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METHOD OF AND APPARATUS FOR REDUCING ORES AND
EFFECTING OTHER CHEMICAL REACTIONS
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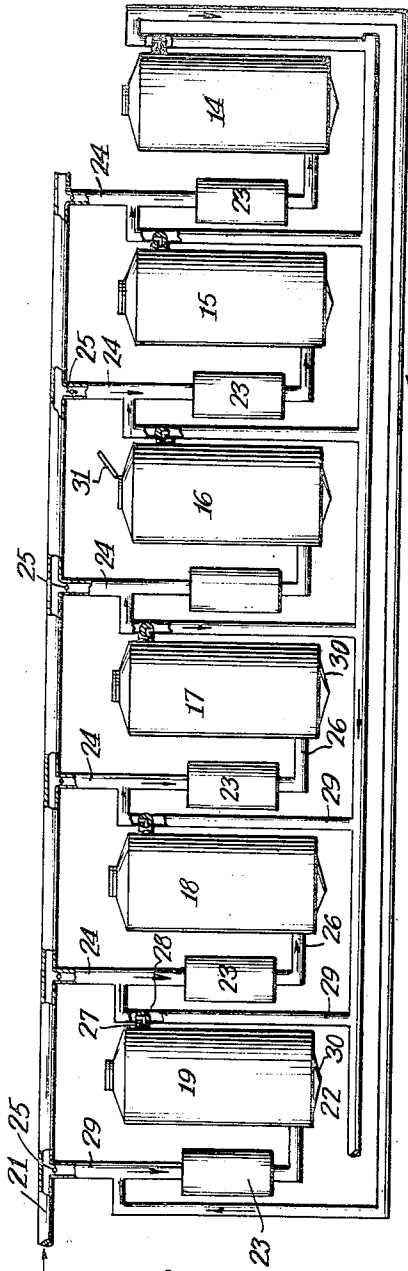


Fig. 2.

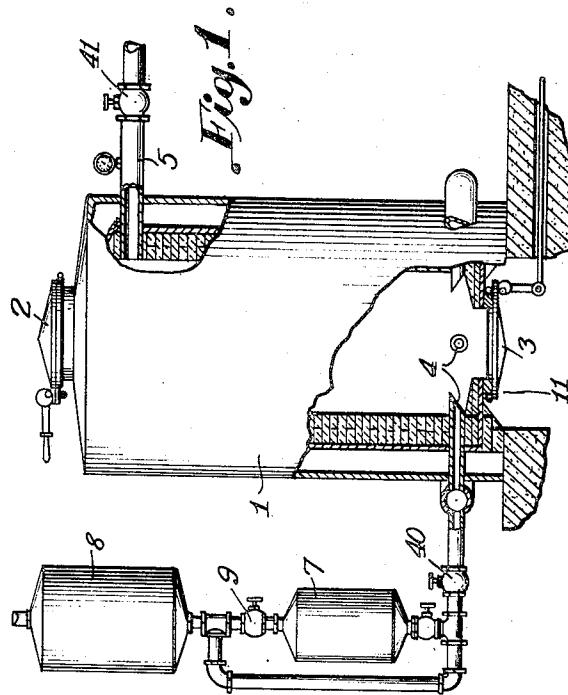


Fig. 1.

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METHOD OF AND APPARATUS FOR REDUCING ORES AND EFFECTING OTHER CHEMICAL REACTIONS

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19 Claims. (Cl. 75—35)

In the description the complete process of separating the iron from the ore and smelting or melting it and compounding it with other alloys will consist of the following major steps:

The present application is directed primarily to the reduction of the ore, preferably at low temperature. The ore may be directly reduced in one step or in several steps, or roasted first for magnetic concentration, depending upon the quality or nature of the ore, or upon the purpose of the operation.

The main feature of the invention is the ability to separate the iron or other metals from their ores or oxides in one continuous process in a pure state and compound them with their alloys if desired in one continuous step. In case of iron, and similarly with other elements, the invention accomplishes both the direct making of steel from the ore and the control of the ingredients and thereby the quality. Both features have been eagerly searched for by the whole metallurgical and chemical industries, without accomplishing either, while my invention accomplishes both.

While in my new device or combination of devices several of the subdevices in themselves constitute new inventions, for which claims will be entered below, their operation will bring about certain chemical and heat reactions and mechanical changes also in a way that the time, quality or nature of the reactions will be controlled automatically or not automatically, by mechanical, electrical or other methods whatever is desirable. The control of the chemical reactions both in quality and speed, and the control of the quality of the product have never before been accomplished by any known device in a continuous step or continuous direct series of operations.

By purity of the product, a commercial degree of purity is meant and not laboratory or absolute pureness. However the purity will be of a greater degree in most cases than is accomplished at present in one similar step. By control, only a commercial degree of control is meant and not absolute control. However the control will be of a distinct nature and to a great enough degree to add to, or in some cases to distinctly show the inventive features of the device. Furthermore, some of the devices themselves when applied separately or in other combinations fall within the scope of my invention.

