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N. W. EFT ETAL

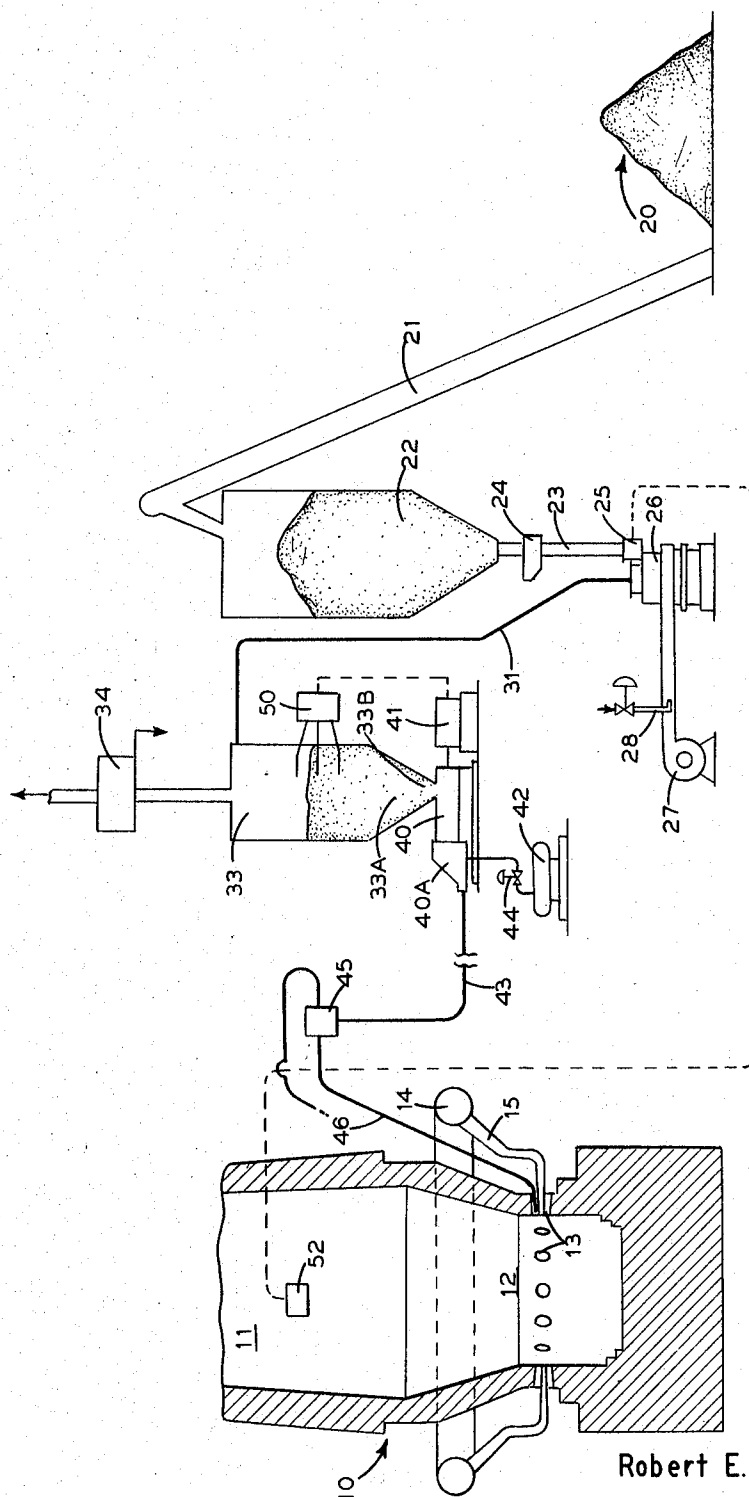
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BLAST FURNACE PULVERIZED COAL FIRING SYSTEM

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FIG. 1



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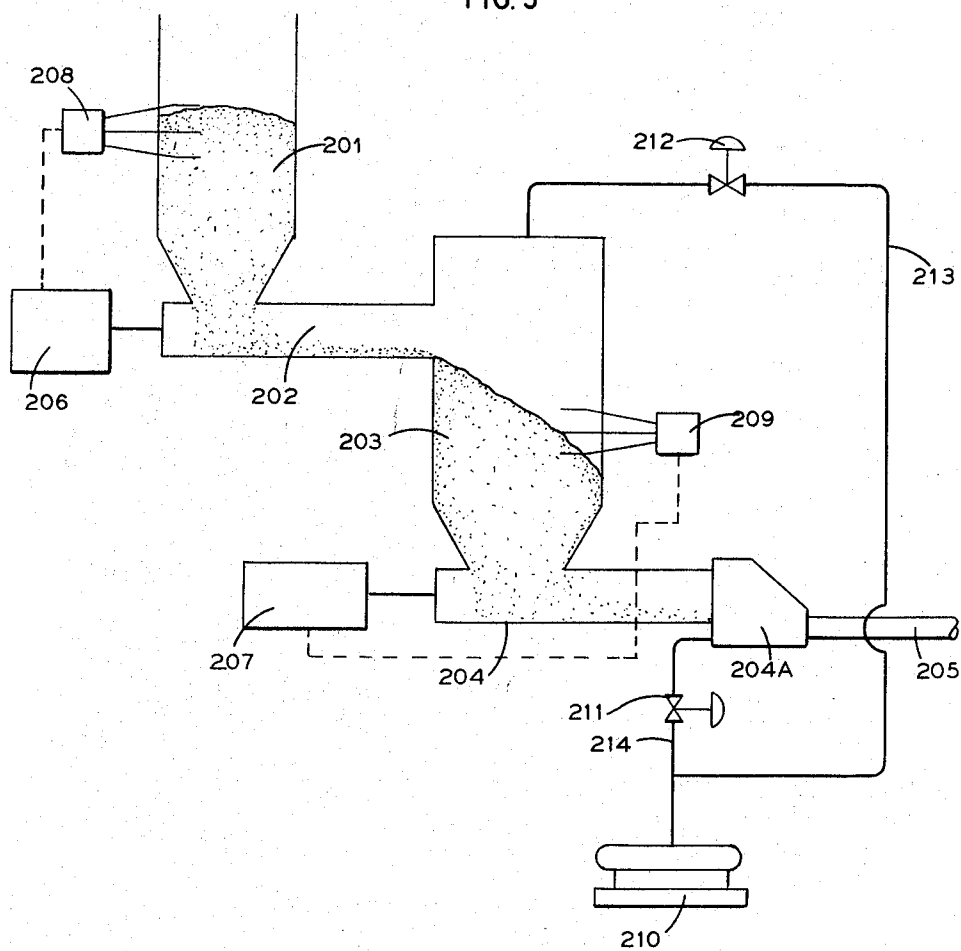
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FIG. 3



