

## [54] METHOD OF MAKING ALUMINUM-SILICON ALLOYS

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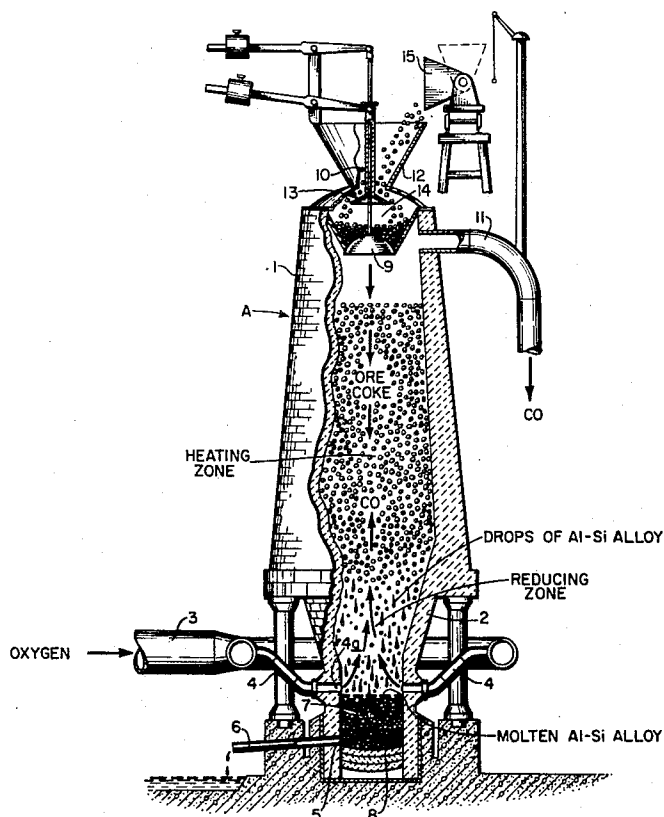
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## [57] ABSTRACT

A method of making aluminum-silicon alloy in a blast furnace utilizing substantially pure oxygen, wherein lumps of silicon carbide comprise all or part of the furnace bed.

