

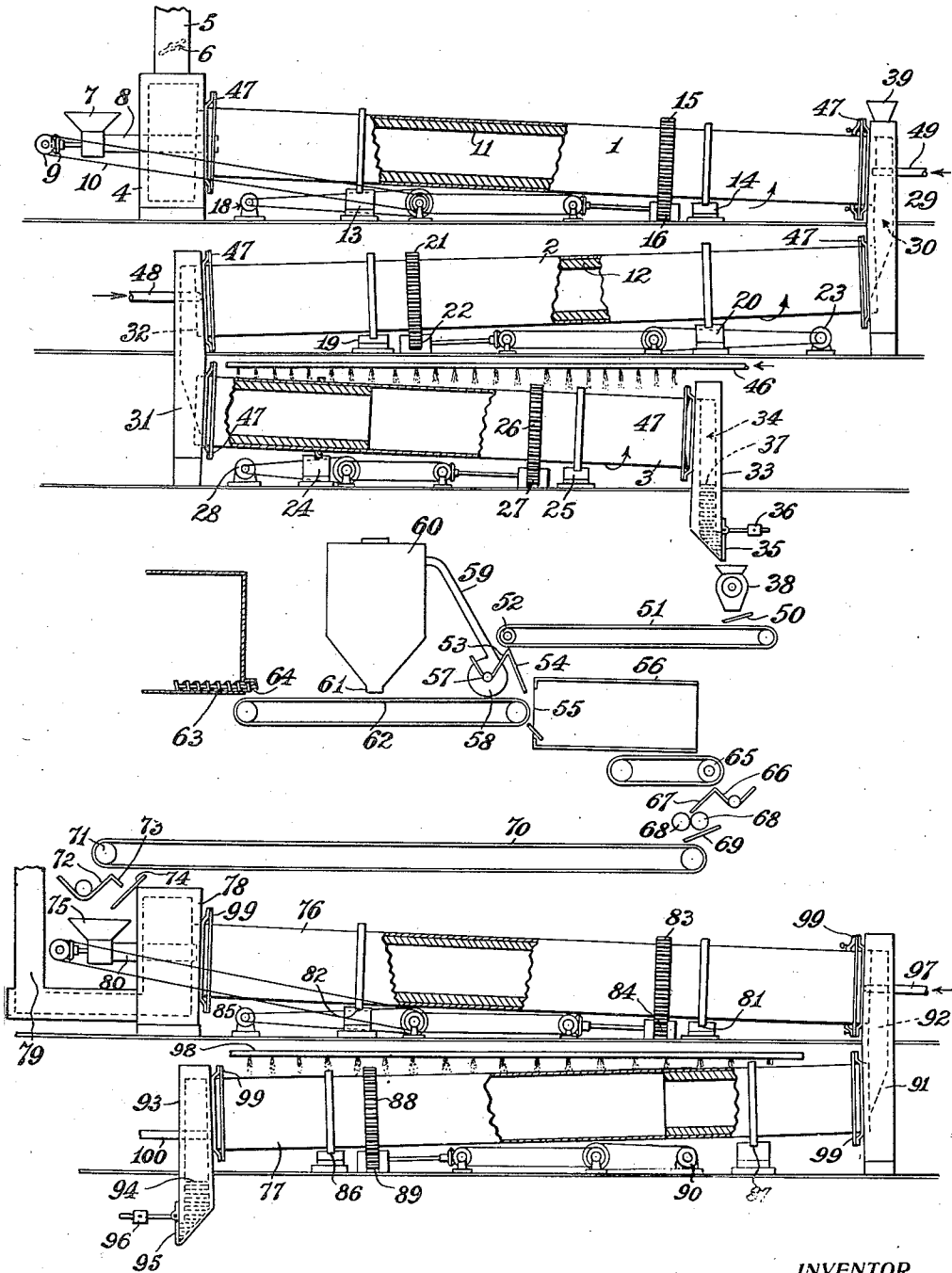
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J. W. HORNSEY

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TREATMENT OF IRON ORES AND THE LIKE

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INVENTOR
John W. Hornsey
BY *Gorham Crosby*
ATTORNEY