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BLAST FURNACE PULVERIZED COAL FIRING SYSTEM

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10 Claims. (Cl. 266—28)

The invention relates to the smelting of iron ore in blast furnaces, and more particularly to an improved method and apparatus for supplying pulverant fuel, e.g., pulverized coal, to a blast furnace.

Traditionally, blast furnaces have been operated using top-loaded charges of iron ore, limestone (or other fluxing material) and coke, the coke serving the dual purpose of providing the necessary carbon and heat to support the reduction and smelting reactions. A large capital investment is required for the construction of coke ovens capable of producing coke in the tonnages required; moreover, operating and maintenance costs on these ovens are very high. To alleviate these high capital and operating costs, increased effort has recently been directed toward substituting a cheaper supplementary fuel for a portion of the coke heretofore required.

Both natural gas and fuel oil have been tried as supplementary fuels, and both have met with some degree of success. The injection of any supplementary fuel into a blast furnace requires a corresponding increase in the temperature of the blast air; moreover, supplementary fuels having a relatively low carbon/hydrogen ratio require a greater increase in blast air temperature than supplementary fuels having a higher carbon/hydrogen ratio. Consequently, the amount of natural gas that can be used to replace coke in a blast furnace is apparently limited, for thermodynamic reasons, to about 7% of the total heat input to the blast furnace. Fuel oil, because of its higher carbon/hydrogen ratio, can be used to replace the coke to a substantially greater degree than natural gas, i.e., about twice as much. Both natural gas and fuel oil have the obvious advantage of being readily adaptable to supplementary firing systems.

Coal, because of its high carbon/hydrogen ratio, relatively low cost, and excellent thermodynamic characteristics, has been recognized throughout the steel industry as the theoretically optimum supplementary fuel for blast furnaces. It is contemplated that a reduction of 40% or more in the coke charge may be realized by using coal as supplementary fuel in blast furnaces, and estimates indicate that a saving of over two dollars per net ton of hot metal would be realized by such a substitution. In spite of these advantages, the use of pulverized coal on a large scale as a supplementary fuel for blast furnaces has not been adopted because the physical characteristics of pulverized coal are such that elaborate and expensive equipment has heretofore been required for the preparation, pressurization and feeding of coal to a blast furnace.

As a part of the general upgrading of blast furnace operation, it has been recognized that furnace output can be improved by increasing the operating pressure within the reaction zone of the furnace, and it is contemplated that blast furnaces of the future may operate with pressures up to 100 p.s.i.g. in the hearth area. With respect to the injection of coal into a blast furnace, any increase in furnace pressure obviously increases the difficulties encountered in injecting pulverized coal into the furnace.

Modern high capacity blast furnaces are provided with 16 to 24 circumferentially spaced air ports or tuyeres through which high temperature blast air (about 1400° F. to 2000° F.) is introduced into the furnace, above the hearth. Recent developments in blast furnace operating techniques have shown that high blast air temperature re-

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sults in higher temperature conditions in the blast furnace hearth for producing the desired quality of pig iron, and that operation at these elevated temperatures will permit higher iron production rates than have heretofore been possible. Thus, it is apparent that, in adapting a coal injection system for use in a blast furnace, the coal must be injected in a manner such as to effect a minimum dilution of the high temperature environment existing in the hearth. To avoid coking or burning of coal in the coal transmission lines, the temperature of carrier air used to convey the coal and inject it into the furnace is limited (to about 250° F.) by the characteristic coking temperature of the particular coal being used. Since the use of large amounts of coal carrier air would negate the favorable temperature conditions created by the use of high temperature blast air, it is highly desirable to limit the amount of relatively cool carrier air to a minimum in order not to introduce an excessive amount of cool air into the furnace and thereby significantly reduce the temperature in the hearth.

Optimal blast furnace operation also requires uniform combustion and temperature conditions throughout the cross-sectional area of the hearth and bosh sections of the furnace. Any local upset in combustion conditions can cause severe channeling of the gases up through the furnace stack or locally depressed temperatures which could lead to the formation of undesirable ash and slag ledges immediately above the combustion zone, either of which would seriously affect the overall operation of the blast furnace. This requirement of uniform combustion conditions in the furnace dictates the necessity of using a large number of evenly spaced blast air tuyeres and also makes it necessary to distribute the supplementary fuel as uniformly as possible within the combustion zone. This distribution of supplementary fuel can best be accomplished by introducing equal quantities of supplementary fuel through all of the tuyeres.

The present invention provides an integrated system for preparing and delivering coal in pulverized form at a controlled rate to the bosh area of a blast furnace, and may be used for supplying pulverized coal to a furnace operating at any presently used or contemplated furnace pressure. The coal injection system described herein may be operated over a considerable load range so that the coal rate may be varied to compensate for upsets during operation of the furnace. Operation of the present system additionally requires the availability and use of a minimum quantity of high pressure coal transport air, thereby insuring a minimum temperature drop within the furnace hearth.

