UNITED STATES PATENT OFFICE.

EDMUND B. KIRBY, OF NEW YORK, N. Y.

METHOD OF OPERATING BLAST FURNACES AND SIMILAR FURNACES.

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To all whom it may concern:

Be it known that I, EDMUND B. KIRBY, a citizen of the United States, residing at New York, in the county of New York and State of New York, have invented a certain new and useful Improvement in Methods of Operating Blast Furnaces and Similar Furnaces, of which the following is a full, clear, and exact description.

The present invention relates to a method or process applicable in the operation of blast furnaces, cupola furnaces or other furnaces of similar nature and for similar purposes.

The objects of the invention and the results will appear more at large as the description proceeds.

Reference should be had to the accompanying drawings forming a part of this specification in which Fig. 1 is an elevation with portions in section of a furnace in which the process may be carried out; Fig. 2 is a transverse sectional elevation of such a furnace; Fig. 3 is a vertical transverse section through the outlet end of the base of the furnace; Fig. 4 is a horizontal section at the level of the lower row of tuyères.

As the description proceeds, reference will be made to the application of the method and process of a blast furnace, but this is done without intending any limitation as to the precise form of furnace which may be used.

Furthermore, in explaining the process reference will be made to the application thereof to the production of pig iron from iron ore but in this instance also no intentional limitation is intended thereby.

In the operation of blast furnaces for various purposes and to produce various products, the material which is to be treated, such as a mixture of various ores with limestone and other fluxes is fed into the furnace together with coke.

The tuyères of the blast furnace are located near its base and introduce a blast of air into the column of material and fuel. The combustion of the latter causes various chemical reactions and the fusion of the products.

In the usual operation of blast furnaces, the carbon burned at the tuyères is oxidized only to carbon monoxide liberating only one-third of the total of the carbon. Attempts to produce carbon dioxide meet with various practical difficulties, such as the dissociation of carbon dioxide, its reduction to carbon monoxide by the heated fuel above through which it rises, the necessity for having carbon monoxide act upon the ore for a certain time, etc.

In the process herein proposed, no attempt is made to restrict the natural formation of carbon monoxide in the zone of combustion at the main blast. In fact, for many cases, the blast is so regulated as to promptly form the maximum quantity.

The carbon monoxide, with such other gases as accompany it, is allowed to rise through the descending column and perform its chemical action upon the heated material for the time required. Supplementary introductions of blast are then made at the proper level or succession of levels and these burn the carbon monoxide to carbon dioxide. This liberates the other two-thirds of the heat which is absorbed by the descending material and conveyed back down to the zone of fusion where the material arrives so preheated that its fusion is rapid. By means to be described, the carbon dioxide escapes without reduction to carbon monoxide.

A blast of oxygen or of air enriched with oxygen constitutes an important and often necessary means of performing the above operation. The increased rapidity of fusion calls for the continuous discharge of molten products in a more satisfactory manner than is possible with present practice while another result flowing from the new method of operation is to make possible the use of fluid or pulverulent fuel when this is desirable.

In carrying the invention into practice, the material and the solid fuel, such as anthracite coal or coke, are fed in at the top of the furnace so that they will descend as separate columns, each of the columns maintaining its identity, but in contact each with the other. The solid fuel, prior to its being fed into the furnace, has been crushed to a size such that the interstices between the pieces of the fuel will be of much smaller average size than the interstices between the pieces of material making up the material column. This will make the fuel col-
umn more dense and less penetrable by the gases which pass upwardly through the furnace, and under the conditions named they will almost entirely ascend through the material column. Solid fuel, such as coke or anthracite does not readily agglomerate or sinter under heat but will remain mobile and will thus descend uniformly and flow into irregularities caused by its combustion.

By referring to the drawings, 10 represents a fuel column such as coke and 11 represents the column of material, both being fed at the top of the furnace. The main blast is delivered by means of the tuyère 13 which communicates with the wind box 14.

As will be noted, the tuyère extends nearly through the coke column so that the blast is delivered within the coke mass sufficiently near its contact with the column of material for the heat and gases of combustion to escape from the fuel mass and act upon the column of material. It will be understood that while only one tuyère is shown in the drawing, there may be a plurality of such tuyères used in actual practice.