Reducing of the ore (single unit)

The following describes some of the construction and operating features of the invention.

The method of making pure iron in solid or molten state, or steel directly from the ore will be used in the description as an illustration. But the same mechanism, or other similar mechanisms, involving the same principles may be used without departing from my invention.

Reduced to the simplest form of operation, the apparatus may be made in a single unit. I will first describe such a single unit in order that the principles of the reducing or deoxidizing of the ore may be set forth.

In the drawing:

Figure 1 is a diagrammatic view of a single unit for reduction of the ore;

Figure 2 is a diagram of a multiple unit device.

In Figure 1 the ore will be charged into container 1 through opening or door 2 and removed through door 3. Any suitable construction may serve as container which will be called henceforth the reducing chamber. Preferably a double pipe may be used with vacuum in between for heat insulation purposes. However the structure may be of any geometric shape, the inside of which may be without partition or with partitions in between, or several pipes may be placed inside the structure, in case it is desirable to provide less space between the wall surfaces in order to give more support for the ore or for other reasons. Also the ore may be removed through the same opening through which it has been charged. Also the chamber may be solidly fixed to the ground structure or it may be removable and portable, or it may be rotating. It may be vertical or at any angle.

At or near the bottom of the chamber there are inlet holes 4 for the entering of the gas. These holes or one hole for the gas inlet may be located at any other suitable part of the chamber. At the top or at any other suitable place there is the outlet pipe 5 for discharging the gas. The inlet and outlet of the gas may be controlled through valves 40 and 41 at inlet 4 and outlet 5 respectively, or the reducing gas may be forced through in a continuous stream. The ore may be charged either in larger pieces or in granulated or pulverized form. The charge may be added in one charge or fed continuously at any desired rate. The ore may be discharged through door 3 which will close the reducing chamber at any desired time, or it may be carried out continuously by a spiral or conveyor or any other suitable device.

In the device illustrated in Figure 1 the container is first charged and the charge may fill the container partially or fully. Preferably a space is left at the top, the purpose of which will

be evident later in the description. The inlet 2, outlet 3 and valve 41 are then closed. Through valve 40 the chamber is charged with the reducing gas to a predetermined pressure and then the valve 40 is closed. The outlet valve 41 is then opened in a controlled way so that when the gas is liberated, the pressure is reduced, the gas expands and forces the ore particles apart, thus maintaining the looseness in the charge, facilitating the freer passage of the gas and accelerating the rate of reduction of the ore by bringing the reducing gas in closer and quicker contact with the ore particles. This is very desirable especially in cases where the ore is dusty and has the tendency of packing together and blocking the circulation of the gas. If the pressure is increased to a sufficient degree in the chamber and if the valve 41 is opened fast enough, the compressed gas in the ore may be forced apart with the suddenness of an explosion while liberating the gas and scattering and mixing the charge. This may be done during the whole operation or repeated at any desired number of times during any phase of the operation to maintain the looseness of the charge and speeding up the reducing reaction either by providing a passage for the gas or forcing it into closer contact with the oxygen and other undesirable elements through the pores of the ore. The gas may be forced through the ore and the pressure varied with something like a pulsating effect. In the method illustrated in Figure 1, when inlet valve 40 opens, outlet valve 41 closes and after valve 40 closes, valve 41 opens, thus pulsating the pressure in the chamber. This method is especially preferable in case when the charge is dusty or tends to block the passage of the gas too much, or at different points of the charge the ore sticks or cakes, making it hard for the gas to penetrate or prevents uniform penetration and uniform reduction of the ore.

The gas may be charged preheated in order to provide the sensible heat for the balance of the heat of decomposition of the oxides, and the formation of the gas oxides, for instance H_2O , CO and CO_2 and other heat losses and raising the temperature. Also the heat may be provided through heaters in the chamber itself in contact with the ore or not in contact. In any case the circulating gas will be used to provide the heat balance for the chemical reactions and losses or other necessary purposes by carrying it from the heating elements to the charge. This phase is the major problem in reducing ores and will be more fully hereinafter discussed.

The temperature at which the ore may be made to reduce, the speed of reduction and the speed of gas circulation and the rate of supply of the sensible heat will be controlled automatically. In Figure 1 the gas is heated in tank 8 by electric heaters or through hot gas pipes in which the temperature may be controlled automatically. Also carbon may be burned to carbon monoxide right in the tank or it may be burned outside of it and the carbon monoxide may then be charged into the tank thus adding also the necessary heat.

In case the nature of the ore makes a pulsating effect desirable, that is a periodical increase and decrease of pressure of gas in the reducing chamber, a smaller pressure tank 7 may be inserted between tank 8 and chamber 1 which will then regulate the pressure and amount of gas supplied. It will serve as kind of a means for measuring out of the gas at a controlled pressure.

When valve 9 opens, tank 7 becomes filled with gas after which the valve closes again. Then valve 40 opens it, lets some of the gas into chamber 1 through holes 4 while outlet valve 41 remains closed. Valve 40 closes and valve 9 opens to fill tank 7. Simultaneously with filling the tank 7, outlet valve 41 opens and releases the gas pressure. The operation will be repeated until the desired chemical state of the charge in chamber 1 is reached.

