

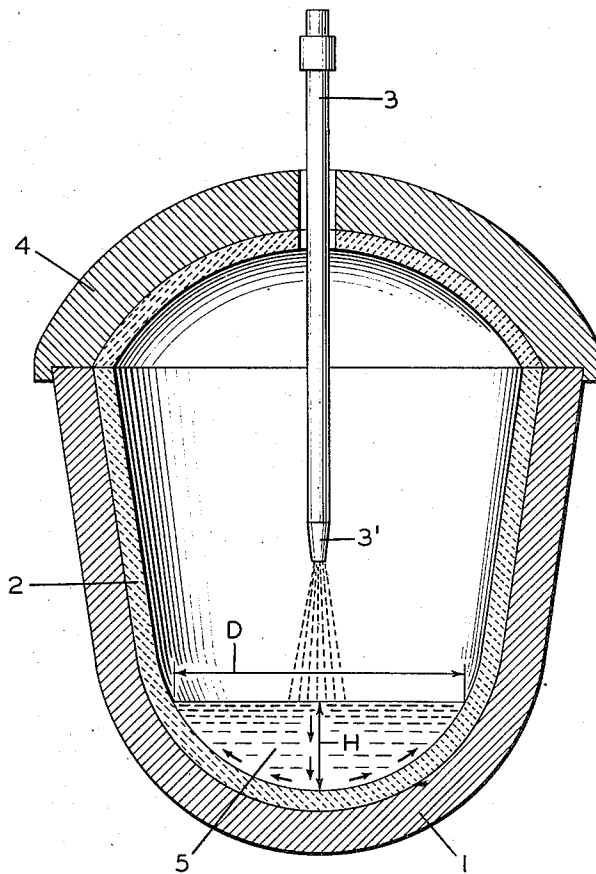
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METHOD OF CARRYING OUT MELTING PROCESSES

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METHOD OF CARRYING OUT MELTING PROCESSES

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This invention relates to a process for the treatment of metallic or metal-containing materials with oxygen-containing gases, preferably high purity oxygen, and has particular relation to a process of this type in which fusible materials are treated at high temperatures with said gases. Still more particularly, the invention relates to a process for the refining of molten metal with high purity oxygen blown downwardly onto the surface of a bath of the molten metal.

The invention is particularly adapted to the refining of primarily hot metal charges, for example, molten pig iron, but it is also applicable to the production of refined metals from solid charges, such as solid pig iron for the production of steel, as hereinafter set forth. The invention is also characterized by the fact that the heat required for the refining of the molten impure metal is autogenous, being produced primarily by reaction of the oxygen gas with the impurities in the molten metal, although when utilizing solid charges of impure metal, the heat required for melting of the charge prior to refining is provided by combustion of a suitable fuel with the oxygen gas.

Processes for the utilization of high purity oxygen in the refining of molten metal charges, such as pig iron, have been suggested ever since the development of the original pneumatic process by Bessemer. Attempts to blow with high purity oxygen in a conventional Bessemer or Thomas converter through bottom tuyeres has resulted in the destruction of the refractory bottom within the short time of one heat. On the other hand, high purity oxygen refining processes have been previously proposed in which the oxygen is directed onto the molten metal bath surface in the form of a jet or jets issuing from tuyeres positioned in the wall of the refining vessel above the melt line. In such processes, the horizontal velocity component of the oxygen jet at the melt surface causes the development of excessively high temperatures above and at the melt-slag interface on the side of the vessel opposite the tuyeres or oxygen jet inlet so that a rapid deterioration of refractory occurs. In addition, with such an inclined oxygen jet, a loss of oxygen efficiency results due to deflection of the gas from the melt surface and burning of a large proportion (40–50%) of the evolved carbon monoxide to carbon dioxide above the melt, which is further undesirable in contributing to the short refractory life. In addition, the heat produced by high purity oxygen-molten metal reactions is more than sufficient to provide the heat necessary for completion of the refining reactions to the desired steel analysis, and this large amount of additional heat developed within the refining vessel due to carbon monoxide combustion is undesirable. Further, in the utilization of high purity oxygen as the refining medium, the reduction in oxygen efficiency resulting from this combustion of the carbon monoxide with a portion of the oxygen feed cannot be tolerated.