The main blast located near the base of the furnace may be introduced in any way which will best enable it to reach and act upon the surface of the fuel column which is in contact with the column of material. Most materials as they approach fusion become pasty and sinter together in such a way as to hinder or prevent the blast as well as the current of gases of combustion from penetrating them. White hot fuel such as coke has no adhesion to such pasty material while the interstices of the fuel mass although smaller than those of the material remain open. These nonadherences and interstices therefore present a relatively easy and continuous by-path or channel wherein the blast and the gases of combustion may find their way past the pasty zone, beyond which zone the gases can readily escape into the open and larger interstices of the column of material and so ascend.

For the reasons specified it is preferable and in most cases necessary to introduce the lower blast substantially at the surface of contact.

The lower tuyères are made adjustable with respect to their position in the furnace so that the tuyères may be properly positioned to discharge the blast in proper relation to the surface of contact between the column of material and the coke under varying positions of this surface, which stands in a curve of equilibrium depending upon the relative specific gravities of the two columns and other factors.

The main blast thus delivered causes the fusion of the material and produces gases of combustion carrying carbon largely or wholly in the form of carbon monoxide. These gases rise through the column of material.

At a suitable point, above the lower tuyère there is a second blast introduced through an auxiliary tuyère, into the column of material as indicated at 15, and if desired an additional blast may be introduced or additional blasts as indicated at 15*. These auxiliary tuyères are positioned at a point above the main or lower tuyère far enough to give the carbon monoxide opportunity to remain in contact with the material through which it ascends, for a desired period of time, this being necessary to effect certain chemical reactions within the descending column.

When the carbon monoxide reaches the zone in which the auxiliary tuyères are located, it is burned to carbon dioxide, which liberates the remaining heat incident to burning the carbon and this heat is absorbed by the descending column of material so that the aforesaid column is in highly heated condition when it reaches the zone of fusion.

The carbon dioxide which is formed at the auxiliary tuyères ascends through the column of material and is conducted away from the top of the furnace. This operation is made possible by the fact that the carbon dioxide ascends from the zone of the auxiliary tuyères through the column of material and not through the fuel column due to the fact before stated that the gases find a more ready passage through the column of material than through the fuel column.

Due to the mobility of the descending fuel column the particles of fuel will flow around the tuyères with which they contact and to assist this the nozzles of the tuyères stand in a downwardly slanting direction which also serves the purpose of preventing fine particles of fuel from entering the tuyères.

In the construction preferred for carrying out the process, this flow of fuel aids in protecting the water-cooled tuyères and since crushed fuel is a non-conductor, the nozzle is protected from extreme heat by that portion of the fuel mass which intervenes between it and the contact surface.

In order to facilitate the action of the auxiliary tuyères and to secure a thorough mixture of the blast introduced through these tuyères, with the ascending gases so as to induce complete combustion, it is desirable and in many cases may be necessary to use oxygen or air enriched with oxygen in the upper or the lower blast or in both.

In both blasts and particularly in the auxiliary one, it is very difficult, within the
interstices of the material, to secure the proper mixture and a prompt absorption of the heat. This is due mainly to the great volume and velocity of the ascending gases owing to their excessive dilution with nitrogen from the air ordinarily used.

The abolition of nitrogen in whole or in part from the blast used will thus reduce the absorption height of the column, concentrate both zones of combustion and at both places provide a higher flame temperature which hastens the transfer of heat.

For the blast it is therefore desirable to use oxygen which is pure or as nearly pure as is commercially practicable for the process which furnishes the oxygen supply.

In special cases, however, and temporarily whenever the furnace is being started or when its operation is resumed after some interruption, I prefer to employ a blast which is not perfectly oxidising and whose oxygen contents may vary anywhere from a little in excess of the contents of air up to the full strength of the oxygen supply available. In starting up for instance, I prefer to begin with an air blast and then to gradually enrich this by substituting oxygen for the air until the current has become pure oxygen or has reached such other degree of enrichment as is desired for the operation being conducted.

The fact that the descending column of material is highly heated due to its absorption of two-thirds of the heat of the fuel prior to its entrance into the fusion zone, brings the material so much nearer to the point of fusion that upon entering the zone where the other third of the heat of the carbon is generated, fusion is much more rapid and this increase in rapidity of fusion is still further increased by the higher flame temperature which is induced when oxygen or air enriched with oxygen is supplied through the lower tuyère or tuyères.

The complete mixing of the blast delivered through the auxiliary tuyères with the ascending gases may also be assisted by the introduction of more than one auxiliary tuyère or bank of tuyères as already explained, the additional tuyères being introduced at one or more successive elevations.

From the foregoing description it will be noted that the zone of fusion is removed from the sides of the furnace and the side walls are protected from excessive heat, and consequently may be made of cheaper materials than those ordinarily employed.