12 Claims, 3 Drawing Figures



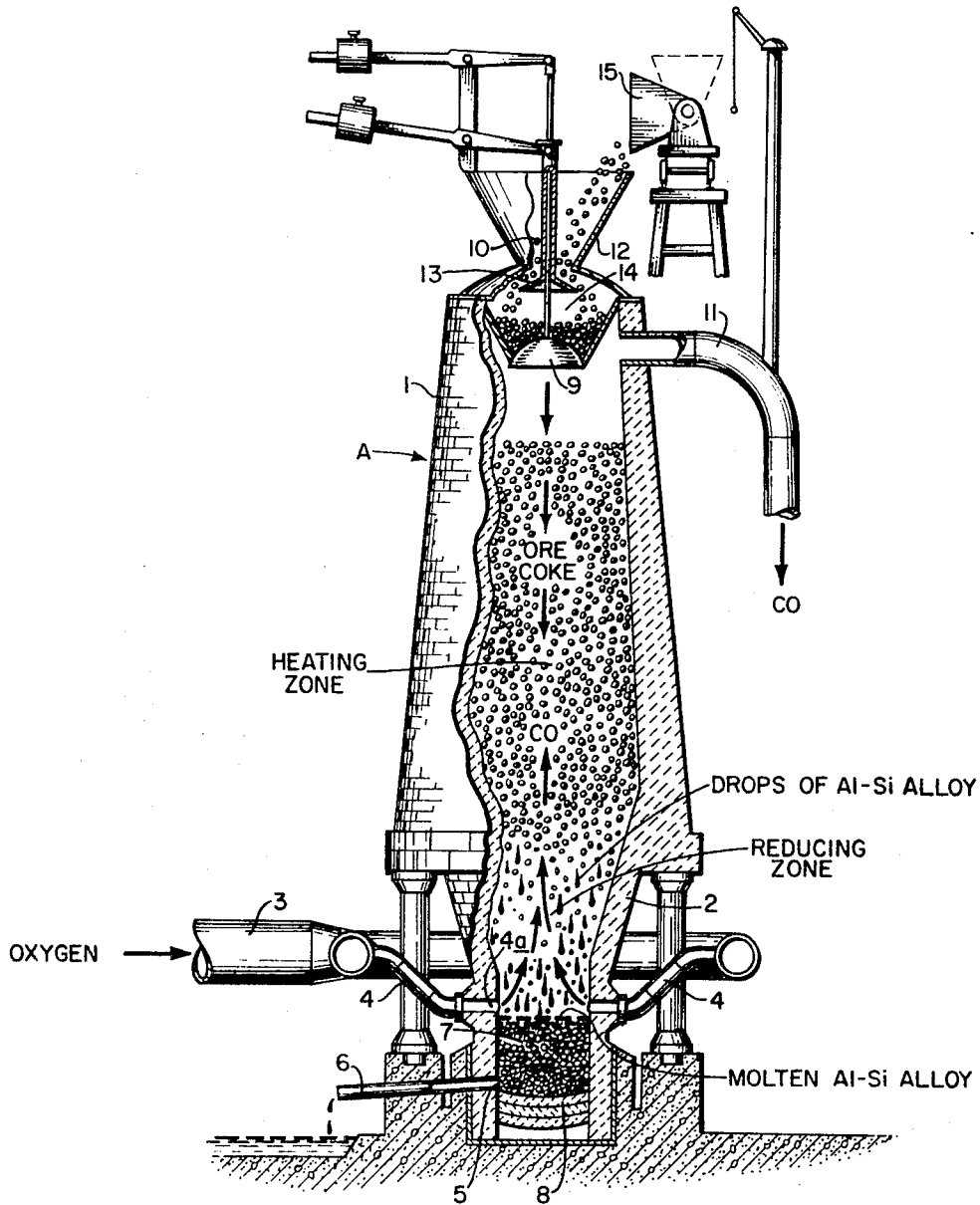


FIG. 1.



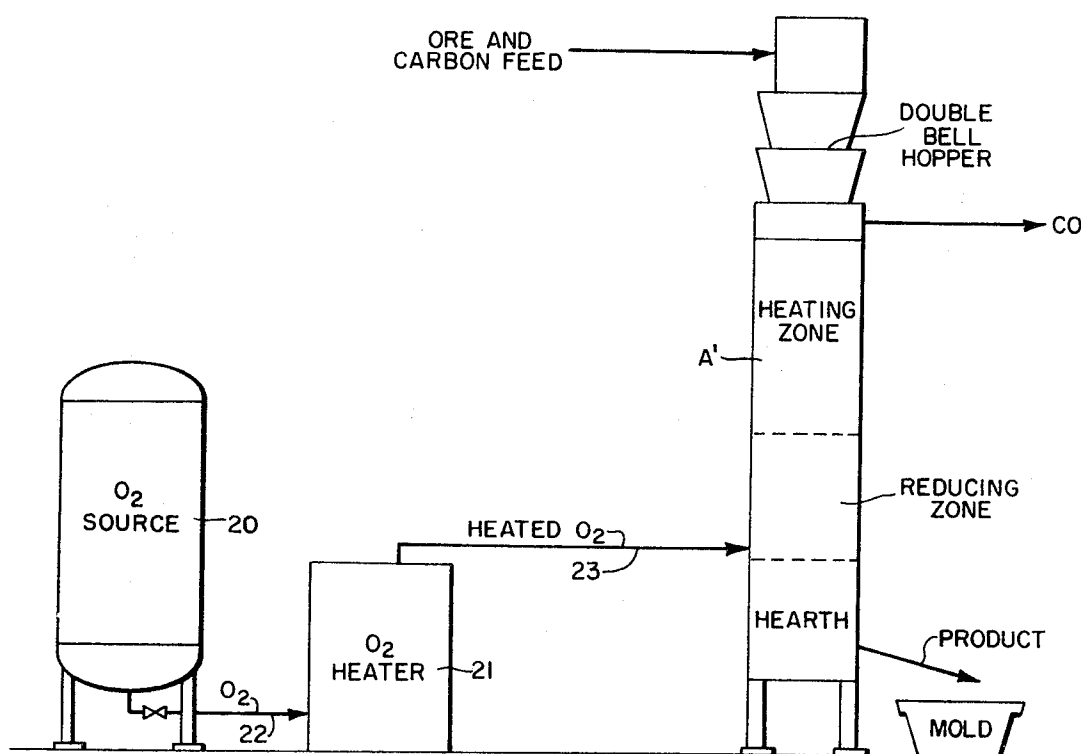


FIG. 3.