Accordingly, it is recognized that the application of such processes, in which the molten materials, for example pig iron, are treated in refining devices provided

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with refractory linings are severely limited due to the extremely high temperatures developed by reaction of the high purity oxygen gas with the molten metal and the short life of the refractory linings when exposed to such temperatures. This is particularly true in those processes, such as production of steel, in which chemical reactions capable of causing corrosion of the refractory lining take place. Thus, in a device provided with refractory lining, such as a converter in the previously proposed processes when high purity oxygen is blown to the surface of a bath of molten pig iron, with or without a slag cover, combustion of the impurities in the metal, and also iron itself result in such extremely high temperatures that the refractory lining is attacked and damaged to such extent that it must be renewed after a short period of use. The refractory materials known at present are unable to resist attacks and stresses of this kind unless the lining is protected by the application of particular conditions from direct exposure to the strong heat developed by the high purity oxygen-molten metal reactions. Accordingly, although the advantages of molten metal refining with high purity oxygen have been recognized, particularly with respect to the reduced nitrogen ballast compared to the air blown pneumatic refining processes, there remains no economical, commercially feasible process for refining of molten metal with high purity oxygen capable of providing long refractory life and high oxygen efficiency. In particular, the deficiencies of the proposed processes, emphasize the lack of a high purity oxygen refining process for molten pig iron having the aforementioned advantages to provide an economical, commercially feasible process for production of refined steel at least equal in quality to that produced by the well known basic open-hearth process from pig iron of widely varying chemical compositions.

It is accordingly one of the main objects of the present invention to provide a process for refining molten metals by surface blowing with high purity oxygen, in which, owing to the particular conditions employed, the refractory walls of the apparatus utilized in carrying out the process are protected from undue corrosion by the excessively high temperatures developed and the chemical reactions taking place at such temperatures.

Another object of the present invention is to carry out the treatment of molten metals, and other molten materials by surface blowing with high purity oxygen in such a manner that the reactions of the oxygen gas with the constituents of the molten bath and the resulting high temperatures, to the extent possible, are limited to an oxygen jet impingement area removed from the refractory lining of the reaction vessel.

It is also a primary purpose and object of this invention to provide a process for the refining of primarily hot metal charges, that is, predominantly molten pig iron, with high purity oxygen gas in which controlled refining at substantially theoretical oxygen efficiency is accomplished.

A further object is to provide a process for refining of molten pig iron with a surface blown high purity oxygen jet in which an exceptionally high refractory life is obtained.

The invention also has as its object to provide a process of surface blowing molten pig iron with high purity oxygen in which the refining reactions and oxygen impingement on the melt surface are controlled in a manner such that over-oxidation of the molten pig iron bath is essentially avoided.

It is still another object of the invention to provide a high purity oxygen refining process which is applicable to pig iron of widely varying chemical compositions, including in particular pig iron of analyses used in or-

dinary basic open-hearth practice, as well as those of higher silicon and phosphorus content required for blowing in the acid Bessemer and basic Thomas converter processes to produce steels having analyses and qualities at least comparable to that of basic open-hearth steels. Another object of the invention is to provide a high purity oxygen refining process for production of steel of excellent quality at a high rate of production, substantially comparable to Bessemer or Thomas converter practice, for example, a blowing time of from 15 to 30 minutes for charges of from 30 to 40 tons to carbon end points of 0.05% or below.

Further objects and advantages of the invention will be apparent from the following detailed description of the process and the appended drawing.

The process of the invention generally comprises refining the molten metal in a converter type or other suitable vessel with a high purity oxygen jet impinging vertically or approximately vertically on the melt surface substantially at the central portion thereof by means of a blast nozzle or other suitable jet producing means under controlled conditions, hereinafter defined, to supply to the molten metal the required amount of oxygen for completion of refining within a predetermined time, and to produce autogenous heat sufficient to insure completion of the refining and adequate temperature in the refined charge for subsequent handling.

It has been found that by suitable arrangement of the nozzle or jet producing device, and operation thereof for the supply and introduction to the molten metal of the high purity oxygen gas, suitable design of the refractory lined refining device in which the process is conducted, and proper use of amounts of materials charged, the foregoing advantages are obtained, including a very efficient protection of the refractory lining.