The use of fuel which is crushed or broken into small pieces, instead of the large size pieces of coke as ordinarily used, lessens the usual space for the accumulation of molten products and hence renders less desirable the intermittent tapping of the furnace as at present practiced.

Furthermore, as before noted, the process or method as described will so increase the rapidity of fusion as to make it particularly necessary to provide other and better means for removing the molten products than the present intermittent tapping. This may be accomplished by providing suitable channels at the lower part of the furnace which permit a continuous flow of the molten material from the lower portion of the furnace while tapping the blast. In this connection the channel 18 shown at the right hand portion of Fig. 1 will provide an exit for the heavier metal, while the channel 19 at the lower left hand portion of Fig. 1 will provide an outlet for the lighter molten material or slag. These channels connect with overflow spouts which are indicated respectively at 20 and 21.

The continuous flow of the molten metal and the slag will maintain the walls of the channels through which they flow in sufficiently heated condition so that their contents will not become chilled. However, in order to provide for the heating of the channels in the event of irregularities or when the molten metal and the slag are insufficient to heat the channels and in order to initially heat the channels when the furnace is started, I prefer to provide a suitable heating means for the aforesaid channels. This heating means may assume any suitable or desired form, such as providing an arrangement for sending an electric current through the molten material or through a resistor provided along the bottom or side walls of the ducts by which the molten metal and slag discharges from the furnace. This resistor is made of a suitable material which conducts the electric current when cold but which will generate sufficient heat when the current is passed through the same.

An arrangement which will answer the purpose is illustrated in Fig. 1 of the drawings in which a resistor element 22 extends beneath and forms a part of the floor of the furnace as well as of the ducts through which the molten metal and slag may discharge. Associated with the resistance material are electrodes 25 and 26, by means of which current may be introduced through the resistance material. Auxiliary electrodes 27 and 28 are shown, which may be used in addition to the electrodes before mentioned, or if desired, merely to heat portions of the resistance material, suitable combinations of electrodes may be made.

A particularly desirable construction for accomplishing the purpose of heating the outlet ducts for the furnace is described and claimed in another application filed by myself.

Up to the present time the difficulties attending the use of injectable fuels in blast furnaces have either prevented or limited their application and in most cases have
overbalanced the advantages of such fuels. Since these difficulties are mainly due to pasty conditions affecting penetration, and to the chilling effect of injection upon the solid fuel, especially when oil or powdered coal are used, the open interstices and the diminution of nitrogen secured by my process makes it now possible to evade such difficulties and to utilize all such fuels freely.

This may be accomplished by introducing a fluid fuel, that is a liquid or gaseous fuel or a finely pulverized fuel such as powdered coal at substantially the place within the furnace where the lower blast is introduced. In fact, the fluid or pulverulent fuel may be introduced along with the blast of air and to indicate this I have shown a tube 30 which extends within the tuyère and is supplied with the fluid or pulverulent fuel and suitable means of pressure injection (not indicated herewith) through a pipe 31 which connects with the pipe 81 within the tuyère. Each tuyère employed is equipped with such a conduit and injector.

It may be explained that the injectable fuels to which I refer constitute a well-understood and clearly defined class distinguished by having the peculiar qualities necessary for combustion within the interstices of a blast furnace column.

Such fuel to be injectable must either be gaseous or be liquid or be a solid powdered finely. They must thus be capable of being scattered by the injection force into liquid globules or solid particles, which are small enough to be carried by the injection current through the fine interstices of a blast furnace column and to mix with the blast and to be consumed quickly by virtue of their small size, before choking these interstices.

For convenience, therefore, I shall refer to all such fuels as "injectable fuel" and shall distinguish between the two kinds of injectable fuels by referring to the first as "gaseous fuels" and to the second as "non-gaseous injectable fuels".

By any of the well-known means such as those indicated, the blast and the injectable fuel are introduced into the furnace at any suitable point. This preferably, as previously explained, will be substantially at the surface of contact or within the fuel mass sufficiently near to the contact for the heat and gases to reach the material effectively.

Under such circumstances, the fluid or powdered fuel will be burned preferentially to the solid fuel and not enough blast is admitted to burn the solid fuel. The sole function of the solid fuel in this case is to maintain an open passageway for the gases which passageway is furnished by the open interstices of the fuel and its non-adherence to the pasty material along the contact. By this passageway, the gases pass above the pasty zone (when this exists) and there escape into the more open interstices of the material column.