UNITED STATES PATENT OFFICE

JOHN W. HORNSEY, OF SUMMIT, NEW JERSEY, ASSIGNOR TO GRANULAR IRON COMPANY, A CORPORATION OF MICHIGAN

TREATMENT OF IRON ORES AND THE LIKE

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My invention relates to the treatment of iron ores and the like and is especially applicable to the reduction of iron oxides to produce metallic iron in a new form. One object of the invention is to provide an improved process and apparatus by which greater fuel economy may be obtained. A further object is to obtain the resulting reduced metal in convenient form for magnetic or other separation of the impurities. A further object is to obtain the purified iron in serviceable form for further operations therewith. Further and more specific objects, features and advantages will more clearly appear from the detail description given below taken in connection with the accompanying drawing which forms a part of this specification. The drawing is an elevation largely diagrammatic, of one form of apparatus by which my improvements may be carried out. Referring to the drawing I there show three substantially horizontal rotary cylinders or kilns 1, 2 and 3 preferably very slightly inclined about $\frac{1}{4}''$ to the foot or less from the horizontal. I have found that it is essential to success at every stage of the process to allow each piece of the material being treated, ample time and opportunity to react to the treatment and that, if rotary apparatus is to be used at all, it must be either substantially level or inclined at a very slight angle (preferably less than $\frac{1}{2}''$ to the foot of length) either way in order to roll over the material and expose all parts of it most thoroughly to the other parts, to the reactive atmosphere, and to the heated walls of the kiln, or the cold walls of the cooler hereinafter described. Herein has lain one of the unsuspected obstacles to successful treatment of ores in rotary kilns of the so-called horizontal type. The incline used caused the larger pieces to roll and progress most rapidly and in consequence to be least effectively treated. I have found that by changing the inclination from $\frac{3}{4}''$ to $\frac{1}{4}''$ to the foot the time of contact and treatment was prolonged from 35 minutes to $4\frac{1}{2}$ hours getting far more complete reaction and increasing the output about 100% as well. At its upper end the rotary kiln 1 is connected with stationary stack base 4 from which leads the stack 5 provided with a suitable adjustable damper 6 therein. 7 represents a hopper for the material to be treated or reduced, the bottom of which is connected with a feed tube 8 provided with suitable feeding apparatus operated through gears 9 and belt 10 to gradually and continuously feed the material from the hopper 7 into the adjacent end of the kiln 1. The kilns 1 and 2 are lined with suitable heat resistant brick linings 11 and 12. The kiln 1 rolls on suitable anti-friction devices indicated at 13 and 14 and is rotated by means of gears 15 and 16 driven by an electric motor 18. The kiln 2 is rotatably supported on similar anti-friction devices 19 and 20 and is driven through gears 21 and 22 by means of an electric motor 23. The rotary cylinder 3 is also rotatably supported on suitable anti-friction devices indicated at 24 and 25 and is driven through gears 26 and 27 by means of an electric motor 28. At 29 I provide stationary passageway means provided with a vertical passageway 30 provided with suitable openings into which the discharge end of kiln 1 and the feed end of kiln 2 project whereby material flowing out of the discharge end of kiln 1 will be conveyed through the passageway 30 and deposited in the feed end of kiln 2. At 31 I provide similar stationary passageway means provided with a vertical passageway 32 into which project the discharge end of kiln 2 and the feed end of rotary cylinder 3 so that material flowing out of the discharge end of kiln 2 will be transferred through the passageway 32 and deposited in the feed end of rotary cylinder 3. At 33 I provide another stationary passageway means provided with a passageway 34 into which the discharge end of rotary cylinder 3 projects so that material flowing out of the cylinder 3 will flow down the passageway 34. At the lower end of the passageway 34 I provide suitable means for removing the treated ore. When working under pressure a form of caisson lock may be used, but for ordinary purposes I use a screw delivery or a pivoted gate 35 having a counterweight 36 so that when the material collects in the passageway 34 to a certain height as indicated at

37, the weight thereof will open the gate 35 and cause the material flowing through the passageway 33 to be deposited into a hammer mill 38. At 46 I provide a spray pipe for spraying cold water over the iron cylinder 3 for the purpose of cooling the same. Where the cylinders 1, 2 and 3 enter the stationary means 4, 29, 31 and 33 I provide suitable means indicated at 47, for sealing the joints therebetween with a radially and laterally flexible closure so as to substantially prevent the egress of gases from the cylinders to the outside atmosphere or the ingress of the outside atmosphere into the cylinders. These sealing means may be of any suitable form, but I prefer to use means such as disclosed in my U. S. Letters Patent No. 1,263,415.

At 48 I provide a pipe extending through the stationary means 31 for introducing fuel and air into the discharge end of the kiln 2, any suitable arrangement being provided for regulating the amount of fuel and air admitted and also the relative amounts of fuel and air. At 49 I provide a similar pipe for introducing fuel and air into the discharge end of the kiln 1, any suitable means being provided for regulating the amounts of fuel and air so introduced as well as relative amount of fuel and air introduced. Any suitable fuel may be used such as fuel oil, fuel gas or powdered coal, coke or the like.