According to the process of the invention, the high purity oxygen jet is blown vertically, or approximately vertically upon the central portion of the surface of a bath of the molten metal, the jet having a diameter and static pressure at the point of origin, that is, at the blast nozzle or other jet producing means, and the point of origin (blast nozzle) being spaced from the bath surface, such that direct contact of the oxygen jet and the molten metal is established and maintained throughout the refining period without deep penetration of the molten metal bath by the jet. In so operating, the area of jet impingement is controlled to produce a relatively confined zone of direct oxygen to molten metal contact with respect to the total surface area of the bath. It has been determined in application of the present invention to the refining of predominantly molten pig iron charges by means of high purity oxygen, that the jet blown onto the surface of the molten iron, as above described, under a relatively low static pressure at the point of origin, for example, at the overhung blast nozzle, of from 5 to 25 atmospheres (about 75 to 375 pounds per square inch), preferably at about 8 to 12 atmospheres (about 115-175 pounds per square inch), with the jet diameter at the point of origin or blast nozzle being about 1 millimeter ($\frac{1}{32}$ inch) per ton of charge, and with the point of origin or blast nozzle spaced from the bath surface from at least 150 millimeters (about 6 inches) up to about 2000 millimeters (about 80 inches), produces a sufficiently high reaction velocity of the oxygen with the bath constituents to insure the development of autogenous heat at a rate sufficient to provide the heat required for completion of the refining in a minimum of time, consistent with controlled temperature and control and development of other necessary and required process conditions, such as fluid slag, avoidance of over-oxidation (undue loss of iron to the slag), and avoidance of slopping. The process conducted under these conditions avoids a deep penetration of the oxygen gas into the molten bath which seriously impairs refractory life

at the bottom of the refining vessel. In addition, the impingement area of the high purity oxygen on the central portion of the bath isolates the refractory walls of the refining vessel from the extremely high temperatures which are developed by the direct reaction of the oxygen and the molten metal.

It has also been found, according to the invention, that the utilization of suitable design of reaction vessel and the use of the proper amount of material charged results in a ratio of the depth of the bath to the surface area of the bath which augments the protection afforded to the refractory lining of the refining vessel and is also beneficial to the progress of the refining reactions to produce finished steels of low impurity content comparable to those produced by the basic open-hearth process. In carrying out the process of high purity oxygen refining of a molten bath of pig iron, the refining vessel is of such design and the charge is of such amount that the ratio of the depth of the molten bath in meters to the surface area of the molten bath in square meters should be from about 1 to 5 to about 1 to 28 in refining vessels of various design or in terms of the ratio of depth to diameter of a circular bath between 1:2.5 and 1:19. In other metallurgical processes to which the present invention is adapted substantially similar ratios may be used.

Although it is not intended to limit the present invention to any specific theory of action or mechanism, it is believed that application of the oxygen jet substantially vertically or approximately vertically upon the central portion of the bath surface brings about a flow in the molten metal from the center of the surface of the bath downwardly and then along the bottom of the refining vessel, and upwardly at the sides of the vessel to the surface of the bath, so that portions of the unrefined metal are continuously presented to a localized center of direct oxygen reaction with the bath metal, while reacted or oxidized portions of the bath move away from this reaction center. This apparent circulation of the molten material is facilitated by shaping of the bottom of the device in its refractory lining in a uniformly curved design, preferably hemispherical or similar shape, so as to offer the minimum of resistance to the circulation.

Due to the very high affinity of oxygen for iron, initial contact of the high purity oxygen jet with the molten metal bath causes a rapid combination of oxygen and iron to form FeO in the confined central reaction zone. This is demonstrated by ignition of the oxygen and the propagation of a visible flame within the first minute of blowing. This reaction, together with oxidation of impurity elements, such as silicon and manganese, develops extremely high temperatures in the zone of direct oxygen contact with the molten metal which approach the boiling point of iron, as demonstrated by the evolution of a fume containing iron oxide and manganese oxide. A portion of the iron oxide goes to the slag with the other oxidized elements and a portion diffuses into the bath under the influence of the bath circulation, so that within the first three minutes of the blowing vigorous carbon combustion is initiated due to the high temperatures developed by these reactions. The ensuing reaction of carbon with the FeO and directly with the oxygen gas in the confined direct oxidation zone causes rapid formation of carbon monoxide and the formation of this CO causes a strong boil or agitation of the bath, which augments the bath circulation to continuously present unrefined metal to the oxygen gas reaction zone and to create a slag-metal emulsion. The oxygen jet thus contacts the emulsion of bath and slag components which presents a larger reaction surface and causes the refining reactions to progress rapidly although the oxygen jet does not penetrate deeply into the molten metal bath and is confined to an impingement area at the central portion of the bath surface. This vigorous boiling action is opposed by the pressure of the oxygen jet only in the area of impingement, and outside of this area it represents primarily endothermic

reduction of FeO by carbon to form the evolved carbon monoxide, which reaction thus effectively encompasses the zone of direct oxygen reaction at which the highest temperatures prevail affording a maximum measure of protection to the refractory lining of the refining vessel.