The solid fuel within the zone of combustion is maintained in the white hot condition necessary for the above purposes and to permit proper combustion of the injectable fuel, not by its own combustion but by contact with the preheated descending material and the flame of the injectable fuel.

The initial forming of carbon monoxide within the zone of fusion and the subsequent formation of carbon dioxide as previously explained take place in the same fashion when the fluid or pulverulent fuel is used.

In the use of injectable fuel, the introduction of oxygen through the lower tuyères or the introduction of air enriched by oxygen, is of great benefit due to the great reduction in the volume and velocity of gases to be passed and further in the attainment of a higher flame temperature in the zone of fusion. In fact by eliminating most of the nitrogen and using sufficient pressure, the reduced volume of gases can in many cases be forced through the pasty zone in the material without any aid such as is afforded by the column of solid fuel and in other cases it can be forced through with the aid of a reduced amount of solid fuel when the latter is introduced as a part of the mixture composing the furnace charge or as alternating layers with the material.

In order to maintain the proper position of the surface of contact between the descending column of solid fuel and the material column when fluid or pulverulent fuel is burned without consuming the solid fuel, the column of solid fuel must descend at a uniform rate which fixes the position of equilibrium for the contact surface. The mobility of the grains in the column of solid fuel makes it possible to discharge this column at any convenient point near the base of the furnace so as to remove a sufficient quantity to maintain the required uniform descent.

This is indicated in Fig. 2 of the drawings where one or more inclined water coiled pipes or conduits such as indicated at 32 are shown. Such conduits as that indicated at 32 may be placed along the side of the furnace at suitable intervals and means are provided such as the slide valves 31, which will control the passage of the solid fuel through the pipes 32. Any suitable means for removing and regulating the flow of the fuel drawn from the pipes 32 may be provided, for example, a screw conveyor 33 as indicated.

By the improved process which has just been described the blast furnace becomes applicable to novel uses among which is the production of calcium carbide. In producing calcium carbide the same arrangement
of the separate descending contacting columns may be employed. The molten carbide will be discharged at the bottom of the furnace in the same manner as previously described.

Having described my invention, I claim:

1. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which will not so agglomerate under heat as to impair the mobility of its particles and which has been crushed so that its particles have less average size than those of the column of material, and supplying an oxidizing blast within the fuel mass sufficiently near the surface of contact between said columns for the heat and gases of combustion to escape to said surface.

8. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, supplying an oxidizing blast in the lower portion of the furnace, and supplying an auxiliary oxidizing blast within the column of material above the zone of fusion.

9. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which has been crushed so that its particles have less average size than those of the column of material, supplying an oxidizing blast in the lower portion of the furnace, and supplying an auxiliary oxidizing blast within the column of material above the zone wherein a reducing or neutral atmosphere is necessary.

10. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which will not so agglomerate under heat as to impair the mobility of its particles and which has been crushed so that its particles have less average size than those of the column of material, supplying an oxidizing blast in the lower portion of the furnace, and supplying an auxiliary oxidizing blast within the column of material above the zone wherein a reducing or neutral atmosphere is necessary.

11. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which will not so agglomerate under heat as to impair the mobility of its particles, supplying an oxidizing blast in the lower portion of the furnace, and supplying an auxiliary oxidizing blast within the column of material above the zone wherein a reducing or neutral atmosphere is necessary.

12. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which will not so agglomerate under heat as to impair the mobility of its particles and which has been crushed so that its particles have less average size than those of the column of material, supplying a blast whose oxygen content exceeds that of air in the lower portion of the furnace, and supplying an aux-
iliary oxidizing blast within the column of material above the zone wherein a reducing or neutral atmosphere is necessary.

13. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which has been crushed so that its particles have less average size than those of the column of material, and supplying an oxidizing blast, substantially at the surface of contact between said columns.

14. The method of operating a metallurgical furnace which consists in supplying it with material to be treated, in subjecting this material to chemical reaction and fusion and in removing two molten products by continuous flow through the same tap and electrically heating the channel of the tap when required by utilizing the most suitable one of these products as a resistor in the form of a permanently retained pool.

15. The method of operating a metallurgical furnace which consists in supplying it with material to be treated, in subjecting this material to chemical reaction and fusion and in removing the molten product by continuous flow through the channel of a tap over a permanent elongated pool of molten metal occupying the bottom of said channel and in heating said metal pool by passing an electric current through it lengthwise between the inside and the outside of the furnace.