While my invention in its broader aspects may be used for the treatment of many different materials in different ways, I will describe as an example thereof the reduction of iron ore comprising mainly iron oxide Fe_2O_3 . The proper amounts of fuel and air are burned from the pipes 48 and 49, a considerable percentage of the fuel may be sprayed down upon the ore and burned more or less completely in direct contact therewith and at the direct expense of the oxygen thereof, when desired. The ore preferably in granular form, is fed into the rotating kiln 1 through the conveying means 8 and as the kiln rotates the material is continuously agitated and gradually fed through the inclined kiln 1 to the discharge end thereof. The hot gases of combustion heat the ore substantially to the temperature at which it may be reduced and it may be partially reduced in the kiln 1 and the ore thus preheated is then automatically transferred through the passageway 30 into the feed end of the kiln 2 wherein it is similarly agitated and fed through the kiln until it flows out and down through the passageway 32 into the cooling cylinder 3. When the preheated ore leaves kiln 1 I preferably mix therewith carbonaceous fuel such as coke or coal reduced to suitable size, the latter may be fed in through a trapped feeding device 39 and down into the passageway 30 where it becomes mixed with the ore as the ore passes therethrough. Generally coal is preferred as the reducing agent and coal

dust is the preferred fuel burned at the nozzles; but local conditions may control the selection. This mixing of carbonaceous fuel with the ore brings the reducing agent in intimate mixture with the iron ore to be reduced and results in a more rapid and efficient reduction. In the kiln 2 the iron oxide is preferably completely reduced to a metallic iron so that the material which flows into the cooling cylinder 3 consists of granular metallic iron with impurities mechanically mixed therewith also in granular form. I preferably adjust the fuel and air supply through the pipe 48 so as to maintain the temperature in the kiln 2 by incomplete combustion of all the fuel elements supplied at both ends of the kiln. That is to say, the hot gases flowing out of the kiln 2 and up into the kiln 1 contain a large percentage of carbonmonoxide, CO. And I then introduce air into the kiln 1 through the pipe 49 with or without additional fuel to more completely combust the fuel elements so that the combustion gases passing out through the stack 5 are substantially completely combusted, the introduction of fuel and air being so regulated that the heat thus generated is just sufficient to bring and maintain the temperature of the material to be treated up to the desired point, radiation and conduction losses being considered. It is, of course, not necessary that all of the combusted carbon pass off in the form of carbon dioxide to obtain substantial advantages from my improvements, but I prefer to so adjust the supply of air from the two separate and independent sources and also the fuel supply so that over 40% of the carbon in the exit gases is in the form of carbon dioxide CO_2 . That is, with fairly rich ores, the operation will generally produce a surplus of gas which may be withdrawn for outside use. For poor ores we may need to supply additional fuel through 49 to achieve a proper preheating of the charge. It will be understood that there may be some reduction of ore taking place in the kiln 1 and there may be some further increase in temperature of the material in kiln 2. But I provide an arrangement in which the ore or the like is subjected to two successive stages of heat treatment in rotary kiln apparatus, in the first stage of which the material is preheated and in the second stage of which the material is reduced to the desired extent, while providing separate air supplies for said stages and preferably maintaining the temperature in the second stage by substantially complete combustion of the air from one source and furnishing heat for the first stage by further combustion of fuel elements from the original fuel or added fuel or both with air from the other source. The air and fuel injected through the pipe 48 I prefer to regulate so that the combustion of the oxygen at least to CO or H_2O is as instantaneous and com-

plete as possible and no free oxygen and suspended carbon are allowed to travel along together for several seconds (nearly the whole length of the kiln) as would be sure to happen in low temperature combustion. Therefore I aim to obtain such regulation of air to fuel as to give this flame as high a temperature as possible without making more than about $\frac{1}{3}$ CO_2 and $\frac{2}{3}$ CO but to distribute its heat as far along the kiln as possible for the following reasons.

The reduction here takes place I believe largely by interchange between the tumbling particles of carbon and iron oxide in an atmosphere chiefly of CO , the CO being partially oxidized to CO_2 , partially reducing the iron, and then the CO_2 coming into contact with carbon and being reduced by the carbon to 2CO which again comes in contact with and reduces more iron oxide. Final reduction of FeO at a temperature somewhat below the softening point of iron (say about 950°C .) requires relative proportions of not more than $\frac{1}{3}$ CO_2 or less than $\frac{2}{3}$ CO in the atmosphere. If there is more CO_2 than about $\frac{1}{3}$ the iron is found to reoxidize rapidly. So I maintain the atmosphere as free from CO_2 as possible. On the other hand this reaction is largely endothermic as follows. FeO reduced to Fe by carbon with production of $\frac{1}{3}$ CO_2 and $\frac{2}{3}$ CO shows a net heat consumption of about 664 B. t. u. per lb. of Fe . If reduced with hydrogen the net consumption is about 198 B. t. u. but hot iron also removed oxygen from water vapour.