In conducting the process in the manner set forth above, the advantage of exceptionally high refractory life is obtained. For example, in refining of pig iron having the following chemical composition: carbon 3.8-4.2, silicon 0.6-1.3, manganese 1.4-2.2, phosphorus 0.120-0.250, and sulfur 0.045 max., and a slag having the following composition SiO₂ 12-17%, CaO 38-44%, MgO 5-10%, MnO 9-13%, P₂O₅ 1.2-1.8%, and Fe 12-17%, in a 30 ton converter, the average durability of the refractory is over 200 heats (foregoing in percentages by weight). By comparison, in basic Bessemer practice utilizing air rather than high purity oxygen, the removable converter bottom must be relined after only 35 to 60 heats. In addition, the refractory life obtainable by the process of the invention surpasses that obtained in normally operated open-hearth practice in that in refining of a normal charge by basic open-hearth about 36 lbs. of refractory brick is consumed per ton of steel produced to which must be added some 40 pounds of sintered dolomite for fettling operations, whereas total refractory consumption in the instant process is only about 24 lbs. per ton of steel produced. This advantage is even greater when compared to oxygen lancing in an open-hearth which accelerates refractory consumption.

The further advantage of high oxygen efficiency is obtainable according to the process of the invention when the oxygen jet impinges on the central portion of the molten bath surface from directly above, that is, approximately vertically. Oxygen efficiencies calculated on the basis of total oxygen input compared to oxygen consumed in the bath reactions is approximately 95%. This is demonstrated by an average oxygen consumption of only 57 normal cubic meters (measured at standard conditions of temperature and pressure) per ton of steel including oxygen consumption for heating the converters after relining. This compared with calculated or theoretical oxygen requirements for the refining of the various pig irons blown to steel analyses set forth below represents about a 95% efficient utilization of oxygen. In addition, analyses of waste gases effluent from the converter indicate that the carbon in the instant process burns almost 100% to carbon monoxide, the analyses showing on the average over 90% CO and less than 10% CO₂, indicating that the oxygen input is not lost by burning with the carbon monoxide above the melt within the refining vessel, as in the case of low angle impingement from tuyeres positioned in the side walls of the refining vessel. Moreover, this is a distinct advantage in the instant process, since the reaction of the oxygen with the melt provides more than sufficient heat for the refining, and additional heat by burning of the carbon monoxide to carbon dioxide above the melt is to be avoided. The potential heat units in the effluent carbon monoxide may be utilized in various ways by subsequent burning.

As above mentioned, it is a characteristic of the process of the invention that in the confined zone of direct oxygen reaction at the surface of the molten metal bath, the oxidation products of the impurities in the pig iron, such as silicon and manganese, as well as the oxidized iron form an early fluid slag which is always very rich in oxides, that is, highly oxidizing. With the formation of the slag-metal emulsion, the iron oxide reacts with the carbon present in the bath, primarily outside of the direct oxygen-metal reaction zone, and since such slag-metal reactions are endothermic, the molten bath is maintained cooler in the vicinity of the walls of the refining vessel or converter. For example in the formation of one kg. of FeO, by direct oxidation with the oxygen jet and absorbed as iron silicate into the slag, 80 kg. calories of heat are developed. An equal amount of heat is absorbed outside

of the confined central zone of direct oxidation as the FeO (as silicate) is reduced by the carbon in the bath, as one example of slag metal reactions occurring during the blowing.

This formation of an early highly oxidizing fluid slag is of particular value in basic refining when the process is applied to pig iron of analyses used in ordinary open-hearth practice, which would not be amenable to refining by either the acid Bessemer process due to the phosphorus content, or the basic Thomas process due to the lack of sufficient phosphorus. With the rapid heating of the slag cover and metal bath, the proper amounts of lime or lime supplying substance, such as limestone, may be added at the beginning of the blow and during the blow to insure formation and maintenance of a slag of sufficient basicity. Thus, the early fluid, basic and highly oxidizing slag formed provides an accelerated rate of phosphorus and sulfur removal from the bath, leaving the finished steel very low in both elements. With normal open-hearth pig irons having phosphorus contents ranging from about 0.1-0.35%, and even higher, e. g., 0.85% P, and with correct lime additions, final phosphorus contents not higher than about 0.025% and as low as 0.010% are obtained by the time the carbon end point is reached with only a single slagging operation. With sulfur contents in the pig iron of from 0.045 to 0.08%, the sulfur is decreased to 0.02-0.025%, and on the lower range of sulfur in the pig iron to values as low as 0.012%. In usual operations, from 1 to about 4.5% lime is charged to obtain the foregoing result, depending upon the phosphorus content in the pig iron. In addition, all of the lime requirement may be added during initial charging before blowing is started, particularly where the silicon content of the pig iron, which is one of the first oxidized elements, is sufficiently high. On the other hand, the lime may be charged in increments during the blow, but with a sufficient amount initially charged to provide a basicity adequate to absorb the phosphorus.