In case the sensible heat is supplied from a heat supply outside of the chamber, the reducing gas may be recirculated several times and may be purified and reheated at some stage on its path. For instance in case of hydrogen used for reduction, the vapor formed through the reduction of ore may be condensed out by any suitable method, or the oxygen absorbed by hot carbon forming carbon dioxide gas and liberating the hydrogen. In such a case the hydrogen serves only as an agent to carry the oxygen from the ore to the carbon and may be recirculated with very little loss. When carbon monoxide is used, the CO_2 gas that forms by the chemical reaction of the CO gas upon the ore may be broken up into $CO+O$ by heating it over $1830^\circ F.$ over which temperature CO_2 gas cannot exist in presence of free carbon, and passing it through hot carbon or adding carbon in dust or gas form to form another CO gas molecule with the oxygen carried away from the ore itself. In such a way, after the process is once started, it will not be necessary to add any oxygen from an outside source and the amount of carbon used for reducing the ore will be reduced to almost one-half. The final exhaust where larger amount of CO_2 has accumulated may be burned to supply the sensible heat in the heaters, or again carbon may be added to increase the quantity of CO to be used for other industrial purposes.

If desired, when the reduction of the ore is completed, valve 40 may be connected to a hydrogen supply for purifying the metal or for cooling down sufficiently for magnetic separation, whenever the quality of ore so requires.

The exhaust gas from the chamber 1 may be used for roasting, for magnetic concentration or beneficiation purposes since this process may be carried out at lower temperature and with much leaner gas. The beneficiated ore then may be charged directly into the reducing chamber without the necessity of first agglomerating the crushed or pulverized ore, thus eliminating the costly process of agglomerating.

When the ore is reduced to the desired stage all inlets into chamber 1 will be closed gas tight and door 3 will be opened and the charge dropped into a closed pit 11 where some reducing atmosphere or vacuum will be provided. In case the ore will be carried out of chamber 1 by a spiral for instance in a continuous way which requires the keeping of the outlet open all the time or for a longer time, the reducing atmosphere in pit 11 may be under higher pressure than the pressure in chamber 1, preventing the passage of gas into the pit.

The multiple units plant

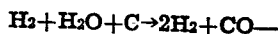
The many advantages and distinctness of my invention will be more fully evident when a number of units are operated in series as one plant as illustrated in Figure 2. One of the many possible combinations of the units illustrates the method and forms a distinctly new and valuable feature and constitutes a part of my invention.

The plant (Figure 2) consists of 6 units 14 to 19 inclusive. 21 represents the intake line and 22 the exhaust line. A heater 23 is arranged between each of the units. A conduit 24 leads from the intake 21 to each heater 23 and is controlled by a valve 25. A conduit 26 connects the other end of the heater to the adjacent chamber 16. A conduit 27 connects the upper end of each chamber to a valve 28 adapted either to connect the conduit 27 with the conduit 24 or with a by-pass conduit 29 leading to the exhaust 22.

In the operation of the multiple units plant the gas will enter through the chamber that was longest in operation, which in the illustration is number 15, and will pass consecutively through all of the units leaving the system through the chamber that was charged last which in the illustration is number 17. Thus as will be observed from the diagram the fresh gas derived from the intake 21 passes through the open valve 25 leading to the heater 23 prior to the unit 15. The gas then passes through unit 15 and through the valve 28 to the next heater and so on through the entire series. When the gas leaves the unit 17, which is the unit last charged, it passes through valve 28 which has been turned to connect the unit to the exhaust line 22 and thus the cycle of the gas is complete.

The unit 16, which is not included in the cycle, is in position to discharge the reduced ore after which it will be again filled with fresh ore. This unit can then be connected with the cycle again when the unit 15 is removed from the same. To do this the valve 28 adjacent unit 17 is turned to direct the gas discharge from 17 through the heater and into unit 16. Valve 25, between units 15 and 16, is closed and valve 25, between units 15 and 14, is opened. Therefore, the fresh gas now starts through unit 14 and finishes with unit 16 and the unit 15 may be emptied and refilled with fresh ore.

In this multiple unit plant the different stages and degrees of chemical reaction and the necessary temperature for the reaction will be separated into several steps and also the supplying of the balance of heat will be accomplished if desired without recirculating the gas. The importance of this will be most evident in cases where the purifying or conditioning of the gas involves cooling the gas. For instance when hydrogen is used as reducing gas, the exhaust will consist of hydrogen and vapor. In order to condense the vapor out of this exhaust gas and use the remaining hydrogen over again, it is necessary to cool the gas to the low temperature where the vapor condenses. Suppose the exhaust gas will consist of one molecule hydrogen and one molecule H_2O . Adding one molecule carbon according to the water gas reaction will regenerate this into three molecules of excellent reducing gas and at the same time maintain the high temperature of the gas. The formula is



When the reduction of the ore is completed in a chamber, all of its valves will be closed and door 30 opened through which the charge will be dropped into the pit below. Then the door 30 will be closed again and the door 31 will be opened to receive the fresh charge. The chamber is then connected into the system again.