Therefore I prefer to have the iron oxid enter cylinder 2 as hot as possible. With iron oxid I prefer not to use a hydrocarbon fuel at 48. I prefer to preheat (by any suitable means) the air used in the combustion of fuel introduced at 48 as much as possible. I prefer to inject it in a long constricted jet under high pressure of air so that a long pencil of intensely hot flame shall progress for a considerable distance up the kiln and distribute its heat all along the kiln to the endothermically cooling mass of reacting oxid and carbon, without overheating and possibly fusing the material near the discharge end. A long flame can be maintained because there is no such obstacle as the burden of the ordinary blast furnace which resists the blast of air. I also prefer to use a mixture of fuel and air in which the amount is substantially two thirds or less the theoretical amount of air required for complete combustion of the fuel. It will be seen that where use can be made of gases rich in CO , as for combustion in gas engines or under boilers, I may introduce all of the fuel into the cylinder 2, without adding any air or fuel in cylinder 1. It will, of course, be understood by those skilled in the art that the rotary kilns 1 and 2 are in essence, the equivalent of one long kiln with the fuel

and air supply 48 at one end thereof and the fuel and air supply 49 intermediate the ends thereof so that two stage treatments may be carried out in this manner. It is preferable, however, to provide two separate kilns with stationary means as 29, 47, sealing the ends thereof and providing passageways through which the material may flow from one to the other because by such an arrangement it is more convenient and expedient to introduce the additional air, fuel, etc. at the intermediate point. I preferably also so adjust the fuel and air supply so that the temperature in the kiln 2, while being maintained sufficiently high to accomplish the reduction of the ore to metal or to the desired extent, yet is insufficiently high to cause any substantial sintering or fusion of the metal particles produced because sintering or fusion thereof causes the material to ball up and make it more difficult to separate the impurities from the reduced metal. For this purpose I preferably keep the temperature below 900°C . The iron is reduced in kiln 2 to metallic iron in the form of small particles or a finely divided condition without fusion or melting of the iron. It is, however, still mixed with the gangue. By suitably sealing the ends of the kilns as above explained I can maintain a completely reducing atmosphere in the kiln 2 so that the reduction is accomplished efficiently while the material passes gradually and continuously through the apparatus. By providing the sealing means as above explained I am enabled to carry out the heat treatments, when desired in particular bases, at pressures substantially above atmospheric and I then preferably adjust the damper 6 relatively to the fuel and air supplies so as to maintain any desired pressure in the kilns 1 and 2 or even 3 up to about 15 pounds per square inch or even more above atmospheric. Since hot reduced iron, as it comes from the kiln 2, will take oxygen either from carbon dioxide or from water vapour, it would be subject to rapid oxidation if merely mixed with excess carbonaceous matter and exposed to the atmosphere or cooled in water or even exposed to reducing gases containing more than $\frac{1}{3}$ CO_2 . I, therefore, transfer it to the cooling cylinder 3 where it is cooled to such a point that when delivered therefrom it will not be subject to any substantial oxidation in the air. By operating the system under pressure substantially above atmospheric, the rate of reaction is in some cases increased and some of the highly reducing gases from cylinder 2 are forced to enter cylinder 3 and provide a sufficiently reducing atmosphere in the cylinder 3 so that the cooling is carried out in a non-oxidizing atmosphere. If pressure above atmospheric be not used, the first metal introduced into cylinder 3 will absorb the oxygen from the air therein and thereafter

the atmosphere therein will be non-oxidizing. Any other means of securing a substantially non-oxidizing atmosphere may be employed. But by maintaining the pressure in the cylinder 2 sufficiently above atmospheric the reducing gases in kiln 2 will not only pass along upwardly counter to the movement of the ore but the non-oxidizing gases will be driven into cooling cylinder 3 and forced downwardly therein in the same direction as the ore, causing the non-oxidizing gases in cylinder 3 to be at a greater pressure than atmospheric, thereby driving out any air that might otherwise get by the gate 35.

It is not necessary that all of the fuel or reducing elements or both be introduced through the supplies 48 and 49 since part of the fuel such as powdered coal, coke or charcoal may be introduced and mixed with the ore before it is fed through the hopper 7 and feed pipe 8. The system being started up in any suitable manner, when the ore and fuel reach the proper point in the kiln 1, volatile matter may be distilled off from which benzol, toluol, ammonia, etc. may be recovered in a manner well-known to those skilled in the art, and thereupon and thereafter the remaining fuel will react with the ore to partially reduce it.

While the temperature and atmospheric conditions to be maintained in the kilns 1 and 2 will, of course, vary according to the nature of the ore or other material being treated and the nature of the reduction or other treatment being effected, yet in reducing the iron oxide Fe_2O_3 , I find that the process works well if the temperature in the kiln 1 reaches about 800 to 850° C. It may, however, be considerably lower depending on the kind of fuel, nature of the ore, etc. The temperature in the second cylinder I preferably maintain substantially the same throughout and preferably over 600° C. and not over 900° C. Although the ore is introduced in granular condition and is reduced to metallic iron, it is not fused together (limestone or other fluxes commonly used in the blast furnace being unnecessary in the present process) but comes out in granular condition mechanically mixed with sand-like material. I believe that when such ore is so reduced less of certain impurities in the ore and fuel will be absorbed by the iron thus producing a better grade of metal. The ore and fuel both generally contain considerable silicon, phosphorus and other elements which have been found to be absent in the metal resulting from this type of reduction but may be present in the metal in minute quantities with low carbon content which make the resulting product take on the character of steel to some extent.