In the normal range of phosphorus in pig iron of basic open-hearth quality from about 0.1 to 0.35%, the required slag volume including the lime charge is advantageously much lower than the slag volume in the bottom blown basic Thomas process. The iron content of the slag varies from about 9 to 18%, with generally higher FeO content in the slag at higher phosphorus contents in the pig iron, and also at lower manganese contents. Accordingly, the lower percentage of slag, for example, 11 to 12% compared to about 22% in the Thomas process results in comparable or lower total iron content lost to the slag, even though the FeO content of the slag may be higher than the usual 10% in the basic Thomas process.

The process in its preferred embodiment utilizes high purity oxygen, by which the term is meant oxygen gas analyzing at least 97% O₂. For minimum nitrogen content in the finished steel of at least 98% oxygen and preferably 99% or higher should be utilized. The frequency curves based on produced steel analyses indicate that oxygen of at least 98% purity provides a peak or maximum at a nitrogen content of from 0.002 to 0.003%, with 95% of all heats blown showing a nitrogen content of 0.004% or less.

The vigorous boil, above mentioned, continues up to the carbon end point, and together with the induced circulation of the bath metal toward and away from the central zone of direct oxygen reaction, effectively counteracts any tendency to overoxidation of the bath. When the flame dies and carbon combustion is completed, the bath becomes relatively quiet and intimate contact between slag and metal bath ceases. The turbulence of the bath and slag due to the oxygen stream impinging from directly above is insufficient to cause continuance of oxygen-metal reactions. As a result, steels blown by the process of the invention do not suffer from the deteriorating effects of high oxygen (FeO) contents. Direct oxygen determination by the hot extraction method yielded oxygen con-

tents of 0.04% maximum for heats that were blown to a carbon end point of from 0.05 to 0.10% C. Thus, the oxygen content of steels produced by the high purity oxygen blowing process compare very favorably with oxygen contents of basic open-hearth steel in the same carbon range, and are definitely lower in oxygen content than bottom blown Bessemer steels using air, oxygen enriched air, oxygen and steam, or other gas mixture.

As in the basic Bessemer process, the silicon is rapidly eliminated. However, in contrast to the basic Bessemer process, the use of high silicon charges presents no problem due to the fact that slopping is not encountered in the process of the invention to any degree similar to that in the bottom blown Bessemer practice. In fact, higher silicon pig irons actually are advantageous in the high purity oxygen blowing due to the heat producing effect of this element in the early stages of the blow with the result that higher scrap charges can be made in the process.

Regarding scrap additions, the process advantageously may utilize scrap charges of up to about 30%, depending primarily upon the silicon content of the pig iron, and also on the temperature of the hot metal charge. For lower ranges of silicon, such as 0.3 to 0.7% scrap charges of from 10 to 15% are permissible. With silicon in amounts from 1 to 1.2%, scrap charges of 20 to 25% may be utilized.

In general, the manganese content of the fully blown metal and of the slag increases with the total manganese content (pig iron and scrap). However, it is a characteristic of this oxygen steel making process that the high temperatures developed in the reaction zone between the bath metal and the slag cause a rereduction of manganese from the slag into the bath during the latter portion of the refining period. In the last minutes of the blow, the manganese content in the bath again decreases as the carbon drops to its final value, that is, at a normal end point of 0.04–0.06. Accordingly, the manganese content in the finished steel and in the slag is subject to some control, and is governed by slag composition and volume, temperature and final carbon content. With the use of a minimum amount of slag rich in iron oxide, for example only 70 kg. per ton of steel, the amount of loss of manganese to the slag by burning may be considerably reduced. As above mentioned, extensive tests have shown that the amount of slag can be kept considerably lower than the conventional pneumatic process, such as the Bessemer and Thomas processes. Under these conditions of high developed temperature in the refining process and low slag volume with high iron oxide content, a finished steel containing manganese in quantities at least 10 times the amount of carbon, for example, 0.6 to 0.8 Mn at carbon end points of 0.05% are obtainable. Accordingly, it is possible to pour rimming steels down to relatively very low carbon contents without any addition of manganese and deoxidizing agents. Under actual operating conditions the best practice for production of standard grades is to refine down to 0.06–0.08% C and to recarburize in the ladle. This practice results in a manganese content of from 0.6 to 0.8 and eliminates the necessity for manganese additions to conform with the usual analysis specifications. The above manganese content easily compares with the conventional composition of rimming low-carbon open-hearth steels, in fact such analyses are near the upper limit of the range. It is also possible to catch the heat at higher carbon contents, so that the resulting content in manganese will be of a higher order than is normally encountered in rimming open-hearth steels of identical carbon content. Thus, it is possible to produce rimming low carbon high purity oxygen blown steels of a predetermined strength which is based on an inherently higher manganese content of the heat.