## METHOD OF MAKING ALUMINUM-SILICON ALLOYS

## BACKGROUND OF THE INVENTION

The present invention is in the field of metallurgy and relates principally to the manufacture of an aluminum-silicon alloy in a blast furnace.

It has been known that high silicon aluminum alloys are useful for a number of purposes, particularly casting, and that ores such as clays are available in quantity which can be reduced to high silicon aluminum alloys by reaction with carbon in an electric arc furnace. Although there have been some processes for making aluminum from naturally occurring aluminum oxides or silicates as taught by U.S. Pat. Nos. 1,551,615 and 1,552,728, respectively, using a fuel fed or other furnace, respectively, there has been no known commercial method of carbothermically reducing naturally occurring aluminum silicates or clays in a blast furnace for the production of an aluminum-silicon alloy. At the present time aluminum-silicon alloys are manufactured using substantially pure aluminum and substantially pure silicon. This is, of course, considerably expensive.

An article entitled "Carbothermic Smelting of Aluminum" by P. T. Stroup published in *Transactions of the Metallurgical Society of AIME*, Volume 230, pages 356-371 (1964), provides an excellent history of the work done in smelting aluminum carbothermically.

Although blast furnaces have been successfully used for many years for the production of iron, there are no known successful uses of a blast furnace for producing an aluminum-silicon alloy.

The modern blast furnace used in the manufacture of iron is essentially a large chemical reactor or plant into the top of which are charged iron ore, coke and limestone. The opening at the top of the furnace is usually a double-bell system. As the iron ore descends through the furnace it is reduced and finally melted by a countercurrent flow of hot reducing gases. The gas is produced by burning coke with preheated air at the bottom of the furnace. As the ore melts it flows downward to the bottom of the furnace. Impurities are separated by the heat and the actions of gases and limestone. From time to time from suitable tapholes in the bottom of the furnace, white hot liquid iron and melted impurities are drawn off.

Inside the furnace an air blast causes the coke to burn at very high temperatures. Near the top of the furnace, the temperature is about 200° C. and near the bottom, it is about 1,700° C. or higher.

The carbon combustion gases given off by the burning coke stream up through the raw materials and heats the ore which is then reduced by the carbon monoxide and the carbon in the charge. About midway down, the ore becomes a spongy mass of iron and impurities. At the bottom of the furnace, the iron melts and goes down through the white-hot coke into the hearth pool.

In addition to producing heat and reducing gases and reacting with the ore, the coke helps to support the burden in the furnace and to provide void spaces for the ascending gases. For smooth operations, the coke should be relatively strong or have a good crush strength at furnace operating temperatures.

The limestone in the furnace fluxes or purifies the iron. It helps some of the impurities in ore and coke to fuse or melt. The limestone then combines with some of the melted impurities to form slag. The slag begins to form below the middle of the furnace. Since the slag is lighter than iron, it floats on top of the melted iron, which is several feet deep. Different types of ore produce different types of slag.

At the bottom of the furnace is the taphole, which is usually an opening filled with a clay plug. Periodically during the furnace operation, the clay plug is drilled out and the molten iron is drawn off through a clay-lined runner for casting or further processing. The taphole is then plugged with fresh clay, usually shot from an air-pressure gun.

In one type of blast furnace metallurgical operations, a bed of coke rests on the hearth of the blast furnace and supports

the weight of the burden. Molten metal and slag trickle through the coke bed. When coke is used as the bed in a blast furnace for the production of aluminum-silicon alloys, at least part of the carbon from the coke reacts with the aluminum-silicon alloy to form aluminum carbide and/or silicon carbide. Such carbides form deposits and plug the reactor, are difficult to remove from the alloy, and tie-up part of the product. The present invention is adapted to overcome this carbide problem.

In an iron blast furnace the slag is lighter than the molten iron and floats on the iron which collects in the hearth area. This layer of molten slag protects the iron from oxidation by the air blast which enters just above the hearth. The production of aluminum-silicon alloy is essentially slag-free, but the alloy is the lightest liquid in the furnace. It floats on a small pool of partly reacted ore which collects at the bottom of the hearth. Thus the alloy is poorly protected from reoxidation. The present invention is adapted to overcome this problem also.