In the above described method the ore is laid in the horizontal plane, but substantially the same method may be applied in the vertical plane

or in a plane at any angle between the horizontal and vertical.

The gas may be by-passed from the different layers by a suitable arrangement which may be similar to the valve and pipe system in the method illustrated in Figure 2. The different layers then may be operated in any desired sequence in a continuous series or the ore may be charged and discharged at the same time in all of them as desired.

After the ore is reduced it will be discharged into a pit or carried away by any suitable mechanism into a reducing atmosphere or vacuum to be stored, concentrated, the metal extracted by any suitable means, or the ore may be charged directly into melting or smelting or compounding furnace. The ore may also be compressed under high pressure to be carried away without melting, or it may be commercially handled in gas tight tanks in reducing atmosphere or vacuum, or by any other suitable arrangement that prevents reoxidization. The different layers may be also operated simultaneously so that the ore will be continuously discharged at the bottom and charged at the top or discharged at one end and charged at the other end. Any other suitable arrangement may be applied involving the same or similar principle of carrying the sensible heat by the gas into the ore from the heaters without departing from my invention.

Continuous formation of reducing gas

Another important and unique characteristic of my invention is that after the operation once starts it is not necessary to add oxygen to the carbon from an external source to form carbon monoxide gas but the oxygen obtained by the deoxidization of the ore may be used to form the reducing gas by passing the gas mixture of CO and CO_2 through hot carbon and adding the difference between the heat of decomposition of CO, into $CO+O$ and the heat of formation of C and O to CO. The gas may be heated before entering the carbon so that it carries sensible heat for the reaction, or the carbon itself may be heated. By this method the amount of carbon used will be reduced to practically half. This reaction will be more fully discussed in the theoretical consideration.

In Figure 2 the carbon will be preferably added in form of coke or charcoal in a container 23 which is placed between connecting pipes 24 and 26 and the gas is conducted through the carbon placed in container 23. Since the temperature of decomposition of CO_2 into $CO+O$ in presence of carbon is within the so-called low temperature reduction range of iron ore and the percentage of decomposition depends upon the temperature, both the temperature of the reducing gas and the ratio of CO to CO_2 may be automatically controlled before entering into the charge. The CO_2 gas may be decomposed and the temperature regulated either in all connecting pipes or in any number of them, in which case the reduction of the ore will be much faster, or it may be heated and decomposed only before it enters into the first reduction chamber. Since the gas will be forming continuously, some of the leanest gas at the exhaust or at any place in the system may be by-passed and may be used to supply heat energy for preheating the gas before entering in the reducing chambers. It also may be used for preliminary roasting and beneficiation of the ore.

In the preceding description, I have referred

to certain types of apparatus which may be used in carrying out my invention. I will now describe some of the features of the invention and some of the factors which must be kept in mind when utilizing the invention. In my process it is necessary, first, that the metal should be separated from the ore free from other ingredients which are present in the ore; second, the metal must not be contaminated by any source of impurities outside of the ore.

In carrying out the first stage of my process, that is the reduction of the ore, it is preferable to use as the reducing gas carbon monoxide or hydrogen or a combination of both. The different stages of reduction of iron ore will occur at different temperatures and with different concentration or quality of the reducing gas. These stages of reduction as a function of temperatures and quality of gas is known in the art and the whole functioning is controlled in my invention in contrast to other devices.

In the variation of my device as illustrated in Figure 1, all the stages of reduction are combined in one reducing chamber. By regulating the height of the ore layer, in a full "charge and empty" method, or the rate of charge and discharge of ore and height of ore, together with the rate supplying the gas, its quality, temperature and pressure, the reduction of ore and its different stages will be controlled. This control may be accomplished either with a continuous gas supply method or by the pulsating method. This control of the reactions will be accomplished easier by the pulsating method. In our further analysis the discussion will be confined to the method where the different stages of reduction will be carried out in a number of reducing chambers as illustrated in Figure 2, but the analysis will be illustrative for the "one stage" method of Figure 1.

The reducing gas, say CO, will be heated and charged into the chamber containing the most reduced ore. The temperature and pressure will be controlled, together with the rate of flow of gas, or in the pulsating method, the frequency of the pulsation. This will cause the gas to come in contact with all particles of the ore in a substantially even or homogeneous way, since at this stage of reduction the ore will either consist of small particles or if the pieces are large, they will be porous and will be penetrated by the gas easily. Under pressure, the number of gas atoms in contact with the ore particles will be proportional to the pressure, which, besides more complete penetration of the ore, will assure a more speedy reduction in all particles. This density of the reducing gas will make it possible and economical to keep the gas in contact with the ore particles for a longer period.