16. The method of operating a blast furnace which consists in supplying it with material to be treated together with fuel and a blast, and in removing the molten products continuously by causing them to collect and flow to their outlets within a contracted channel upon the hearth bottom and to pass through the furnace walls in channels also contracted and in electrically heating the stream thus contracted in cross section by utilizing the most suitable one of said products as a resistor in the form of a pole permanently retained in the bottom of the entire channel.

17. The method of operating a blast furnace which consists in supplying it with material to be treated together with fuel and a blast and removing two molten products by continuous flow through the same tap and electrically heating the channel of the tap when required by utilizing the most suitable one of these products as a resistor in the form of a permanently retained pool.

18. The method of operating a blast furnace which consists in supplying it with material to be treated together with fuel and a blast whose oxygen content exceeds that of air and removing two molten products by continuous flow through the same tap and electrically heating the channel of the tap when required by utilizing the most suitable one of these products as a resistor in the form of a permanently retained pool.

19. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, supplying an oxidizing blast in the lower portion of the furnace, supplying an auxiliary oxidizing blast within the column of material above the zone of fusion, and removing one or more of the molten products by continuous flow through a tap or taps, the channels of which are heated when required by passing an electric current through a resistor provided in or beneath or alongside such channel.

20. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, supplying an oxidizing blast in the lower portion of the furnace so controlling said blast as to form CO and burning the CO to CO₂ by supplying an auxiliary oxidizing blast within the column of material above the zone wherein a reducing or neutral atmosphere is necessary.

21. The method of operating a blast furnace which consists in supplying to the furnace the material to be treated together with solid fuel, and supplying a blast whose oxygen content exceeds that of air and a nongaseous injectable fuel.

22. The method of operating a blast furnace which consists in supplying to the furnace the material to be treated, and supplying a blast whose oxygen content exceeds that of air and a nongaseous injectable fuel.

23. The method of operating a blast furnace which consists in supplying to the furnace the material to be treated, supplying in the lower part of the furnace a blast whose oxygen content exceeds that of air and a nongaseous injectable fuel, and supplying an auxiliary oxidizing blast above the zone wherein a reducing or neutral atmosphere is necessary.

24. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, and supplying an oxidizing blast substantially at the surface of contact between said columns and an injectable fuel.

25. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, supplying an oxidizing blast in the lower portion of the furnace with injectable fuel, supplying an auxiliary oxidizing blast within the column of material above the zone of fusion, and maintaining the descent of the fuel column by drawing fuel
out of the furnace from the lower part of the column.

26. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, supplying an oxidizing blast together with injectable fuel, regulating the blast to a quantity sufficient to burn only the injectable fuel and maintaining the descent of the fuel column by drawing fuel out of the furnace from the lower part of the column.

27. The method of operating a blast furnace which consists in supplying to the furnace the material to be treated with solid fuel, supplying a blast whose oxygen content exceeds that of air, together with injectable fuel, regulating the blast to a quantity sufficient to burn only the injectable fuel and maintaining the descent of the fuel column by drawing fuel out of the furnace from the lower part of the column.

28. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, and supplying an oxidizing blast, within the fuel mass sufficiently near the surface of contact between said columns for the heat and gases of combustion to escape to said surface, with injectable fuel.

29. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which has been crushed so that its particles have less average size than those of the column of material, supplying an oxidizing blast in the lower portion of the furnace, substantially at the surface of contact between said columns, with injectable fuel, and supplying an auxiliary oxidizing blast within the column of material above the zone wherein a reducing or neutral atmosphere is necessary.

30. The method of operating a blast furnace which consists in supplying to the furnace the material to be treated with solid fuel, and supplying a blast whose oxygen content exceeds that of air and pulverulent fuel.

31. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, and supplying an oxidizing blast and pulverulent fuel.

32. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which has been crushed so that its particles have less average size than those of the column of material, and supplying an oxidizing blast and an injectable fuel in the lower portion of the furnace.

33. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which will not so agglomerate under heat as to impair the mobility of its particles, supplying an oxidizing blast, and introducing under pressure with or near the blast an injectable fuel.

34. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which will not so agglomerate under heat as to impair the mobility of its particles, supplying an oxidizing blast substantially at the surface of contact between said columns, and introducing under pressure with or near the blast an injectable fuel.

35. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which will not so agglomerate under heat as to impair the mobility of its particles, supplying a blast whose oxygen content exceeds that of air, and introducing under pressure with or near the blast an injectable fuel.

36. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which will not so agglomerate under heat as to impair the mobility of its particles, and supplying a blast whose oxygen content exceeds that of air and an injectable fuel.

37. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which will not so agglomerate under heat as to impair the mobility of its particles, and supplying a blast whose oxygen content exceeds that of air in the lower portion of the furnace, substantially at the surface of contact between said columns and an injectable fuel.

38. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which has been crushed so that its particles have less average size than those of the column of material, and supplying an oxidizing blast and an injectable fuel in the lower portion of the furnace.
material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which has been crushed so that its particles have less average size than those of the column of material, supplying an oxidizing blast in the lower portion of the furnace substantially at the surface of contact between said columns, and supplying an injectable fuel.

40. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which has been crushed so that its particles have less average size than those of the column of material, and supplying a blast whose oxygen content exceeds that of air in the lower portion of the furnace substantially at the surface of contact between said columns and an injectable fuel.

41. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, supplying a blast whose oxygen content exceeds that of air in the lower portion of the furnace so controlling said blast as to form CO and burning the CO to CO₂ by supplying an auxiliary blast whose oxygen content exceeds that of air within the column of material above the zone of fusion.

42. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, supplying an oxidizing blast in the lower portion of the furnace substantially at the surface of contact between said columns so controlling said blast as to form CO and burning the CO to CO₂ by supplying an auxiliary oxidizing blast within the column of material above the zone of fusion.

43. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which has been crushed so that its particles have less average size than those of the column of material, supplying an oxidizing blast in the lower portion of the furnace, and supplying an auxiliary oxidizing blast within the column of material at a point above the first mentioned blast.

44. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which has been crushed so that its particles have less average size than those of the column of material, supplying an oxidizing blast in the lower portion of the furnace substantially at the surface of contact between said columns, and supplying an auxiliary oxidizing blast within the column of material at a point above the first mentioned blast.

45. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which will not so agglomerate under heat as to impair the mobility of its particles, supplying an oxidizing blast in the lower portion of the furnace with an injectable fuel, so controlling said blast as to form CO and burning the CO to CO₂ by supplying an auxiliary oxidizing blast within the column of material above the zone of fusion.

46. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which will not so agglomerate under heat as to impair the mobility of its particles, supplying an oxidizing blast in the lower portion of the furnace substantially at the surface of contact between said columns with an injectable fuel, so controlling said blast as to form CO and burning the CO to CO₂ by supplying an auxiliary oxidizing blast within the column of material above the zone of fusion.

47. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which will not so agglomerate under heat as to impair the mobility of its particles, supplying an oxidizing blast in the lower portion of the furnace substantially at the surface of contact between said columns with an injectable fuel, and supplying an auxiliary oxidizing blast within the column of material above the zone of fusion.

48. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which will not so agglomerate under heat as to impair the mobility of its particles, supplying an oxidizing blast in the lower portion of the furnace substantially at the surface of contact between said columns with an injectable fuel, and supplying an auxiliary oxidizing blast within the column of material above the first mentioned blast.

49. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which will
not so agglomerate under heat as to impair the mobility of its particles, supplying a blast whose oxygen content exceeds that of air in the lower portion of the furnace substantially at the surface of contact between said columns, with an injectable fuel, and supplying an auxiliary oxidizing blast within the column of material above the first mentioned blast.

50. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, using fuel which will not so agglomerate under heat as to impair the mobility of its particles, supplying an oxidizing blast in the lower portion of the furnace with injectable fuel, and maintaining the descent of the fuel column by drawing fuel out of the furnace from the lower part of the column.

53. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, supplying an oxidizing blast in the lower portion of the furnace substantially at the surface of contact between said columns with injectable fuel, and maintaining the descent of the fuel column by drawing fuel out of the furnace from the lower part of the column.

54. The method of operating a blast furnace which consists in so supplying the material to be treated and the solid fuel, that they will form separate descending contacting columns, supplying an oxidizing blast in the lower portion of the furnace substantially at the surface of contact between said columns with injectable fuel, supplying an auxiliary oxidizing blast within the column of material above the zone of fusion.

55. The method of operating a metallurgical furnace which consists in supplying to the furnace the material to be treated together with solid fuel, supplying a blast whose oxygen content exceeds that of air with injectable fuel, so controlling said blast as to form CO and burning the CO to CO₂ by supplying an auxiliary oxidizing blast within the column of material above the zone of fusion.

In testimony whereof, I hereunto affix my signature.  

EDMUND B. KIRBY.