## SUMMARY OF THE INVENTION

In a blast furnace operation utilizing substantially pure oxygen for the production of an aluminum-silicon alloy, lumps of silicon carbide (SiC) are introduced into the furnace to form all or part of the furnace bed or hearth. Since the carbon in the furnace is already in the form of silicon carbide, the problem of carbon forming new compounds with the aluminum-silicon alloy made in the furnace is eliminated.

In the preferred form of the invention, the oxygen is preheated to a temperature of about 1,000° C. Oxygen temperatures may range from about 0° C. to about 2,000° C. as desired.

## BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a vertical section of a blast furnace illustrating the present invention.

FIG. 2 is a diagram showing the aluminum-silicon-carbon (Al-Si-C) system.

FIG. 3 is a schematic presentation of the invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

In the preferred form of the invention, silicon carbide lumps are placed in the furnace bed in a sufficient quantity to completely form the furnace bed. Alternatively, the furnace bed may comprise coke and silicon carbide lumps. The silicon carbide must be present in sufficient quantity however to avoid the problem of aluminum carbide or silicon carbide forming with the carbon from the coke in sufficient quantity to be a processing problem. Some coke or other suitable carbon may need to be added to the furnace bed to react out any residual oxygen picked up from blast.

In the preferred embodiment of the invention, an opening is placed in a blast furnace for receiving oxygen thereinto from an external source. Pure oxygen is introduced into the furnace to burn with the carbon (coke, charcoal or other suitable carbon) thereby producing carbon monoxide gas at very high temperatures. The hot carbon monoxide gas passes into the furnace which has been filled with the ore and coke mixture required for the carbothermic reduction of the ore to an aluminum-silicon alloy. Cooling of the hot carbon monoxide gas provides the necessary energy for the ore reduction, although it does not enter into the reduction reaction. The carbon in the coke reacts with the ore to form metal and more carbon monoxide.

Preferably, the oxygen is preheated prior to introduction into the blast furnace. The oxygen is preheated to a temperature of about 1,000° C. in any suitable oxygen heater before introduction into the furnace. Oxygen temperatures of from about 0° C. to about 2,000° C. are suitable, if desired. At the high temperatures of the blast furnace, the hot oxygen reacts with the carbon forming hot carbon monoxide gas. Such gas does not react with the aluminum or silicon metal products

produced at the high temperatures required in the reduction zone.

In a typical ore reduction, a blast furnace of the type used in iron smelting is employed, except that there is a means for introducing oxygen into the furnace and the furnace is designed for the higher reduction zone temperatures. The furnace charge comprises coke or charcoal and an ore comprising aluminum and silicon. Silicon carbide or other suitable carbide is added to the charge as desired.

The coke-ore mixture is charged into the furnace by means of a "bell" in the usual manner. The oxygen is introduced into the furnace, and temperatures in excess of 2,050° C. are maintained in the reaction zone of the furnace. Molten aluminum-silicon alloy is collected in the bottom of the furnace and is removed therefrom by means of the usual taphole.

Unlike the iron blast furnace, the aluminum-silicon furnace is essentially slag free. Some small amount of slag may occur as the result of a slight deficiency of carbon in the furnace. This unreacted molten ore collects at the bottom of the hearth area and does not protect the aluminum-silicon product which collects in the hearth. The silicon carbide lumps which fill the hearth area prevent the hot oxygen from the tuyere area from contacting the alloy and re-oxidizing it.

Referring now to FIG. 1 of the drawing, a typical blast furnace A is shown. The furnace comprises a tower 1, narrowing somewhat toward both the top and the bottom. The walls 2 are built of steel and lined with suitable refractory. The base 2 is girdled with a pipe 3, through which oxygen is forced. Leading from the pipe 3 are smaller pipes 4, called tuyeres, which conduct the oxygen into the furnace. At the base of the furnace A is a taphole 5 for the molten aluminum-silicon alloy, through which the liquid metal can be drawn off from time to time by the conduit or liner 6.

Lumps of silicon carbide 7 are placed in the bottom 8 of the furnace A up to a height just below the opening 4a of the tuyeres 4. Alternatively, lumps of coke and silicon carbide may be used, but the silicon carbide must be in sufficient quantity to substantially inhibit the formation of silicon carbide from the silicon in the ore and the carbon in the furnace.

