO or MnO content of the slag into the metal without increasing the carbon content. This step is naturally taken only in case the carbon content of the first test is at the correct level or lower; if the melt carbon is higher than the required final carbon content it is not possible to add ferro-silicon,

since it is first necessary to reoxidize with a second slag to remove the carbon and the effect of a prior addition of a reducing material such as ferro-silicon would be lost.

After the proper additions have been made, slag notch 12 is opened (or if the furnace is a tilting type, it is tilted) and the slag is tapped. The height of the slag notch is maintained at such a level in a stationary furnace that the final level of the steel reaches the bottom of the slag notch and that all of the slag is properly tapped. This is an easy matter to provide in a plant of this type. After the first slag has been tapped, a second slag can be charged in the normal manner. Additions of ferro-manganese, ferro-silicon, or other materials are then made, and the temperature of the steel is brought to the required level. Subsequently tapping hole 13 is opened and the metal tapped into ladles. Finally the walls and if necessary the bottom are repaired with magnesite or dolomite in the regular manner. Several shovelfuls of limestone are fed over the bottom and the furnace is now ready to recommence its cycle. The combined refining, tapping and repairing cycle will take approximately one hour. However, the flexibility of the plant permits the charging of furnace 10 to be delayed or accelerated, or it also permits the cycle of furnace 10' to be prolonged.

The cycle of furnace 10' is entirely analogous to that of furnace 10 except for a phase lag of approximately two hours.

Since it is advisable that, with respect to the flow of gas, all of the preheating chambers of each unit and normally of the entire plant be connected in parallel with each other, a certain superpressure is necessary to maintain the flow of gas through the entire system. This pressure is estimated at several millimeters of water column for a unit, and greater for several parallel units. Such superpressure must be also maintained in the furnaces during the reduction part of the cycle, although not in the refining period when the furnace is disconnected from the remainder of the system. Therefore it is characteristic of our process that the individual furnaces during the reducing cycle, and the connected gas system as a whole, be maintained under a slight superpressure. If adequate superpressure cannot be maintained under normal conditions, it is necessary to create such superpressure by, for instance, compressing a portion of the waste gases and recycling it into the furnaces during the reduction cycle.

In conclusion, the advantages to be obtained by practicing the presently claimed improvements in all types of iron and steel production arise from the combination of continuous charging and preheating and batch refining. Whereas previously it has not been feasible, practically and economically, to produce steel on a large scale by the direct process, my claimed improvements will overcome this disability. The two sets of desirable conditions obtained by the combinations of my claims are listed as follows:

A. Advantages of continuous operation obtained by this process:

(1) Continuous charging into and out of the preheating chambers of each unit; and into the plant as a whole.

(2) Regular production of metal from the plant as a whole due to staggering the tapping of the individual furnaces in accordance with the typical cycle.

(3) Power consumption per ton of metal decreased by preheating and/or partial reduction charges resulting in the case of steel production in a considerable decrease in power consumption per ton as compared with 2500 kwh./metric ton in a batch process.

(4) Full and efficient use of the gas from the electric furnace plant as a whole to preheat and partially reduce the charge.

(5) Constant volume of gas delivered for other uses in the plant.

B. Advantages of batch refining cycles obtained by this process:

(1) Regular production from ore in each plant unit of all grades of high, medium, low carbon and alloy steel products of uniform analysis and to specification.

(2) A long refractory life due to the fact that temperature of furnace walls is maintained low for a major portion of each cycle. The temperatures only exceed the melting temperatures of the materials during the short refining period. Roof temperatures are likewise kept low.

(3) A period is allowed during each cycle for repairs to the bottom, walls and roof, thereby permitting an enormous increase in lining life as compared with a continuous refining operation.

C. Advantage unique to this process:

A further advantage that is not characteristic of either a purely continuous or a purely batch operation is that within each unit, if sufficient elements are provided, in the event of a breakdown of a single preheat chamber or of a single furnace, another sequence of chamber or furnace operation can be substituted. Frequently such substitution would not disturb in any degree the continuous features of the operation. As an example, in an individual unit consisting of two preheat chambers and three electric furnaces, the preheat chambers may be so designed that one can handle the full rated charge of the unit, and that the cycles of two furnaces can be staggered so as to handle this charge in the event the third furnace is temporarily shut down. Such substitutions provide a degree of flexibility that cannot be obtained in either a batch or a continuous plant, and the greater average availability reduces down time cost and overhead charges, thus improving the efficiency of operation.

In the following claims, the term "unit" refers to a number of electric furnaces and preheating chambers, including that number of electric furnaces (never less than two and usually not more) which is connected, with respect to the flow of solid raw materials, in series with a single preheat chamber or in series with several preheat chambers connected in parallel with each other, and including the number of preheat chambers thus connected in parallel. The term "battery" refers to all of the electric furnaces in the unit or to all of the preheating chambers in the unit.

I claim:

1. The method of operating a plant for the production of molten pure iron and iron carbon alloys from ores, said plant being of the type including one or more plant units, each unit comprising two or more electric furnaces connected with each other in parallel with respect to the in-flow of solid charge materials and the out-flow of evolved gas and one or more preheating chambers connected in series with said furnaces with respect to said flows, in which the cycle of each individual furnace includes a reduction period during which the flow of evolved gases from said furnace is connected so as to preheat solid charge materials continuously entering said furnace from one or more of the preheating chambers by countercurrent flow in such chamber, a batch refining period during which said furnace is disconnected from the rest of the unit with respect to the flows of solid charge materials and evolved gas, and a repair period during which said furnace is conditioned for the succeeding cycle.

2. The method of claim 1 in which the solid charge material includes iron ore and carbonaceous material in a proportion to said ore such that the available carbon, after allowances for flue dust and alloying, does not exceed the amount theoretically sufficient to reduce 100% of the iron content of said ore.

3. The method of claim 1 in which the temperature of the furnace walls and roof is maintained below about 1300° C. during at least two-thirds of the cycle.

4. The method of claim 1 in which a gas pressure of at least several millimeters of water column gauge, is

maintained in each furnace and in the gas system of the unit connected thereto during its reduction period.

5. The method of claim 1 in which the preheating of the solid charge materials in the chambers is conducted at such a temperature or for such a period of time as to produce, as the solid charge material fed into a furnace at the beginning of a cycle, a material of a conductivity sufficient to start an electric furnace arc.

6. The method of claim 1 in which the preheating of solid charge materials in the chambers is conducted at 600° C.–1000° C.

7. The method of operating a plant for the production of molten pure iron and iron carbon alloys from ores, said plant being of the type including one or more plant units, each unit comprising two or more electric furnaces connected with each other in parallel with respect to the in-flow of solid charge materials and with respect to the out-flow of evolved gas and one or more preheating chambers connected in series with said furnaces with respect to the flow of said charge materials and evolved gas, comprising the steps of partially reducing said charge materials in said chambers by preheating with said evolved gas to a temperature of 600° C.–1000° C., further reducing said charge materials in a single furnace while at the same time charging said single furnace with said charge materials, disconnecting said single furnace from the unit with respect to the flow of said charge materials and evolved gas, completing the reduction and melting of the charge materials in said single furnace.

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