The mixture of finely divided metallic iron particles and gangue which is delivered into the hammer mill 38 is so treated therein that

particles of gangue which may be attached to the iron particles are separated therefrom and the gangue broken up so that iron particles included therein are free. The mixture is delivered from the hammer mill 38 on to a distributing plate 50 from which it slides on to an endless belt 51. The endless belt carries the material to any suitable separating means but preferably a magnetic separator indicated diagrammatically by the roll 52 and dividing plates 53 and 54. On passing over the magnetic roll 52 the gangue drops off and falls down the plate 53 while the metallic particles are carried to a point where they fall down the plate 54 and are directed through an opening 55 in a rotating tumbling cylinder 56. The gangue may possibly still contain some metallic iron particles and is conveyed by screw-conveyor 57 into a blower 58 which blows the material through pipe 59 and into a cyclone separator 60. This separator of well-known construction and in it the heavier metallic particles separate out and are deposited through a bottom discharge opening 61 on to an endless belt 62, the lighter gangue material being separated therefrom and carried away in any well-known manner. I may also provide means indicated at 63 for gradually depositing a cleaning material such as sawdust on to the belt 62 through the distributing screw 64. The endless belt 62 carries the sawdust and metallic particles from separator 60 to the tumbling cylinder 56 where they are mixed with the metallic iron particles from the plate 54. The metallic iron particles from the plate 54 with those also from the separator 60 and the sawdust are tumbled about in the cylinder 56 as the same continuously rotates and the metallic particles thereby cleansed. The material gradually runs out the lower end of the cylinder 56 to a magnetic separator indicated at 65 where any remaining gangue is deposited on the plate 66 and the metallic iron particles deposited on the plate 67 which conducts them to crushing rolls 69 so that any further particles of gangue containing metallic particles are crushed to relieve the metallic particles and the whole is deposited on distributing plate 69 which deposits the same on an endless belt 70 which conveys the material to another magnetic separator 71 where further separation or purification takes place, the gangue being deposited on plate 72 and the metallic particles on plate 73 from which they are deposited on plate 74 which conducts them into a hopper 75. 76 and 77 represent two very slightly inclined rotating cylinders or kilns similar in all respects to the rotating cylinders 2 and 3 respectively. The cylinder 76 is provided at its upper end with a stationary head piece 78 connected to a stack 79. The material in the hopper 75 is fed into the upper end of the cylinder

76 by suitable screw conveying means 80. The cylinder 76 is provided with anti-friction bearings at 81, 82 and is slowly rotating by gears 63 and 64 driven by motor 85, which also operates the screw conveying means 80. The rotating cylinder 77 is provided with anti-friction bearings at 86 and 87 and is driven through gears 88 and 89 which are in turn driven by electric motor 90. 91 represents a stationary passage-structure provided with suitable openings into which the discharge end of the kiln 76 and the feed end of the cylinder 77 extend and a passageway 92 through which material leaving the discharge end of the kiln 76 may fall into the feed end of cylinder 77. The discharge end of the cylinder 77 extends into a stationary hood 93 provided with an outlet passage 94 normally closed by screw conveyor or by the gate 95 operated by counterweight 96, in all respects similar to the gate 35 with its weight 36, thus substantially sealing the discharge opening of passage 94. 97 represents a fuel pipe extending into the discharge end of kiln 76 through which fuel and air are injected and burned in order to heat the kiln 76 and the material therein. The proportion of fuel and air introduced, however, is so selected as to soften the iron and yet maintain a non-oxidizing or reducing atmosphere in the kiln 76. This sounds simple and I am aware that others have said they would maintain a reducing flame but, as a matter of fact, previous processes have failed partly because they have not done so. Nor is there the slightest indication of their having comprehended what doing so involved, or how to do it. What is under ordinary circumstances a reducing flame is easy to obtain but a flame which is reducing for iron at 800° C. to 1200° C. (where iron takes oxygen away from either water or CO₂) requires precise adjustment of conditions and choice of fuel that is nowhere indicated so far as known to me. If much less than 1/3 the carbon is burned to CO₂ the temperature produced will be so low that iron will not be softened and that owing to slow combustion free oxygen will be carried along unconsumed for the greater part of the length of the kiln and iron oxid will not be reduced or kept in the reduced state, while on the other hand if more than 1/3 of the fuel is burned to CO₂ the temperature required will be produced but so much CO₂ will be formed that the iron will take oxygen from the CO₂ and not be kept reduced but will become reoxidized. If too little of the hydrogen is burned to H₂O likewise the temperature will be so low and combustion so slow that free oxygen will be present in the atmosphere all through the kiln and if, on the other hand, much hydrogen is burned there will be such a large proportion of water vapour in the flame that the iron at about 800-1200° C. will be oxidized thereby.