The top is closed by a movable trap 9, called the bell, and the raw materials 10 are introduced thereinto. The gases resulting from the combustion of the fuel and the reduction of the ore escape through the upper pipe 11. These gases have a temperature of 200°-250° C. and are essentially pure carbon monoxide which is a valuable by-product.

Charges of raw materials 10, comprising coke and ore which are preferably pelletized together, but may be mixed together in predetermined proportions are introduced at suitable intervals into the furnace A through the bell 9 via the hopper 12. The upper bell 13 is opened at desired intervals to admit the raw materials 10 into the compartment or area 14 above the lower bell 9.

The ore or raw materials 10 are conveyed to the furnace A by means of a car 15 or other suitable method. At the bottom of the furnace, the silicon carbide being less soluble in the nascent Al-Si alloy remains substantially stable. Any silicon carbide that is dissolved can be recovered from the alloy in subsequent processing and recycled to the furnace. The phase diagram shown in FIG. 2 shows that the silicon carbide can be recovered by simply cooling the alloy and separating the silicon or aluminum carbides which precipitate.

The temperature of the furnace at the point at which the oxygen enters is about 2,300° to 2,500° C., but gradually decreases toward the top of the furnace, where it is only from about 200° C. to about 250° C. Heating of the ore begins at the top of furnace through exchange of the sensible heat in the hot carbon monoxide. As the ore descends, reduction proceeds by the action of the coke or carbon, and the resulting aluminum and silicon melts and collects as a liquid in the bottom of the furnace.

The process is essentially slag free, but a portion of the ore remains only partially reduced because of a slight deficiency of carbon in the furnace. This partially reduced ore is molten

at the hearth temperature of about 1,900° C. and collects in the bottom of the hearth.

After a desired quantity of aluminum-silicon alloy has collected, it is drawn off, and run out into suitable containers for further processing or use. The molten slag is drawn off with the alloy, separated therefrom and charged back to the furnace. The process is preferably a continuous ore, and once the furnace is started, it is kept in operation for a desired length of time, usually several months without interruption.

In FIG. 3 of the drawings, the furnace A' is illustrated schematically. The oxygen is supplied to the furnace from a suitable source 20. The oxygen is transferred to an oxygen heater 21 via a suitable conduit 22. After the oxygen is heated to the desired temperature, usually about 1,000° C., it is introduced into the furnace A' via a suitable conduit 23.

It can be appreciated that the drawings and description thereof are merely illustrative and that various changes may be made in the construction of the furnace and its component parts without departing from the scope of the invention.

The opening and/or openings into the furnace for the introduction of oxygen thereinto are preferably so arranged as to be substantially in line with the combustion area in the furnace and so constructed as to be suited for oxygen introduction.

The ores which may be used in the instant invention are naturally occurring alumina-silica or aluminum silicate clays and/or minerals. Some examples of these raw materials are diaspore, kyanite, boehmite, sillimanite, andalusite, mullite, kaolinite clays and/or minerals. They may also contain quartz, cristobalite and the like. Impurities may also be present. Preferably, the ores contain from 50 percent alumina to 70 percent or more alumina.

The ores may be physically or chemically treated or otherwise beneficiated prior to introduction into the furnace. The type of treatment is varied with the type of ore used.

The present invention is also suitable for the production of ferro-silicon or silicon, with the raw materials being varied for such use.

The form of the carbon that is used is not critical. Some forms which may be used are metallurgical coke, coal, lamp black, graphite and petroleum coke. The form of carbon used is very important in iron blast furnace operations. Metallurgical coke is preferred because of its low reactivity with carbon dioxide in the upper portion of the furnace. This lowers the so-called carbon volatility losses. The volatility problems does not occur in the aluminum blast furnace and the form of the carbon is therefore not critical in this respect.

In the preferred form on the invention, the coke and ore are pre-prepared in pellets or intimately mixed briquettes. The pellets are preferably of from about 1/8 inch to about 1 inch in diameter. Smaller or large sizes may be used if desired for a particular operation. The pellets or briquettes are also preferably of a uniform particle size.