The various features of novelty which characterize the present invention are pointed out with particularity in the claims annexed to and forming a part of this specification. For a better understanding of the invention, its operating advantages and specific objects attained by its use, reference should be had to the accompanying drawing and descriptive matter in which there is illustrated and described a preferred embodiment of the invention.

Of the drawings:

FIG. 1 is a schematic diagram of a blast furnace and the associated pulverized fuel preparation and delivery system in its general form;

FIG. 2 is a schematic diagram of a blast furnace and the preferred pulverized fuel preparation and delivery system; and

FIG. 3 is a schematic diagram of a coal pulverizing and conveying system employing serially arranged conveyors.

A pulverized coal preparation and delivery system for use in conjunction with a blast furnace 10 is shown in FIG. 1. It should be understood that the blast furnace 10 is of the usual type wherein iron ore, coke and a fluxing material are charged into the shaft 11 from the

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top thereof and high temperature, high pressure blast air is injected into the bosh area 12 of the blast furnace 10 through a row of circumferentially spaced tuyeres 13. The air supplied through the tuyeres 13 is heated in regenerative type stoves (not shown) to a temperature of about 1800° F. and passes via a duct (not shown) to the torus-shaped bustle pipe 14 and thence to each of the tuyeres 13 by way of connecting gooseneck pipes 15. It is customary to operate with a superatmospheric pressure in the hearth area 12 of the blast furnace 10, e.g., not less than 10 p.s.i.g., and more usually about 25 p.s.i.g., depending on the pressure due to the weight of the column of burden in the shaft 11 and the pressure required to cause the gases, as they are generated, to pass upwardly therethrough. It has been established that the production output of a blast furnace can be substantially increased, while at the same time a higher quality of end product can be attained, by the use of high temperatures and pressures in the hearth area. The temperature can be increased by increasing the temperature of the blast air; however, the blast air temperature is limited by practical design considerations to about 1800° F. The hearth pressure may be increased above that imposed by the burden by using an adjustable pressure gate in the gas outlet duct (not shown) from the furnace to further restrict the flow of gases.

As hereinbefore stated, it is proposed to inject a quantity of pulverized coal into the bosh area 12 of the blast furnace 10 so that the amount of relatively expensive coke in the charge may be reduced. Calculations indicate that slightly more than one pound of coke can be replaced by one pound of coal.

During normal operation of a blast furnace the coke that is charged into the top of the shaft takes a considerable amount of time (about 8 hours) to pass downwardly to the hearth area where it is consumed. During the time of this downward movement, the coke serves the dual function of supplying the necessary non-fluxing bulk to the charge or burden so that the requisite amount of porosity is maintained in the burden and serving as a reducing agent for the purpose of removing some of the oxygen from the iron oxide present in the ore. About 20% of the total reduction is accomplished by the coke as it descends gradually in the shaft. The remaining necessary reduction takes place in the bosh as the carbon is rapidly burned to produce the heat required for melting the ore. When a portion of the coke charge is replaced by coal, it will be necessary to maintain substantially constant pressure and temperature conditions in the hearth at all times. Thus when it is desired to commence the introduction of coal into the bosh, or when the coal introduction rate is to be changed during operation, the correlative change in coke charging rate will have to be made some time (about 8 hours) prior to the time the change in coal injection rate is actually made. Thus it is essential to have positive control both of the coal feed rate and of the coal firing rate at all times so that predetermined quantities of coal can be introduced at precisely the proper time to establish and maintain proper hearth conditions. In actual practice coal firing rate will be adjusted in response to a measured variable representative of hearth conditions and/or in response to visual inspection of the hearth. For example, the coal firing rate could be made responsive to hearth temperature, outlet gas temperature or to changes in outlet gas analysis.

The coal preparation and feed system shown generally in FIG. 1 provides a method of positively metering and feeding pulverized coal to the bosh area 12 of the blast furnace 10 so that control of hearth conditions can be maintained at all times during operation of the furnace. The bulk coal is carried from a storage area 20 to the raw coal bunker 22 via a conveyor 21. The coal passes from the bunker 22 to the pulverizer 26 through a raw coal feed pipe 23. A coal gate 24 is provided in the feed pipe 23 so that coal flow may be positively terminated

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when desired. A coal feeder 25 is provided upstream of the pulverizer 26 for metering and regulating the coal feed to the pulverizer 26. Feeders of this type are well known in coal transport technology, thus no detailed description is necessary. It should be recognized that the feeder 25 serves the dual purpose of regulating the quantity of coal entering the pulverizer 26 and metering this coal so that the rate of feed is known. In a fully automated system the coal feeder could be operated in response to an external signal, as for example, a signal indicative of hearth conditions, or, more particularly, hearth temperatures.

Air is supplied to the pulverizer 26 by a forced draft primary air fan 27. A direct fired gas burner 28 is provided to heat the air prior to its entry into the pulverizer 26. Other known types of air heaters, such as a steam coil air heater, could be used. The heated air, passing through the pulverizer 26, dries the coal and conveys the pulverized coal through the pulverizer outlet line 31 to the separator 33. The separated pulverized coal is deposited in the lower portion 33A of the separator 33, and the air is vented out of the separator 33 into the vent or cleaner 34. Coal still remaining in the air will be stripped from the vent air in the cleaner 34, which may be of any suitable type, as for example, a venturi type wet scrubber or a dry bag filter.

It should be noted that the entire coal preparation system thus far described operates at somewhat above atmospheric pressure. For example, the discharge from the fan 27 is at about one pound above atmospheric pressure and the separator 33 is at a somewhat lower pressure, about five inches of water, i.e., substantially atmospheric pressure.