I can, however, by suitable preheating of the air secure the desired velocity of combustion and at the same time obtain the necessary thermal energy to make up for the endothermic character of the reaction or soften the iron. But in either case I prefer substantially to burn the fuel in kilns 2 and 76 with about 2/3 or less of the air theoretically required for the combustion of the typical fuel (carbon) and do not desire to use a highly hydrocarbon fuel. The cylinder 77 is continuously cooled by sprays of water flowing over the same from the water pipe 98. Both ends of both cylinders 76 and 77 where they extend into the stationary heads are preferably sealed from the outside atmosphere by sealing means 99 in all respects like the sealing means 47.

The finely divided or small iron particles conveyed into the feed end of kiln 76 are heated therein in a reducing or non-oxidizing atmosphere to a temperature of about 1200° C. or a point at which they will become slightly soft on the surface and in tumbling about in kiln 76, and pressing upon one another the particles become welded together so as to become agglomerated into relatively larger masses of iron having relatively less surface and without melting or fusing the iron particles. The small iron particles before being deposited in the hopper 75 would in finely divided condition become more or less oxidized even under atmospheric conditions because of the relatively large surface exposed per mass of iron, and furthermore the iron in such finely divided condition is difficult to handle in further furnacing operations for making steel, etc. But by passing the same through the heated rotating cylinder or kiln 76 and carefully regulating the temperature therein so that the particles do not become melted or fused but only slightly soft on their surface, pressure and weight of the particles against one another as they tumble about causes them to be welded together to form lumps of iron relatively more dense than when in the finely divided condition. In this manner masses of agglomerated iron particles are produced which are more or less porous and are substantially free from iron oxides even on the surfaces thereof. They are also substantially free from mineral matter other than metallic iron or carbon. For these reasons they are of a readily self-binding character. Iron produced by a reduction of iron oxide in the form of relatively small iron particles without fusion or melting of the iron is called sponge iron, and the material which I produce in the kiln 76 may, therefore, be termed agglomerated sponge iron. This material, however, should be cooled below the temperature at which the iron would oxidize before being submitted to the air or an oxidizing atmosphere and for this purpose, as it leaves the discharge end of the kiln

76 I prefer to run it into the feed end of the cylinder 77 in which a reducing or non-oxidizing atmosphere is maintained. The cylinder 77 is continuously cooled by water sprays from pipe 98 so that as the iron passes therethrough it becomes cool and when it is discharged into the head 93 and through the passageway 94, it is reduced to a temperature below that at which it will be materially oxidized in the air. In order to maintain the desired non-oxidizing atmosphere in the cylinder, 77, non-oxidizing or reducing gases from the head 29 may be introduced into the discharge end of the cylinder 77 through pipe 100 or gases forced backward from the kiln 76 by adjusting the stack damper. These may be introduced under such pressure as to maintain the pressure of the cylinder 77 slightly above atmospheric so that there is no danger of air leaking through gate 95 and through the iron material supported thereby.

By providing the sealing means 47 and 99 the operation throughout may be kept under accurate control and air is prevented from entering the system at any point even though the pressure in the cylinders be slightly below atmospheric. If even small amounts of air were permitted to leak in around the ends of the kiln cylinders, they would at least locally cause reoxidization of the iron so that a material would not be produced which was substantially free from iron oxide as air entering thus would form an oxidizing shell around the flame and come directly into contact with the hot iron.

From the above it will be seen that I have provided an improved process in which the iron ore is first preheated in the kiln 1 and then heated in a reducing atmosphere in the kiln 2 to reduce the iron to the form of small iron particles without melting the iron, then cooling the resulting mixture of iron particles and gangue in a non-oxidizing atmosphere in cylinder 3 to a temperature below the oxidation temperature of the iron, then separating the metallic iron particles from the gangue by means of the magnetic separator, etc., this being done in the outside atmosphere and finally converting the mass of iron particles into relatively large masses or lumps of iron with relatively less exposed surface in the kiln 76 and then cooling the same in a non-oxidizing atmosphere in the cylinder 77 before they are again permitted to be taken out into the air. Before the iron ore or oxide is subjected to the reducing operation, it is preferably crushed or otherwise reduced into size so as to pass through one-quarter mesh. One reason why every practical attempt to directly reduce iron ore has been unsuccessful has been that the ore to be treated has been in lumps of $\frac{1}{2}$ " to 1" or more in size because no method was known of handling the very fine pyrophoric iron produced from finely powdered ore. Large

lumps on the one hand do not effectively reduce to the core in a practical period of treatment and on the other hand bounce and jump along and through the treatment apparatus at a much greater rate than the finer dust particles that are almost instantly reduced. Thus all the ore has to be retarded to the rate of the slowest lumps. Consequently I prefer to reduce the ore to as fine a mesh as possible without excessive dust losses from the kiln preferably not over $\frac{1}{4}$ " in the largest dimension and, after reduction and separation, to agglomerate the iron into usable size. The charge may even be, in part at least, flue dust from ordinary blast furnace installations. The reduction is preferably carried out in the kiln 2 at substantially atmospheric pressure or above at a temperature below 900° C., the reduction being carried out with substantial exclusion of all air not introduced with a proportionate amount of fuel. It will also be noted that in transferring the reduced iron particles from the kiln 2 to the cooling cylinder 3, that they are still kept in a non-oxidizing atmosphere in the passageway 32. I prefer to cool the iron particles in the cylinder 3 to about 300° C. or below.