It has also been found that a steel containing 0.1% carbon and as high as 1.5% manganese may be obtained, for example by the addition of ordinary blast furnace

ferromanganese, e. g., 15 kg. of 48% blast furnace ferromanganese per ton suffices, and results in an increase of about 0.05% in the carbon content. In normal steel making operations it was not previously possible to obtain such steels without the use of expensive refined ferromanganese products. Steels of such analyses, not only exhibit increased toughness and yield strength but other properties, such as pressure weldability, are improved.

To exemplify the high manganese recovery in the steel without ferromanganese additions after the blow, the results of the following heats are provided. As indicated above, since the manganese content, under otherwise equal conditions, increases in the finished steel with increase in pig iron, it is to be noted that particularly high manganese content pig irons were employed. Nevertheless, it is evident that due to the extremely high temperatures developed in this high purity oxygen process, a manganese recovery is possible which cannot be reproduced in known processes.

Heat No. 1.—Pig iron analysis: 4.16% C, 3.02% Mn, 0.14% Si, 0.074% P, 0.040% S. Last converter control test (without ferromanganese or deoxidizers): 0.09% C, 0.96% Mn, 0.005% Si, 0.039% P, 0.013% S, 0.007% N₂.

Heat No. 2.—Composition of pig iron: 4.30% C, 3.24% Mn, 0.33% Si, 0.072% P, 0.034% S. Last converter control test (without ferromanganese or deoxidizer): 0.08% C, 1.02% Mn, 0.005% Si, 0.037% P, 0.010% S, 0.004% N₂.

Heat No. 3.—Composition of pig iron: 4.21% C, 2.88% Mn, 0.27% Si, 0.076% P, 0.044% S. Last converter control test (without ferromanganese or deoxidizer): 0.07% C, 0.93% Mn, 0.005% Si, 0.037% P, 0.012% S, 0.004% N₂.

From the foregoing test, it may be seen that manganese recovery at least 10 times as high as the final carbon content in the finished steel is obtainable by the process of the invention utilizing pig iron having manganese on the order of 3%.

In regard to output, the combustion of the impurities of the pig iron and the iron content of the slag total a loss of about 8.0% with an additional 0.8% of iron lost in the dust fume from the process. With mechanical losses averaging about 0.8%, the percentage recovery of the refining process is approximately 90%, comparable to the yield obtainable by the basic open-hearth process. In the progress of the high purity oxygen blowing, up to about the eighth minute, oxidation of the iron progresses under formation of comparatively large amounts of FeO, which, as above stated, promotes a desirable quick liquefaction of the basic lime slag. At this stage in the blow, the slag shows maximum values of from 25–30% FeO. In the further course of the process reduction of Fe from the slag occurs which continues until the carbon content of the bath of about 0.07% is reached. The FeO in the slag decreases to about 10–12%. On further removal of carbon, the FeO in the slag again increases so that in the final slag generally an iron content averaging 14% is obtained, and only at very low carbon heats does the iron content exceed this value.

Under these known metallurgical conditions above set forth, the total oxygen requirement is calculated on the basis of oxygen pick-up of the heat during the refining period. Summation of these oxygen gas volumes required for the oxidation to complete refining indicates substantially a straight line function on oxygen input, and corresponding to this relative constancy of oxygen input, the oxygen pick-up proceeds uniformly during the blow. The oxygen input is maintained at a rate such that the speed of the refining process insures satisfactory rereduction of FeO from the slag, in the manner set forth above. In actual practice, based on experience in operation of 30 ton converters, oxygen feed rates may be maintained such that depending upon pig iron analysis, amount of scrap addition and desired finished steel analysis, the

refining to usual carbon-end points on the order of 0.05% C is completed in from about 15 to about 30 minutes, preferably 18 to 22 minutes. Flow rates of from about 4000 to 8000 cubic meters of oxygen per hour are representative of the oxygen input under these conditions.