The coal from the hopper 33B discharges into a coal conveyor or pump 40 which is driven by a variable speed drive mechanism 41 which may be an electric motor of the type capable of controlled speed operation or a combination of a constant speed motor with a transmission capable of variable speed output. In either event, the drive mechanism 41 must be of the type providing control of output shaft speed within the specified limits. The coal pump 40 is preferably of the type wherein the coal is compacted in and moved through a casing by a rotating element or screw to an aeration chamber 40A. A coal pump of this type is described, for example, in U.S. Patent No. 2,494,887, H. S. Lenhart, issued January 12, 1950. Coal pumps of this type create a continuously advancing, pressure sealing "plug" of coal due to the interaction of friction forces and the conveying force imparted by the rotating element. Because of the dependence on friction for proper operation, pumps of this type are not normally used as coal metering devices when delivering coal into a region of high or variable pressure.

Coal pumps of the type contemplated for use in conjunction with the system shown are generally limited to being able to handle only pulverized, as opposed to crushed, material. Pulverized material as here used refers to material having a fineness such that more than about 60 percent will pass through a 200 mesh screen. Although the present description is in terms of pulverized coal, it should be recognized that other pulverized carbonaceous fuels (e.g., char or devolatilized coal) could be used without departing from the spirit of the invention.

Conveying air is delivered from the compressor 42 to the aeration chamber 40A in the desired quantities at the desired pressures to be discussed hereinafter. The resulting coal-air mixture passes from the aeration chamber 40A via the main coal conveying line 43 to the distributor 45. To avoid congestion in the immediate vicinity of the blast furnace 10, according to the present invention, all of the component mechanical equipment including the pulverizer 26 and coal pump 40 can be located a considerable distance (several hundred feet if necessary) from the blast furnace 10. Thus, it should

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be understood that the main conveying line 43 may be of any length suitable for the particular plant lay-out in which the coal feed system is to be utilized.

The distributor 45 is preferably of the type shown in copending U.S. application, Serial No. 259,149, of Kidwell and Matthys, filed February 18, 1963, now U.S. Patent No. 3,204,942, issued September 7, 1965; however, the present invention is not intended to be limited to the use of this particular type of distributor. The distributor 45 divides the coal/air mixture from the main conveying line 43 into a plurality of equal density streams of the mixture equal in number to the number of tuyeres 13 in the blast furnace 10. These streams pass from the distributor 45 to tuyeres 13 via feed lines 46. The coal/air stream from each feed line 46 is directed into the bosh area 12 of the blast furnace 10 so that each stream is projected into the high temperature blast air being injected through the corresponding tuyere.

As mentioned hereinbefore, the pressure in the bosh area 12 of the blast furnace 10 may be as high as 25 p.s.i.g. In order to convey and inject the coal/air mixture from the pump 40 into the blast furnace 10, it is necessary that the pressure of the conveying air delivered by the compressor 42 be great enough to overcome the combined bosh pressure and the pressure drops through the main conveying line 43, distributor 45 and feed lines 46. Thus assuming these pressure drops to be about 15 p.s.i.g. at normal operating conditions, the static pressure in the aeration chamber 40A will be about 40 p.s.i.g. Of course, this pressure will vary from installation to installation depending on the pressure at which the blast furnace is operated and the conveying system pressure drop or losses.

As discussed previously, it is highly desirable that a minimum quantity of conveying air be used to carry the pulverized coal from the pump 40 into the blast furnace 10. It has been found the above described coal transport system can be successfully operated while limiting the air flow from the compressor 42 to the aeration chamber 40A to a quantity equal to approximately one cubic foot of air (measured at standard conditions of temperature and pressure) per pound of delivered coal at full system output. The desired air flow and pressure may be established by means of a control valve 44 interposed in the line between the compressor 42 and the aeration chamber 40A. In actual practice, it has been found to be advantageous to establish the conveying air flow rate at some constant value and to maintain this same air flow rate at all coal flow rates, thus simplifying the air flow controls. Of course, if the system is to be operated at reduced fuel rates and/or reduced pressure conditions, for extended periods, it would be worthwhile to adjust the air flow rate accordingly.

A primary feature of the present invention lies in the fact that the coal pump 40 serves as the pressure seal between the relatively low pressure coal preparation system (including the pulverizer 26 and the separator 33) and the pressurized blast furnace 10. Thus, the majority of the equipment in the system, and especially the pulverizer which constitutes a major portion of the cost of the system, can be designed and built for low pressure operation, thereby avoiding the high costs associated with equipment designed for and operated at elevated pressures.

To simplify control of the system, and to automate the system to the extent that only one external signal (to the coal feeder 25) is required for control of the entire system, a pump speed controller 50 is provided so that the speed of the pump drive mechanism is made responsive to the quantity of pulverized coal in the separator 33. For example, when using a level control system, a level controller (of known design) could be installed in the separator 33 so that as the level of the fuel in the hopper 33B increases above a predetermined height the pump 40 rotates at a higher speed. A satisfactory alternate arrangement for obtaining the same result would

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be to use a weighing system. The entire separator 33 and associated apparatus could be placed on a weight sensing device (not shown) and as the weight of the separator and the fuel therein increases, the drive mechanism 41, in response to a controller (not shown) associated with the weight sensing device, would increase the speed of the pump 40.

With a level control system installed on the lower portion 33A of the separator 33, the controller 50 tends to maintain a constant level in the separator 33, and therefor the density of the pulverized coal in the hopper 33A may vary in proportion to the amount of coal passing therethrough. For example, at low through-puts the elapsed time during which the coal may settle in the bottom of the hopper 33B is greater than at high throughput rates. Thus, when operating at maximum speed, the pump 40 will be receiving material which includes a substantial amount of entrained air while at low load or low speed operation of the pump 40, there will have been a greater degree of deaeration in the separator 33 and the coal handled by the pump 40 will have a higher density. Since the power consumption and the pressure sealing ability of pumps of this type are dependent to some extent on the density of material handled, it would be desirable to maintain the density at some uniform condition. To accomplish substantially constant density conditions at the inlet of the pump 40, it is proposed to vary the fuel level in the separator 33 such that the settling or residence time of the coal in the separator 33 is proportional to pump loading. This may be accomplished by varying the controlled level of coal in the separator 33 in proportion to the coal throughput so that the residence time of the coal in the hopper 33B is constant. This may be accomplished by varying the level control point in the controller 50 with respect to the speed of the coal feeder 25. By maintaining a constant density of material at the inlet of the coal pump 40, the integrity of the pressure seal will be maintained constant over the entire load range and power consumption at low loads will be reduced.