It is not in all cases necessary to use the multiplicity of separating and crushing means, etc., 38, 52, 60, 56, 65, 68, 71. In many cases the resulting product will be sufficiently pure and desirable yields obtained if the iron particles as they leave the passageway 34, are deposited directly on the belt 70 and one magnetic separation effected thereon by the magnetic separator 71 from which the iron particles are conducted directly into the agglomerating kiln 76. Likewise any other means for agglomerating the iron particles may be used, but in any case I prefer to use an arrangement which welds or adheres particles together into larger lumps or masses by heat and pressure without actual fusion.

Many other changes and modifications may be made without departing from the spirit and scope of the invention in its broader aspects and hence it is desired to cover all forms coming within the terms or spirit of any of the appended claims.

The term iron ore used herein is intended to include various other iron oxide bearing materials.

What I claim as new and desire to secure by Letters Patent, is:

1. The process of reducing iron ore to metallic iron which consists in treating a mixture of iron ore about $\frac{1}{4}$ " mesh or finer and solid carbonaceous fuel in a substantially horizontal rotary kiln and maintaining the temperature about 850° C. substantially by the combustion of carbon with about $\frac{2}{3}$ or less the theoretical air required.

2. The process of reducing iron ore to metallic iron which consists in treating a mixture of iron ore about $\frac{1}{4}$ " mesh or finer and

solid carbonaceous fuel in a substantially horizontal rotary kiln and maintaining the temperature about 850° C. substantially by the combustion of carbon with about $\frac{2}{3}$ or less the theoretical air required and preventing practically all ingress of air to the mixture while being reduced and cooled.

3. The process of reducing iron ore to metallic iron which consists in treating a mixture of iron ore and solid carbonaceous fuel in a kiln and maintaining the temperature about 850° C. substantially by the combustion of carbon with about $\frac{2}{3}$ or less the theoretical air required.

4. The process which consists in treating iron ore with heat in a reducing atmosphere to reduce the iron to the form of small iron particles without melting the iron, then simultaneously agitating and cooling the resulting mixture of iron particles and gangue in a non-oxidizing atmosphere to a temperature below the oxidation temperature of the iron then separating the metallic iron particles from the gangue and finally converting the mass of iron particles into relatively large masses of iron with relatively less exposed surface.

5. The process which consists in treating iron ore with heat in a reducing atmosphere to reduce the iron in the form of finely divided iron particles without melting the iron, then subjecting the resulting mixture of finely divided iron and gangue to a rapid cooling treatment while agitating it in a non-oxidizing atmosphere at a temperature below the temperature at which the iron will reoxidize, then separating the metallic iron particles from the gangue, and finally agglomerating the finely divided iron, without melting, into relatively large masses of iron with relatively less exposed surface.

6. The process which consists in reducing iron oxide ore to a size to pass through $\frac{1}{4}$ inch mesh and treating iron ore with heat in a reducing atmosphere to reduce the iron to the form of small iron particles without melting the iron, then subjecting the resulting mixture of iron particles and gangue to a rapid cooling treatment in a non-oxidizing atmosphere at a temperature below the oxidation temperature of the iron then separating the metallic iron particles from the gangue and finally converting the mass of iron particles into relatively large masses of iron with relatively less exposed surface.

7. The process which consists in treating iron ore with heat in a reducing atmosphere to reduce the iron to the form of small iron particles without melting the iron, the ore being heated during reduction by combustion of fuel with substantially $\frac{2}{3}$ or less of the theoretical amount of air required therefor, then cooling the resulting mixture of iron particles and gangue in a non-oxidizing atmosphere to a temperature below the oxida-

tion temperature of the iron then separating the metallic iron particles from the gangue and finally converting the mass of iron particles into relatively large masses of iron with relatively less exposed surface.

8. The process which consists in treating iron ore with heat in a reducing atmosphere to reduce the iron to the form of small iron particles without melting the iron, transferring the resulting mixture of small iron particles and gangue from the reducing operation to a cooling atmosphere in a non-oxidizing atmosphere, then simultaneously agitating and cooling the resulting mixture of iron particles and gangue in a non-oxidizing atmosphere at a temperature below the oxidation temperature of the iron then separating the metallic iron particles from the gangue and finally converting the mass of iron particles into relatively large masses of iron with relatively less exposed surface.