Another functional characteristic of my invention, due to handling the gas under compression, is the nature of the transfer of heat from the gas to the ore. The speed of reduction of ore and also the practical operating temperature of reducing the ore depends upon the transfer of heat of reduction to the ore, rather than upon the rapidity of the chemical reaction between the liberated oxygen and the reducing gas. In parting the oxygen atom from the metal atom a large amount of heat has to be supplied, which is a function having a lower order of rapidity than the reaction between the oxygen and the gas, which is a reaction of exceedingly high order, having the rapidity of explosion. Since the oxygen must be first separated from the

ore before it can unite with the gas, and since the parting of the oxygen from the iron results in the loss of heat, this heat for decomposition must be supplied first before the decomposition can be accomplished. The proper supply of this heat of decomposition before the decomposition happens is of primary importance, besides the proper method of bringing the gas in contact with the metallic oxide molecules.

In my invention, the gas under pressure will not only be in closer contact with the ore particles under more violent vibration, and not only more gas molecules will act upon the ore molecules, but all the gas molecules will surround the ore molecules for a much longer duration, resulting in more efficient heat transfer of a different character than when the gas is flowing in a stream.

Furthermore the reaction between the oxygen and gas molecules always results in an exceedingly large increase of temperature of the new molecule, this increase being the heat of combustion of the gases. This temperature will only be reduced by the transfer of heat to the ore, and at a much higher rate to the surrounding gas molecules. Since this high heat of combustion will occur right in contact with the ore molecules where other unreduced molecules are present in contact with other reducing gas molecules, the transfer of the heat of combustion to these molecules results in a different speed of reaction than if the burned gas molecule is at once removed and travels at hazard until by chance it will meet at an other place in a new combination with active reducing gas molecules and the ore molecule. But by that time it will give up most of its heat of combustion where the probability of the presence of reducing gas molecules and ore molecule is of a lower order. This functional characteristic of my invention may be also shown mathematically. This characteristic is distinct in spite of the fact that any motion of gas stream may be treated mathematically as stationary in an infinitesimal time interval when compared to the molecular motion of the gas.

After the pressure is released and the gas stream sets into motion, the gas molecules will travel with different speeds of motion, under different pressure, further reducing the ore, re-mixing the ore and loosening it for the admission of new gases. The gas, practically all, will be made inactive for the particular stage of reduction. However, most of the gas will leave the ore, which will be refilled with fresh gas under pressure again. The formation of unreduced pockets and hot and cold zones will also be eliminated, my invention differing also in this respect from other devices. It will even be possible to explode larger pieces of the ore at any stage of the reduction, if for some reason it had not been pulverized or granulated at an earlier stage.

Another important functional characteristic of my invention is that it may supply a good part of the balance of heat energy in form of pressure energy. The heat necessary to raise the temperature of the ore to the reducing temperature and also some of the heat losses may be supplied by circulating preheated gas or by preheating the reducing gas, or both. In order to clearly define this characteristic, it is necessary to state that the purely chemical functions of the reduction of ore with hydrogen is endothermic and with CO it is exothermic. How-

ever, in an operating device in practice it is found that it is necessary to add heat even in case of CO being used. This heat may be added in form of sensible heat with the gas, which would necessitate recirculating the preheated gas several times or raising the temperature of the ore first in contact with the gas to an undesired degree. As there is a great difference between the temperature and active gas concentration for reducing Fe_2O_3 and Fe_3O_4 to FeO and further between reducing FeO to Fe in any practical operating device, the iron ore may be reduced first to FeO with less rich gas and the temperature brought up to the desired degree by recirculating the gas and heating it. From that stage on, at zones or in chambers where the FeO is reduced to Fe , any desired amount of the sensible heat may be supplied by compressing the gas. During the process of compression heat is added to the gas, equal in heat units to the work done on the gas, and accordingly the temperature tends to increase according to the adiabatic change of pressure and volume. However, at the same time the reduction of the ore progresses which will cool the gas, the sensible heat thus being supplied by the work done on the gas. Therefore, if desired, the gas will be compressed isothermally or the change of volume may be a combination of adiabatic and isothermal change. This may be done in a controlled way, controlling the rate of reduction of the ore and the temperature in the chamber. Some of the sensible heat may be supplied by direct heating of the gas and some of it by compressing it, at any desired rate, or by a combination of these two expedients.

Also a part of the pressure energy may be directly supplied by heat energy. For instance the colder gas may be first compressed, then heated either on its way to the ore or in the compression tank, preferably the former.

About one million B. t. u.'s may be provided in form of pressure energy by expending about 300 K. W. hrs. net work in compressing the gas in the reducing chamber.

Another important problem in reducing and smelting the ore is reducing ores that are pulverized, granulated, or in general consist of too many small particles, in other words, dusty ores. On first consideration, this may seem to be a matter of quantity, for seemingly any amount of gas may be forced through the ore by providing the proper pressure of gas at the entrance. However, due to the nature of ores, this may result in undue loss of ore in the flue, on unreduced and isolated pocket formations in the furnace, or both. To overcome this difficulty costly intermediary steps are introduced. For instance, at present the ore has to be formed intoglomerules after beneficiation, resulting in large expenses and other losses. In course of the operation, when the pressure is increased with every fresh charge of gas, the ore particles will come in contact with fresh gas and at the same time the ore layer will be loosened. This will also eliminate the problem of "packing" of the ore while heated and reduced.