In such exemplary commercial practice with 30 ton converters charged to 35 to 36 tons, oxygen pressures at the blast nozzle of about 8 to 10 atmospheres and oxygen jet or blast nozzle diameters of from about 27.5 to 35 millimeters (1.1 to 1.4 inches) with nozzle spacings varying from 25 to 50 inches (about 650 to 1250 millimeters) have been used, the preferred spacing being from 30 to 40 inches (about 750 to 1000 millimeters). In general, it may be stated that as the oxygen pressure and nozzle diameter are increased, the nozzle spacing is also increased, for example, as the capacity of the refining vessel and total charge is increased. Under these conditions, deep penetration of the molten metal bath is avoided, while the necessary displacement of the slag cover to maintain direct oxygen to molten metal contact is insured. However, in the unusual circumstances of an abnormally stiff slag cover, the blow may be initiated using mechanical means for penetrating the slag cover to establish oxygen to metal contact.

It is to be noted, that in certain instances particularly where the rate of oxygen input is relatively high, that is, the total blowing time is in the lower portion of the range above stated, the pressure of the oxygen jet at the blast nozzle may be reduced in the last few minutes of the blow to reduce the rate of oxygen input, which is beneficial in supporting the inherent characteristic of the process in regard to avoidance of over-oxidation of the heat. Due to this characteristic of the process, it is generally unnecessary to utilize any deoxidizing agents such as ferromanganese and ferrosilicon in the production of semi-killed steels, and only in the production of killed steels are the conventional deoxidizers employed.

The process has as one of its major advantages the applicability to pig iron of analyses used in ordinary open-hearth practice, which would not be amenable to refining by either the acid Bessemer process or the basic Thomas process. In addition, the process is fully applicable to pig irons having analyses of the type which are normally utilized in either the acid Bessemer or basic Thomas processes. Typical illustrations of the following pig irons and the finished steels produced therefrom indicate that the process produces steels comparable to open-hearth quality from pig irons of widely varying phosphorus and silicon contents.

(1) 4.0% C, 1.5–2.0% Mn, 0.7–1.2% Si, 0.1–0.24% P, 0.05% S, and 0.01% N blown to a finished steel of the following analysis: 0.06% C, 0.35% Mn, 0.00% Si, 0.026% P, 0.025% S, and 0.0025–0.0035% N (oxygen about 98%).

(2) Pig iron analyzing 3.6–4.25% C, 1.4–3.2% Mn, up to 0.3% Si, 0.06–0.1% P, 0.04–0.07% S, and 0.01% N from which steel of the following analysis is obtained: 0.06% C, 0.35% Mn, 0.00% Si, 0.01–0.02% P, 0.022% S, and 0.001–0.002% N.

(3) Illustrative of a grade of pig iron falling between that of normal open-hearth analysis and basic Bessemer pig iron is the following: 3.61% C, 2.16% Mn, 0.46% Si, 0.856% P, 0.062% S. Blowing of such a charge of rather unfavorable chemistry by the process of the invention yielded a steel of the following composition: 0.04% C, 0.15% Mn, 0.0% Si, 0.014% P, 0.045% S. Clearly, such a pig iron would be definitely unsuitable for basic Bessemer (Thomas) process refining, and would also present considerable difficulty if used for open-hearth refining.

The accompanying drawing diagrammatically illustrates a device for carrying out the present invention. In this drawing, reference numeral 1 denotes a metallic wall and 2 the refractory lining of the refining vessel. An oxygen supply lance 3 is centrally positioned and overhung above the charge and is provided with a nozzle

3' for the introduction of the oxygen gas, inserted in an opening of the cover 4. The material charge, including molten pig iron, melted scrap, and slag forming additions, such as limestone, is indicated at 5 and the depth and diameter of the upper surface of the molten bath in the quiescent state are denoted by H and D, respectively. The lance 3 is retractable, and is provided with water cooling ducts and connections (not shown). The cooling water in actual practice is supplied to the lance at a pressure of from 4 to 6 atmospheres and the normal flow rate is about 36 to 40 cubic meters per hour. Under such conditions the temperature of the cooling water increases from approximately 14° centigrade input to a maximum of about 30° centigrade in the effluent from the lance.

In the preferred commercial practice of the invention, a converter shaped vessel with an open mouth is usually provided, through which the lance is inserted into and retracted from operating position, as indicated in the example set forth below. In this manner, suitable gas take off devices may be positioned at the throat of the converter type vessel to collect the off gases and separate the particulate fume therefrom.

The following is a detailed description of a typical operation of the process, which is not to be regarded as a limitation on the invention, but rather as a complete specific embodiment thereof.

Example 1

A closed bottom converter of normally 30 tons (metric) capacity is charged with a total of about 36 tons of metal through an open mouth. The oxygen lance is inserted through the mouth of the converter to the adjusted distance above the melt surface. The diameter of the surface of the bath with such a charge is about 5 meters and the depth of the bath about 1 meter. A typical cycle of operations is given below on a time table basis.