It is obvious that, with the speed of the pump 40 being responsive to the amount of coal in the separator portion 33A, and with the air flow being set at a predetermined level by the control valve 44, the entire system will automatically respond to changes in coal feed rate to the pulverizer 26 as established by the coal feeder 25. In a completely automated system, the speed of the coal feeder 25 could be made responsive to a signal from a furnace conditions controller 52, which is indicative of operating conditions within the blast furnace 10. For example, the furnace conditions controller 52 could be arranged to sense hearth temperature and to adjust the speed of the coal feeder 25 in response to indicated changes in hearth temperature so that the hearth temperature can be maintained within predetermined limits commensurate with optimum conditions for producing the desired quality of pig iron at a maximum rate.

From the above description it is apparent that the system disclosed provides a completely integrated coal preparation and delivery system capable either of semi-automatic or fully automatic control in direct response to blast furnace operating conditions. Additionally, by having the coal pump 40 in direct firing relationship to the blast furnace 10 and by providing only a small pulverized coal storage capacity in the system, the lag time between a change in speed of the coal feeder 25 and the desired change in coal feed rate at the blast furnace is minimized.

Coal pumps or conveyors of the type contemplated for use in the above described system inherently have a limited turn-down ratio on the order of 2-to-1, the lower operating limit being defined by the speed of the rotating member at which incipient failure of the pressure seal formed by the pulverized material would occur. For the practical operation of blast furnaces, it is desirable that

the turn-down ratio of the coal feed system be greater than the 2-to-1 limit of this type of pump. For example, if conditions in the blast furnace became unstable for any reason, it may be desirable to temporarily reduce the flow of coal to the furnace until the cause of the instability has been reconciled.

The system shown in FIG. 2 comprises essentially the same equipment described above in relation to FIG. 1; however, this arrangement of equipment provides a coal injection system capable of turn-down ratios on the order of 8-to-1. The system of FIG. 2 would also be suitable for use where the blast furnace is of such a large capacity that the supplementary fuel cannot be supplied by a single pulverizer.

In the arrangement of FIG. 2 two similar coal preparation and delivery systems 100A and 100B are provided to serve the blast furnace 110. The operation of each of the systems is substantially similar to that described above in relation to FIG. 1 in that raw coal is delivered by a feeder 125 from a raw coal bunker 122 to a pulverizer 126, while heated air is supplied to the pulverizer 126 from the fan 127, the air being heated by direct contact in a suitable fuel burner or convection heater 128. The pulverized coal passes via the pulverizer outlet line 131 to the separator 133 where the air is vented and passed through a suitable scrubber 134 and the coal is deposited in the dual bottom hopper 133A of the separator 133. Each hopper 133A supplies pulverized coal to coal pumps 140A and 140B which are arranged in parallel flow relation. In the description of the operation which is to follow, the four coal pumps 140 shown in FIG. 2 have been given the added descriptive designations A, B, C, and D, pumps 140A and 140B being included in the system 100A, and pumps 140C and 140D being in the system 100B. Each pair of coal pumps 140A-140B and 140C-140D deliver coal from their respective hoppers 133A to a common aeration chamber, 140AB for system 100A and to chamber 140CD for system 100B, the transport of conveying air being supplied in regulated quantities from an air compressor 142. The coal/air mixtures are delivered from the aeration chambers 140AB and 140CD through conveying lines 143A and 143B to the primary distributors 145A and 145B, respectively. As in the system shown in FIG. 1, the conveying lines 143A and 143B are designed and arranged so that the coal preparation equipment may be located remotely from the blast furnace 110 to avoid congestion of the immediate vicinity of the blast furnace 110. However, it will become obvious from the following description that the distribution system (including the primary distributors 145A and 145B) should be located near the blast furnace 110 to avoid the expense and operating problems incidental to servicing and maintaining a multiplicity of long coal transport and delivery pipes.

While the blast furnace 110 shown in FIG. 2 has 16 tuyeres 113, it should be recognized that the above described coal preparation system and the associated distribution system may be adapted to a blast furnace having any number of tuyeres without departing from the spirit of the invention.

The coal/air mixture flowing from the aeration chamber 140B enters the primary distributor 145A where it is divided into two equal density streams which flow from the distributor 145A via lines 146A to the two secondary distributors 147A which are disposed on opposite sides of the blast furnace 110. Each of the secondary distributors 147A divides the incoming coal/air stream into four equal density streams which flow through the coal feed lines 148A to the blast furnace, the fuel-air mixture entering the blast furnace in the vicinity of the tuyeres 113. The coal/air mixture flowing into the primary distributor 145B from aeration chamber 140CD is similarly divided into equal density streams, flowing through the pair of parallel-flow intermediate lines 146B, and dis-

charging into the secondary distributors 147B, which are disposed on opposite sides of the blast furnace 110 between the secondary distributors 147A, and thence through the eight coal feed lines 148B into the furnace 110. It should be noted on FIG. 2 that alternate tuyeres 113 are supplied with coal from one of the preparation and delivery systems 100A through feed lines 148A, while the remaining tuyeres 113 are served by system 100B through lines 148B, i.e., each of the systems 100A and 100B supplies coal to circumferentially spaced alternate tuyeres 113.

As discussed hereinbefore, it is essential that the distribution of supplementary fuel to the blast furnace 110 be uniform to avoid upset conditions or non-uniform combustion in the blast furnace proper. The distribution system described in relation to FIG. 2 effects optimum distribution of coal to the combustion zone of the blast furnace 110 even though one of the preparation and delivery systems 100A, 100B may be delivering slightly more fuel than the other.