9. The process which consists in treating iron ore with heat in a reducing atmosphere to reduce the iron to the form of small iron particles without melting the iron, then cooling the resulting mixture of iron particles and gangue in a non-oxidizing atmosphere to a temperature below the oxidation temperature of the iron, then separating the metallic iron particles from the gangue and then introducing the iron particles into a hot non-oxidizing atmosphere and therein converting the mass of iron particles into relatively large masses of iron with relatively less exposed surface.

10. The process which consists in treating iron ore with heat in a reducing atmosphere to reduce the iron to the form of small iron particles without melting the iron, then cooling the resulting mixture of iron particles and gangue in a non-oxidizing atmosphere to a temperature below the oxidation temperature of the iron then separating the metallic iron particles from the gangue and finally introducing the iron particles into a non-oxidizing atmosphere at about 1200° C. and therein welding the particles into relatively large masses of iron with relatively less exposed surface.

11. The process which consists in treating iron ore with heat in a reducing atmosphere in contact with carbonaceous fuel and at a temperature below 900° C. to reduce the iron to the form of small iron particles without melting the iron then transferring the mixture from the reducing operation to a cooling atmosphere in a non-oxidizing atmosphere then cooling the resulting mixture of iron particles and gangue in a non-oxidizing atmosphere to a temperature below the oxidation temperature of the iron, then removing the mixture into the outside air then separating the metallic iron particles from the gangue, under atmospheric conditions and then welding the iron particles together with-

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out fusion thereof, thereby converting the mass of iron particles into relatively large masses of iron with relatively less exposed surface.

5 12. The process of treating finely divided crude sponge iron which consists in mechanically disintegrating and separating the non-ferrous impurities and then agglomerating the resulting substantially pure iron particles
10 with the aid of heat and pressure into relatively larger masses of iron.

13. The process of treating finely divided crude sponge iron which consists in mechanically disintegrating and separating the non-ferrous impurities and then agglomerating the resulting substantially pure iron particles
15 by heating them to the softening point and agitating them to cause them to unite into relatively larger masses of iron.

14. The process of treating finely divided crude sponge iron which consists in mechanically disintegrating and separating the non-ferrous impurities and then agglomerating the resulting substantially pure iron particles
20 in a non-oxidizing atmosphere with the aid of heat and pressure into relatively larger masses of iron.

15. The process of treating finely divided crude sponge iron which consists in mechanically disintegrating and separating the non-ferrous impurities and then agglomerating the resulting substantially pure iron particles
25 in a non-oxidizing atmosphere with the aid of heat and pressure into relatively larger masses of iron, and cooling the iron in a non-oxidizing temperature and to a temperature below the oxidation temperature of the iron.

16. The method of stabilizing finely divided sponge iron to prevent oxidation and
30 loss thereof, which consists in rotatably tumbling the iron particles to agglomerate them into relatively dense larger masses by the combined action of heat and pressure.

17. The process which consists in heating
35 iron ore in a reducing atmosphere in an inclined rotary cylinder to reduce the iron to the form of small iron particles without melting the iron, then cooling the resulting mixture of iron particles and gangue in an inclined rotary cylinder containing a non-oxidizing atmosphere and to a temperature below the oxidation temperature of the iron, the material being gradually fed through
40 said cylinders and from one cylinder to the other in a non-oxidizing atmosphere, and causing the reducing gases in the first cylinder to move counter to the movement of the iron material therein and the non-oxidizing gases in the second cylinder to move with the
45 iron material therein.

18. The process which consists in reducing
50 iron ore in a reducing atmosphere to small iron particles without melting the iron and then cooling the iron particles in a non-oxidizing atmosphere, the material being fed
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gradually through the reducing operation and through the cooling operation and from one to the other in a non-oxidizing atmosphere and while causing the reducing gases in the reducing operation to move counter to the
60 iron material and the non-oxidizing gases in the cooling operation to move with the iron therein.

19. The process of reducing iron ores and other products which consists in passing the material to be reduced through a rotary kiln while maintaining a reducing atmosphere and temperature therein and while maintaining the pressure in the kiln substantially
65 above atmospheric pressure.

20. The process of reducing iron ores which consists in furnacing the ore while maintaining two separate and independent sources of air supply thereto and relatively
70 adjusting the supply of air from said sources so that over 40% of the carbon in the exit gases is in the form of carbon dioxide, CO₂.

21. The process which consists in treating iron ore with heat in a reducing atmosphere to reduce the iron to the form of small iron
75 particles without melting the iron, then cooling the resulting mixture of iron particles and gangue in a non-oxidizing atmosphere to a temperature below the oxidation temperature of the iron then separating the metallic
80 iron particles from the gangue, then mixing and agitating the iron particles with a polishing material to polish or clean the iron particles, and finally converting the mass of iron particles into relatively large masses
85 of iron with relatively less exposed surface.

Signed at New York, in the county of New York and State of New York, this 19th day of January, A. D. 1922.

JOHN W. HORNSEY. 105

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