The difference between my device and other devices in this respect may be seen the easiest, when considering that other devices cannot handle too dusty ore in a practical commercial way, not excepting the so called rotary furnace, while in my device even ore dust or any type of solid ore may be even packed tight and exploded at will in a controlled way. Before discarding or

discharging the gas, it may be introduced under pressure into a chamber filled with ore, the pressure suddenly released and at repeated operation the ore will be not only pulverized but reduced to a magnetic state and concentrated. Before concentration it may be ground if desired. Then without cooling or agglomeration, it may be charged into the reducing chambers.

To give some numerical figures concerning the pressure, about a seven feet high layer of packed or solid ore may be lifted by one atmosphere pressure difference between the bottom and top. At proper increase of pressure, the gas will penetrate the packed ore dust from all sides, tearing the particles apart from all sides and loosening the complete charge.

Another novel feature of my invention is that after the operation starts it may entirely utilize the oxygen of the ore to form the reducing CO gas in case that gas is used for a reducing medium.

The reactions of $2\text{CO} \rightleftharpoons \text{C} + \text{CO}_2$ are a reversible system and form a mobile equilibrium, and any change in the factors of equilibrium (such as pressure and temperature and active masses) from an outside source must be followed by a reverse change in the system. Also, at the temperature regions where the reduction chambers operate, between 800°C . and 1000°C ., the rate at which 2CO is dissociated into $\text{C} + \text{CO}_2$ is many times less than at which the reverse occurs. Furthermore, in a practical commercial plant, to assure the practical rate of reduction, the CO content in the gas must be kept well above 65% that is the CO_2 content well below 35%. When the oxygen is provided from an outside source to form CO reducing gas, an excessive amount of carbon will be used up and also an excessive amount of flue gas will result with all its heat losses, and other mechanical disadvantages.

In my device, at a stage, or at the chamber, where the discharged gas will be the most free of impure gases, the gas will be tapped and recirculated over hot carbon increasing the CO percentage to a large extent. For instance at 900°C ., which is in the operating range, the CO_2 content will be only a little above 2% at one atmosphere pressure, and, at say four atmospheres, it will be approximately 5%, forming an almost equally rich reducing gas. This reaction will be endothermic and the heat balance may be supplied by adding the sensible heat, by either heating the coke or charcoal or preferably heating the gas before entering the carbon, thus keeping both carbon and the reducing gas at a desired and controlled temperature. When CO_2 stops forming, the ore will be practically all reduced. Any simple, practical device may be used for this purpose that will indicate the temperature difference. Or the CO_2 content at the entrance of the gas into the ore, and when it leaves the ore, may be indicated by any other suitable means, thus determining the state of reduction of ore in the chamber.

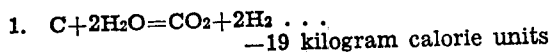
Since, while the reduction progresses, new gas will be formed continuously, some of the gas has to be by-passed, that is, bleeding will be necessary. The reducing gas may also be enriched between two reducing chambers while entering from one to the other chamber. The richness of the gas and its temperature and pressure may be controlled automatically or manually at will. This method of control and formation of reducing gas will cut the amount of carbon utilized, and will keep the gas so rich, thereby

the rate of reduction so high, and the contamination of the metal so low that it adds to my invention another distinct functional characteristic. Practically the same task will be accomplished by mixing some of the carbon right with the ore and circulating the gas and supplying the balance of heat.

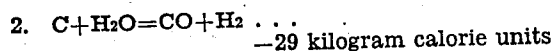
By mixing the carbon with the ore and heating it to start and maintain the chemical reaction, seemingly and approximately the same reactions may be accomplished. However, in practice, this results either in an inoperative or a commercially inoperative device. Also it results in the use of a substantially greater amount of carbon. Besides, it will reduce the ore unevenly and will contaminate the ore with carbon and with some of the impurities present in the ore.

The advantage and distinctiveness of my device may be better illustrated in the case of reduction by hydrogen where the hydrogen will be used mostly as a catalytic agent to carry the oxygen of the ore to the carbon forming CO and CO₂, resulting in a faster reaction, purer form of metal extracted, and great saving in the amount of hydrogen used.

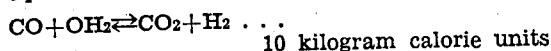
The interaction between steam and carbon will be according to the equations:



This reaction will prevail from 500° C. to 600° C.