The system shown in FIG. 2 may conveniently be controlled in a manner similar to that previously described in relation to FIG. 1. Thus each of the lower portions 133A of separators 133 has associated therewith a controller 150 which renders the drive mechanisms 141 responsive to the amount of coal in the corresponding separator 133, thereby making the entire system responsive to the changes in delivery rate by the feeders 125. As has already been described relative to the system shown in FIG. 1, the coal feeders may similarly be made responsive to a furnace conditions controller 152 so that the system can be rendered completely automatic. A control system of this type would be practically operational only over the load range of the system with all equipment operating, i.e., the limit would be the turn-down ratio of the pumps 140. Control of the system at lower loads could readily be accomplished manually or by suitably modifying the controls.

During start-up of the supplementary coal feed system or during periods of up-set or unstable operation, it will be desirable to reduce the coal input to the blast furnace 110. On the basis that the turn-down ratio of the coal pumps 140A, B, C, and D is limited to a 2-to-1 range, the system shown in FIG. 2 allows an 8-to-1 load range. At all system loads between full and half-load, both of the preparation systems 100A and 100B and all four coal pumps 140A, 140B, 140C, and 140D are in operation. If it is desired to go below half-load on the system, one coal pump (for example 140A and 140C) from each of the systems 100A and 100B is shut down completely, while the other coal pumps 140B and 140D will convey the coal required of the system over the range of one-half to one-quarter load. It should be noted that at all system loads between full and one-quarter load, coal is being injected uniformly into all of the tuyeres 113 in substantially equal amounts. If it becomes necessary to operate the coal system between one-quarter and one-eighth load, one of the two remaining pumps (for example 140B) can be shut down and the load carried on a single coal pump 140D. Thus, at system loads between one-quarter and one-eighth, with only one of the systems (100B in the example) in operation, coal would be delivered only to alternate tuyeres 113 around the periphery of the furnace 110. Thus, the entire system shown in FIG. 2 may be operated over a total load range of 8-to-1 while maintaining uniform distribution of coal to the blast furnace 110.

Although not shown in the drawing, it should be understood that isolating or shut-off valves would be placed in the lines between the coal pumps 140A, 140B, 140C, and 140D and their respective aeration chambers 140AB and 140CD, and between the coal pumps and the bottom portions 133A of the hoppers 133 to prevent the back-flow of gases when the pumps are not in use. Additionally, shut-off valves (not shown) should be provided in each of the coal feed lines 148A, 148B so that the furnace

operator may terminate coal feed to any part of the furnace 110 at his discretion.

Pumps of the type proposed for use in the systems shown are capable of pressurizing coal up to about 50 p.s.i.g. In pumps of this type, the pressure seal is established by compressing the pulverized material between a cylindrical casing and a high speed screw, the pressure seal limitation being imposed by practical limits of screw length, friction and power consumption. Thus, in instances where a blast furnace is to be operated at higher pressures, it becomes necessary to make additional provisions for effecting a seal between the aeration chamber 40A and the bunker 33A. The coal conveying arrangement shown in FIG. 3 provides an arrangement of equipment whereby pumps of the character described may be used to feed coal to a furnace operating at pressures above the sealing limit of a single pump.

In this arrangement, pulverized coal is supplied from a pulverizer (not shown) to a first bin 201 which is at substantially atmospheric pressure. The coal is transferred by a first coal conveyor pump 202 to a second bin 203 which is maintained at a pressure which is about half of the pressure differential existing between the first bin 201 and the aeration chamber 204A of the second pump 204. The second pump 204 transfers the coal from the second bin 203 to the aeration chamber 204A where the coal is picked up by conveying air and transported through a main conveying line 205, thence through an appropriate distribution system and into a blast furnace as described above in relation to FIGS. 1 and 2. The coal pumps 202 and 204 are respectively driven by motors 206 and 207, which operate in response to controllers 208 and 209, the controllers 208 and 209 being respectively responsive to the amount of coal in the bunkers or bins 201 and 203. The conveying air is supplied to the aeration chamber 204A through a line 214 from the compressor 210, the air pressure and flow to the chamber 204A being controlled by a valve 211. The pressure in the second bin 203 may be controlled to the desired level by means of a pressure regulating valve 212 in the line 213 leading from the compressor 210 to the second bunker 203.

By way of example and not limitation, if the pressure required in the aeration chamber 204A to deliver the coal to the blast furnace is 80 p.s.i.g., the pressure in the second bin 203 should be maintained at about 40 p.s.i.g. by means of the regulating valve 212. It should be noted that since there is substantially no flow of air through the second coal pump 204, there will be practically no flow of air through the line 213 to the second bin 203 and therefore no additional duty imposed on the compressor 210 other than there would normally be imposed in a single pump installation.

Although the foregoing description has been in terms of two pumps serially arranged it should be recognized that if necessary, more pumps may be serially staged to attain high pressures without departing from the spirit of the invention.

While in accordance with the provisions of the statutes there is illustrated and described herein a specific embodiment of the invention, those skilled in the art will understand that changes may be made in the form of the invention covered by the claims, and that certain features of the invention may sometimes be used to advantage without a corresponding use of the other features.

What is claimed is:

1. Apparatus for smelting iron ore comprising a pressurized blast furnace, a pulverized fuel preparation system operating at substantially atmospheric pressure and including a pulverized fuel collection bin and means for feeding pulverized fuel thereto, means for withdrawing fuel from said bin at a controlled rate, means defining a pressurizing chamber arranged to receive fuel from said withdrawing means, means for detecting the amount of fuel in said bin, means responsive to the amount of fuel

in said bin and being controlled by said detecting means for controlling the operation of said withdrawing means to thereby control the rate at which fuel is withdrawn from said bin, means for pressurizing the fuel in said chamber for injection into said blast furnace, and means for regulating the flow of pulverized fuel to said bin in response to a condition of said blast furnace to thereby control the rate at which pulverized fuel is fed to said blast furnace.