The coke and ore are finely ground prior to pelletizing or prior to introduction into the furnace. For optimum results the coke and ore are mixed at a ratio of about 1 part ore to about 1-3 parts carbon.

In general, the smaller the particles being processed, the less time required for processing. The particle sizes should be sufficiently large, however, to prevent fluidization of the ore passing down through the furnace by the hot carbon monoxide flowing up.

The temperature in the reduction zone of the furnace should be a minimum of about 2,050° C. up to a maximum of the temperature of vaporization of aluminum and silicon, approximately 2,500° C. An optimum temperature is about 2,200° C., with a preferred temperature range of from about 2,150° C. to about 2,250° C.

The pressure of the blast furnace is about 10 p.s.i.g. and the oxygen being introduced thereinto is about 15 p.s.i.g. The external pressure must be sufficiently greater than the internal pressure to permit the injection of oxygen into the furnace.

A small scale blast furnace operation is carried out with a furnace whose inside dimensions are 1 foot in diameter by 10 feet in height. About 175 pounds of pellets are fed to the top of the furnace each hour. Pellets are one-fourth to one-half inch in diameter and comprise about 35 percent by weight kyanite ore and about 65 percent by weight of coke breeze. Essentially pure oxygen heated to about 950° C. is fed through a nozzle near the bottom of the furnace. The rate of oxygen flow is 120 pounds per hour.

After steady operation is achieved, the rate of carbon monoxide gas being drawn off from the top of the furnace is about 260 pounds per hour. The carbon monoxide is essentially pure and is at a temperature of about 250° C. Every 2 hours the metal is tapped from the hearth area. The average tap size is about 60 pounds. The metal comprises by weight about 55 percent aluminum and 40 percent silicon, with small amounts of iron, titanium, carbon and oxygen.

Silicon carbide sublimates about 2,200° C. so the temperature of the furnace hearth should be maintained below such temperature. In addition to silicon carbide other forms of carbide may be used. Some examples are zirconium carbide, titanium carbide, tantalum carbide and hafnium carbide.

The silicon carbide should preferably be in lump form with the lumps uniform in size, to provide a large void area which can be filled with aluminum-silicon alloy. The lumps are preferably from about ¼ inch to about 1½ inches in diameter. The lumps are also preferably of a size close to the size of the feed pellets so that the voids between the silicon carbide lumps will not tend to become filled with unreacted feed pellets.

Silicon and ferro-silicon alloys may be produced in a manner similar to that described hereinbefore using appropriate ores and/or raw materials to achieve the desired end results.

The foregoing disclosure of the invention is illustrative and descriptive thereof and various changes may be made within the scope of the claims without departing from the scope of the invention.

What is claimed is:

1. A process for producing aluminum-silicon alloys in a blast furnace which comprises, providing a charge containing carbon, an aluminum-silicon ore and pure oxygen; providing a furnace bed comprising lumps of silicon carbide, said silicon carbide being in an amount sufficient to substantially prevent the formation of aluminum carbide and silicon carbide in harmful amounts; igniting the charge to reduce the ore in the furnace; continuing the operation until an aluminum-silicon alloy is produced; and recovering the latter.
2. The method of claim 1, wherein the oxygen is preheated prior to being introduced into the blast furnace.
3. The method of claim 1, wherein the oxygen is preheated to a temperature of about 1,000° C. before introduction into the blast furnace.
4. The method of claim 1, wherein the oxygen is preheated to a temperature of from about 0° C. to about 2,000° C.
5. The method of claim 1, wherein the oxygen is preheated to a temperature of from about 500° C. to about 1,500° C.
6. The method of claim 1, wherein the alumina-silica ore is kyanite concentrate.
7. The method of claim 1, wherein the alumina-silica ore is diasporic clay.
8. The method of claim 1, wherein the alumina-silica ore is kaolinite.
9. The method of claim 1, wherein substantially the entire bed is composed of lumps of silicon carbide of an average size in ranges of about ¼ inch in diameter to about 1½ inches in diameter.
10. The method of claim 1, wherein substantially the entire bed is composed of lumps of silicon carbide which are substantially the same size as pellets of ore and carbon fed to the blast furnace.
11. The method of claim 1, in which the reaction temperature is between about 1,800° C. and about 2,500° C.
12. The method of claim 1, wherein the furnace bed comprises lumps of silicon carbide and coke.

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