This is the water gas reaction, where, at and over 1000° C., the main result will be equal volumes of H₂ and CO. In my device the operating temperature zone will be such that both CO and CO₂ will be formed. However, at the operating range, the proportions of CO and CO₂ will be such that they practically constitute an inactive gas for the iron oxide, and will serve mostly as a diluent for the hydrogen. When, however, the hydrogen unites with the oxygen of the ore forming H₂O, and when this H₂O content of the gas reaches the balance limit of the relative concentration, the excess oxygen will be transferred to the carbon, in accordance with the dynamic equilibrium equation



which may be defined at different temperatures, as

$$\frac{\text{CO} \times \text{OH}_2}{\text{CO}_2 \times \text{H}_2} = K$$

In this equation within range of operative temperature of my invention K will be always kept between 0.1 and 1.5, which means that for any reducing purpose in the reduction chamber, the gas will be practically free of vapor, that is a very small percentage of vapor will be present, thus keeping the hydrogen rich and maintaining a high rate of reduction of ore.

Also neither CO nor CO₂ has any tendency to bind the hydrogen, beyond the equilibrium limits consequently they will not retard the reaction between the H₂ and ore except in a diluting and cooling way. For the latter reason an additional amount of heat must be provided also for this part of the heat balance. This may be done by preheating the gas or by compressing it or both.

Since outside of favorably affecting the action of hydrogen as a reducing gas, the carbon ox-

ides will serve as diluent only, like nitrogen in the gas, it will be possible to carry on a hydrogen reduction process by using much less hydrogen without condensing the vapor or eliminating the CO₂ at frequent intervals.

The carbon may be added at any stage of the reduction process, in many combinations, some of it even mixed with the ore without departing from my invention. Furthermore the carbon oxides and hydrogen, together with the pressure and temperature may be controlled automatically or manually.

While eliminating the nitrogen from the reducing gas, my invention will also speed up the reactions materially. It will not only prevent dilution, but also will lower the temperature of reactions. Another main function will be the prevention of contaminating the metal by nitrogen that results in such harmful effects and remains in the metal in spite of all subsequent purification efforts with the present systems.

In a purely hydrogen system, the vapor may be condensed out by any suitable device. This however, will result in a great loss of hydrogen. Preferably, the oxygen will be combined with carbon as described above, and in case further purification of the ore is desirable to eliminate any residual carbon at the last stage of reduction, pure hydrogen may be used.

Besides the great advantages that my device offers in the quality and economy and speed of operation, it has also very evident advantages of construction and maintenance. The different stages of reactions may be carried on in standardized, interchangeable units. Also the speed of operation may be controlled and regulated without great loss of heat, material and labor, according to the requirements of the final output. Also the reduction may be carried on independently of the melting process.

From the magnetic separation viewpoint, the ore will be kept in a reducing atmosphere, preferably hydrogen, after it passes into the pit, and will be kept free of oxygen. The pressure may be automatically kept a little above atmospheric, assuring the isolation of the ore from the air. Also a vacuum may be maintained in the pit.

When the reduced ore drops into the bin, or is carried quickly through the grinder into the magnetic field, it will be completely dry, the iron separated from the impurities and the ore will be in an ideal physical condition for magnetic separation. The working of the gas stream against the magnetic field results in purer and more complete separation of the metal and also allows a higher intensity of magnetic field.

The pure iron may be stored for use at very little cost. It may be kept free of gases or other impurities in pulverized state, the best form for quick and easy melting. Also the iron storage may be kept under vacuum, thus further eliminating some of the gases remaining with the iron.

For melting or smelting purposes the iron may be left in pulverized form, eliminating the costly step of conglomerating the iron after the magnetic separation. Or it may be bricketted for transportation under pressure to prevent reoxidation, or for facilitating the transportation without melting the iron. It may also be packed into gas tight containers, if transportation in this form is desired.

In my device, it will also be possible to compress the pulverized iron into ingots and work

the metal as wrought iron. Or further fusion may be accomplished by heating the metal to a higher temperature, but below the melting point, and forging or rolling it, or further working it by any suitable method. The pulverized iron, when compressed for such treatment, may be kept under hydrogen atmosphere continuously, and heated and worked in hydrogen atmosphere.

It is desirable to point out that it comes within the scope of my invention to separate two or more different metals from the other constituents of an ore in which the metals are contained. When the two metals are to be reduced it is desirable to first reduce one with one reducing agent and then reduce the other with a different reducing agent or use the same reducing agent at a different temperature. It may be desirable to remove one of the reduced metals before reducing the other. As an example of such a process, consider an ore which contains both manganese oxides and iron oxides. By properly controlling the temperatures in the reducing chambers these metals may be differentially separated, first reducing the iron oxide to metallic iron and separating, and then reducing the manganese oxide to metallic manganese and separating. In reducing manganese oxides hydrogen may be used in the presence of carbon or carbon monoxide gas.

What I claim as my invention is:

1. Apparatus for obtaining metals from ores without fusion comprising a series of closed containers, means for introducing ore into each of said containers, means for circulating a reducing gas successively through said containers, means for heating said gas intermediate successive containers, valve means for disconnecting a predetermined container and shunting the gas around the same during such disconnection, and means for withdrawing the charge from the disconnected container.

2. A process for reducing solid oxides with reducing gas comprising passing gas through the body of the ore while pulsating the pressure of the gas in the oxide and maintaining the correct temperature until the desired degree of reduction is reached.