2. Apparatus for smelting iron ore comprising a pressurized blast furnace, a pulverized fuel preparation system operating at substantially atmospheric pressure and including a pulverizer, a fuel feeding and metering device for supplying fuel to said pulverizer, a separator, a pulverized fuel collection bin, means for supplying carrier fluid to said pulverizer for feeding fuel to said separator and said bin, means for withdrawing pulverized fuel from said bin at a controlled rate, means defining a pressurizing chamber arranged to receive fuel from said withdrawing means, means for detecting the amount of fuel in said bin, means responsive to the amount of fuel in said bin and being controlled by said detecting means for controlling the operation of said withdrawing means to thereby control the rate at which fuel is withdrawn from said bin, means for pressurizing the fuel in said chamber for injection into said blast furnace, and means for regulating the amount of fuel delivered to said pulverizer by said fuel feeding and metering device in response to a condition of said blast furnace to thereby control the rate at which pulverized fuel is fed to the blast furnace.

3. Apparatus for smelting iron ore comprising a pressurized blast furnace, a pulverized fuel preparation system operating at substantially atmospheric pressure and including a pulverized fuel collection bin and means for feeding pulverized fuel thereto, means for detecting the amount of fuel in said bin, a fuel conveyer connected to said bin for withdrawing pulverized fuel from said bin for pressurization and injection into said blast furnace and including a casing and a rotating element within the casing for progressively compacting the withdrawn fuel, means defining a pressurizing chamber wherein the fuel is received from said fuel conveyer and is aerated to produce a condition of fluidity, means for supplying pressurized fluidizing medium to said chamber, a variable speed drive mechanism connected to said rotating element for controlling the rate of fuel passing through said conveyer, the speed of said drive mechanism being responsive to the amount of fuel in said bin and being controlled by said detecting means, said conveyer being in direct fuel firing relation to said blast furnace and forming the pressure seal between said bin and said blast furnace, and means for controlling the rate of fuel passing from said fuel preparation system to said bin in response to a condition of said blast furnace to thereby control the rate at which pulverized fuel is fed to said blast furnace.

4. Apparatus for smelting iron ore comprising a pressurized blast furnace, a pulverized fuel preparation system operating at substantially atmospheric pressure and including a pulverizer, a fuel feeding and metering device for supplying fuel to said pulverizer, a separator, a pulverized fuel collection bin, means for supplying carrier fluid to said pulverizer for feeding fuel to said separator and said bin, means for detecting the amount of fuel in said bin, a fuel conveyer connected to said bin for withdrawing pulverized fuel from said bin for pressurization and injection into said blast furnace and including a casing and a rotating element within the casing for progressively compacting the withdrawn fuel, means defining a pressurizing chamber wherein the fuel is received from said fuel conveyer and aerated to produce a condition of fluidity, means for supplying pressurized fluidizing medium to said chamber, a variable speed drive mechanism connected to said rotating element for controlling the rate of fuel passing through said conveyer, the speed of said drive mechanism being responsive to the amount of fuel in said bin and being controlled by said detecting means, said conveyer be-

ing in direct firing relation to said blast furnace and forming the pressure seal between said bin and said blast furnace, and means for regulating the quantity of fuel delivered to said pulverizer by said fuel feeding and metering device in response to a condition of said blast furnace to thereby control the rate at which pulverized fuel is fed to said blast furnace.

5. Apparatus for smelting iron ore comprising a pressurized blast furnace including upwardly extending walls defining a hearth, a bosh, and a stack, said blast furnace being formed with a plurality of circumferentially spaced tuyeres opening into said bosh, means for charging iron bearing material, carbonaceous solid fuel, and a fluxing agent into the upper portion of said stack, and means for supplying an additional amount of carbonaceous solid fuel to said bosh comprising a pulverized fuel preparation system operating at substantially atmospheric pressure and including a pulverized fuel collection bin and means for feeding pulverized fuel thereto, means for detecting the amount of pulverized fuel in said bin, screw-type coal conveyor means connected with said bin for continuously withdrawing fuel therefrom at a controlled rate responsive to the amount of fuel in said bin and being controlled by said detecting means, means defining a pressurizing chamber arranged to receive from said conveyor the pulverized fuel withdrawn from said bin, means for pressurizing and aerating the fuel discharged from said conveyor into said chamber, means for regulating the flow of pulverized fuel to said bin in response to a condition of said blast furnace to thereby control the rate at which pulverized fuel is fed to said blast furnace, a distributor connected with said chamber, and a plurality of fuel delivery pipes connecting said distributor to said blast furnace for the introduction of plural streams of aerated fuel to the bosh in the vicinity of said tuyeres.

6. Apparatus for smelting iron ore comprising a pressurized blast furnace including upwardly extending walls defining a hearth, a bosh, and a stack, said blast furnace being formed with a plurality of circumferentially spaced tuyeres opening into said bosh, means for charging iron bearing material, carbonaceous solid fuel, and a fluxing agent into the upper portion of said stack, and means for supplying an additional amount of carbonaceous solid fuel to said bosh comprising a pulverized fuel preparation system operating at substantially atmospheric pressure and including a pulverizer, a fuel feeding and metering device for supplying fuel to said pulverizer, a separator, a pulverized fuel collection bin, means for supplying carrier fluid to said pulverizer for feeding fuel to said separator and said bin, means for detecting the amount of fuel in said bin, a fuel conveyor connected to said bin for withdrawing pulverized fuel from said bin for pressurization and injection into said blast furnace and including a casing and a rotating element within the casing for progressively compacting the withdrawn fuel, means defining a pressurizing chamber wherein the fuel is received from said fuel conveyor and aerated to produce a condition of fluidity, means for supplying pressurized fluidizing medium to said chamber, a variable speed drive mechanism connected to said rotating element for controlling the rate of fuel passing through said conveyor, the speed of said drive mechanism being responsive to the amount of fuel in said bin and being controlled by said detecting means, said conveyor being in direct fuel firing relation to said blast furnace and forming the pressure seal between said bin and said blast furnace, means for controlling the rate of fuel passing from said fuel preparation system to said bin in response to a condition of said blast furnace to thereby control the rate at which pulverized fuel is fed to said blast furnace, a distribution system connected with said chamber and located in the immediate vicinity of said blast furnace, and a plurality of fuel delivery pipes connecting said distribution system to said blast furnace for the introduction of a plu-

ality of equal streams of aerated fuel into the bosh of said furnace in the vicinity of said tuyeres.

7. Apparatus for smelting iron ore comprising a pressurized blast furnace, a pulverized fuel preparation system operating at substantially atmospheric pressure and including a first pulverized fuel collection bin and means for feeding pulverized fuel thereto, means for detecting the amount of fuel in said first bin, means for withdrawing the fuel from said first bin at a controlled rate and pressurizing said fuel for injection into said blast furnace including a second collection bin, means for detecting the amount of fuel in said second bin, means for maintaining the pressure in said second bin between the pressure in said first bin and the pressure in said blast furnace, means for transferring fuel from said first bin to said second bin at a controlled rate in response to the amount of fuel in said first bin and being controlled by said first bin detecting means, a conveyor for withdrawing fuel from said second bin, said conveyor forming the pressure seal between said second bin and said blast furnace, a drive mechanism operatively associated with said conveyor and being responsive to the amount of fuel in said second bin for controlling the operation of said conveyor to thereby control the rate at which fuel is withdrawn from said second bin, said drive mechanism being controlled by said second bin detecting means, means for pressurizing and fluidizing the fuel withdrawn from said second bin, means for passing the pressurized and fluidized fuel to said blast furnace, and means for regulating the flow of pulverized fuel to said first bin in response to a condition of said blast furnace to thereby control the rate at which pulverized fuel is fed to said blast furnace.

8. Apparatus for smelting iron ore comprising a pressurized blast furnace, a pulverized fuel preparation system operating at substantially atmospheric pressure and including a first pulverized fuel collection bin and means for feeding pulverized fuel thereto, means for detecting the amount of fuel in said first bin, means for withdrawing the fuel from said first bin at a controlled rate and pressurizing said fuel for injection into said blast furnace including a second collection bin, means for detecting the amount of fuel in said second bin, means for maintaining the pressure in said second bin between the pressure in said first bin and the pressure in said blast furnace, a first conveyor for transferring fuel from said first bin to said second bin, a first variable speed drive mechanism operatively associated with said first conveyor and being responsive to the amount of fuel in said first bin for controlling the operation of said first conveyor to thereby control the rate at which fuel is transferred from said first bin to said second bin, said first variable speed drive mechanism being controlled by said first bin detecting means, a second conveyor for continuously withdrawing fuel from said second bin and including a rotating screw member, an aeration chamber arranged at the discharge end of said screw member, a second variable-speed drive mechanism connected to rotate said screw member and being responsive to the amount of fuel in said second bin for controlling the rate of fuel passage from said second bin to said blast furnace, said second variable speed drive mechanism being controlled by said second bin detecting means, means for introducing pressurized carrier gas into said aeration chamber to suspend the fuel therein in a state of fluidity, a piping and distribution system connected to said chamber for delivering the fluidized fuel from said chamber to said blast furnace in a plurality of continuous streams, and means for regulating the flow of pulverized fuel to said first bin in response to a condition of said blast furnace to thereby control the rate at which pulverized fuel is fed to said blast furnace.

9. Apparatus for smelting iron ore comprising a pressurized blast furnace having a plurality of circumferentially spaced air tuyeres in the lower portion thereof, a pair

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of separately operable pulverized fuel preparation systems operating at substantially atmospheric pressure, each of said systems including a pulverized fuel collection bin and means for supplying pulverized fuel thereto, means for withdrawing fuel from said bin at controlled rate, means defining a pressurizing chamber arranged to receive fuel from said withdrawing means, means for detecting the amount of fuel in said bin, means responsive to the amount of fuel in said bin for controlling the operation of the withdrawing means to thereby control the rate at which fuel is withdrawn from said bin, the means for controlling the operation of the withdrawing means being controlled by said detecting means, and means for aerating the fuel in said pressurizing chamber to a condition of fluidity; a pair of fuel distribution systems, each of which is connected to one of said pressurizing chambers, one of said distribution systems being constructed and arranged to deliver the fuel from one of said chambers to alternate ones of said tuyeres, the other of said distribution systems being constructed and arranged to deliver the fuel from the other of said bins to the other of said tuyeres, and means for regulating the flow of pulverized fuel to said collection bins in response to a condition of said blast furnace to thereby control the rates at which pulverized fuel is fed to said blast furnace from said separate chambers.

10. Apparatus for smelting iron ore comprising a blast furnace having a bosh section operating at a substantial superatmospheric pressure, a pulverized fuel preparation system operating at substantially atmospheric pressure and including a first collection bin and means for feeding pulverized fuel thereto, means for withdrawing

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the fuel from said first bin and pressurizing said fuel for introduction into the bosh area of said blast furnace, said last mentioned means including a second collection bin, means for detecting the amount of fuel in said second bin, means for transferring fuel from said first bin to said second bin, means for pressurizing said second bin to a pressure substantially above atmospheric pressure, means for withdrawing fuel from said second bin, said means for withdrawing fuel from said second bin being responsive to a signal from said detecting means, a fluidizing chamber arranged to receive the fuel withdrawn from said second bin, and means for supplying pressurized fluidizing and conveying medium to said chamber at a pressure substantially higher than the pressure in said blast furnace to suspend the fuel in said chamber in a state of fluidity, a piping and distribution system connected to said chamber for delivering the fluidized fuel therefrom to said blast furnace in a plurality of continuous streams, and means responsive to a condition of said blast furnace for controlling the delivery of fuel to said second bin to thereby control the rate at which fuel is delivered to said blast furnace.

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