3. A process for reducing solid oxides with reducing gas comprising subjecting the oxide to the reducing gas under pressure and correct controlled temperature, releasing the pressure permitting the gas to escape and carry away the products of reaction and repeating the cycle until the desired reduction is accomplished.

4. A process for reducing solid oxides with reducing gas comprising subjecting the oxide to the reducing gas at or above atmospheric pressure at the correct controlled temperature, reducing the pressure below atmospheric pressure permitting the gas to escape and carry away the products of reaction and repeating the cycle until the desired reduction is accomplished.

5. A process for partially reducing solid oxides to obtain a magnetic product comprising passing gas through the body of the oxides while pulsating the pressure of the gas in the oxide, maintaining a predetermined temperature for the reduction, and continuing the introduction of gas until the oxide is in the magnetic state.

6. A process for reducing iron oxide to the metallic state comprising subjecting iron oxide to a reducing gas at or above atmospheric pressure at a predetermined controlled temperature, reducing the pressure below atmospheric permit-

ting the gas to escape and carrying away the products of reaction and repeating the cycle until all of the oxygen of the oxide is removed.

7. A process for heating finely divided material comprising passing gas at elevated temperature and pressure through the body of the material, releasing the pressure and repeating the cycle until the desired temperature is reached.

8. A process for reducing solid oxides comprising passing preheated reducing gas under pulsating pressure through the oxides and maintaining the temperature of the oxides at the desired temperature by the sensible heat of the preheated gas.

9. A process for reducing oxides which comprises first passing one kind of a reducing gas under pulsating pressure through the oxides to bring the reduction to a predetermined stage and completing the reduction by passing a different type of gas under pulsating pressure through the oxides.

10. The method of effecting a chemical reaction between a solid and a gas comprising introducing the gas into the body of the solid at a predetermined pressure, maintaining a predetermined temperature to cause a reaction between the gas and solid, releasing a substantial part of the reacted gas thereby lowering the pressure, introducing additional gas at a predetermined pressure and repeating the cycle until the desired stage of reaction is obtained.

11. The method of reducing solid oxides comprising introducing a reducing gas into the body of the solid oxides at a predetermined pressure, maintaining a predetermined temperature to cause a reaction between the oxide and gas, releasing a substantial part of the reacted gas thereby lowering the pressure, introducing additional reducing gas at a predetermined pressure and repeating the cycle until the desired stage of reaction is obtained.

12. The method of making sponge iron from iron ore comprising introducing reducing gas into the body of the iron ore at a predetermined pressure, maintaining a predetermined temperature to cause a reaction between the ore and gas partly reducing the ore, releasing a substantial part of the reacted gas thereby lowering the pressure, introducing additional reducing gas at a predetermined pressure and repeating the cycle until the ore is completely reduced to sponge iron.

13. Apparatus for obtaining metals from ores without fusion comprising a series of closed containers, means for introducing ore into each of said containers, means for circulating a reducing gas successively through said containers, means for regenerating the gas intermediate successive containers, means for heating said gas intermediate successive containers, means for disconnecting a predetermined container and shunting the gas around the same during such disconnection, and means for withdrawing the charge from the disconnected container.

14. A process for reducing solid oxides with reducing gas comprising preheating the oxide external to the reducer, charging the preheated oxide into the reducer and passing hot reducing gas through the body of the preheated oxide while pulsating the pressure of the gas in the oxide, and maintaining a temperature favorable to the reduction of the oxide until the desired reduction is reached.

15. A process for reducing ores with reducing gas comprising roasting the ore in an external furnace to reduce the oxide from Fe_2O_3 to Fe_3O_4 ,

charging the hot roasted ore into the reducer and passing hot reducing gas through the body of the preheated oxide while pulsating the pressure of the gas in the oxide, and maintaining a temperature favorable to the reduction of the oxide until the desired reduction is reached.

16. A process for reducing solid oxides with reducing gas which comprises partially reducing solid oxides external to the reducer from Fe_2O_3 to FeO and Fe , charging the partially reduced oxides into a reducer and passing reducing gas through the body of said oxides while pulsating the pressure of the gas in the oxides, and maintaining the correct temperature until the desired degree of reduction is reached.

17. A process for reducing solid oxides with reducing gas comprising passing gas through the body of the ore contained in two or more reducers in series while pulsating the pressure of the gas in the oxide, and maintaining the correct temperature until the desired degree of reduction is reached.

18. A process for reducing solid oxides with reducing gas comprising passing gas through the body of the ore contained in two or more reducers in series while pulsating the pressure of the gas in the oxide, maintaining the correct temperature until the desired degree of reduction is reached, preheating the reducing gas between reducers and maintaining the correct temperature until the desired degree of reduction is reached.

19. A process for reducing solid oxides with reducing gas comprising treating iron ore with one pass of hot reducing gas while pulsating the pressure of the gas in the oxide and maintaining the correct temperature until the desired reduction is reached, passing the partially spent reducing gas through other reducers in series for the reduction of oxide favorable to reaction with partially spent gas until the desired reduction of the other oxide is reached.

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