Hours.

7100 kg. plant return scrap charged to converter	0
29,600 kg. pig iron poured from mixer into converter having an analysis as follows: 4.04% C, 0.99% Si, 1.73% Mn, 0.153% P, and 0.045% S	0.08
Addition of 850 kg. limestone and 60 kg. bauxite	0.10–0.13
Introduction of nozzle, oxygen jet initiated at a nozzle pressure of 10 atmospheres (147 p. s. i.) with a nozzle spacing above the bath of 1000 millimeters	0.15
850 kg. limestone and 200 kg. rolling mill iron slag added	0.16
750 kg. limestone chips added in five parts of 150 kg. each	0.22–0.28
Oxygen pressure reduced to 8 atmospheres	0.30
Mouth flame transparent, nozzle withdrawn, oxygen supply turned off—end of blowing time at 19 minutes	0.34
Converter contents sampled and analyzed as follows: 0.05% C, 0.00% Si, 0.31% Mn, 0.024% P, 0.02% S	0.35
Slag drawn off	0.35–0.39
150 kg. Spiegel iron added to contents of converter	0.39
Slag remaining in converter stiffened with 30 shovelfuls of limestone	0.39–0.42
Steel poured into pan, temperature measured at 1575° C., 6 kg. electroflour added to pan	0.42–0.45

Final test analysis on pouring into ingot mold was: 0.07% C, 0.32% Mn, 0.022% P, 0.020% S, 0.0035% N. Oxygen consumption 1950 cubic meters. This oxygen consumption is about 54 cubic meters (measured at standard conditions) per ton and compares with a theoretical oxygen requirement of 51 cubic meters (measured at standard conditions), and therefore indicates an oxygen efficiency of 95%.

The process of the present invention may be also applied to the production of metals, for example, production of steel, from solid starting materials. In the production of steel, pig iron and scrap iron, and if desired certain alloys and fuels, such as coal or wood, are introduced into the refining vessel. As materials for producing heat for melting, coke, ferrosilicon, calcium carbide, aluminum alloys and the like, which are converted into slag or gaseous products at the prevailing refining temperatures can be added. The total amount of the starting material mixture may be introduced as a single charge prior to initiation of the melting, or may be gradually fed in small incremental amounts. Sufficient fuel should be present for producing the combustion necessary to provide the heat of fusion of the solid charge. After ignition of the fuel, melting of the initial mixture is brought about by the action of the oxygen jet.

The melting procedure is started by means of an ignited body which is introduced immediately prior to the initiation of blowing of the oxygen jet, and is preferably positioned at that portion of the solid charge where the oxygen jet comes in direct contact therewith.

Thus, according to the present invention, a steel may be produced with a minimum consumption of fuel, for foundries or rolling mills, by melting the iron to be converted into steel with low grade fuel and a high purity oxygen jet blast, for example, in cupola furnace, or in a converter type vessel itself, and subjecting the thus melted solid charge to high purity oxygen refining in the above described manner in a suitable refining vessel, such as a converter. In carrying out such a melting and refining treatment with high purity oxygen, the energy consumption is extremely low, amounting to only 100 cubic meters of oxygen (measured at standard conditions) per ton of steel produced. Of course, as indicated above in the refining of primarily hot metal charges constituting pig iron with analyses as set forth above to refine steels of 0.05% carbon content and analyzing as above indicated, the average oxygen consumption is only about 57 cubic meters per ton (measured at standard conditions).

The present process of surface blowing with high purity oxygen is also applicable to the desulfurization of coprous materials and to the production of glass in the converter with the use of sodium chloride. Furthermore, the process is applicable to the treatment of blast furnace slag to the elimination of sulfur and conversion of slags into melted cement or glass-like materials of the type used for the manufacture of slag wool.

This application is a continuation-in-part of my co-pending application Serial No. 206,147, filed January 16, 1951, now abandoned. It will be understood that the present invention is not limited to the specific materials, steps and other specific details described above and may be carried out with various modifications without departing from the scope of the invention as defined in the appended claims.

We claim:

1. Method of refining molten impure iron in the presence of a slag in a vessel having a refractory lining by blowing with oxygen, which comprises discharging a stream of oxygen vertically downwardly through the slag layer onto and below the surface of the bath at the central portion thereof, to an extent to avoid material agitation of the bath by the oxygen stream, the contact of the oxygen with the bath resulting in reaction of the oxygen with a portion of the iron and with the oxidizable impurities of the bath in a localized reaction zone spaced a substantial distance from the refractory lining, the reactions in said zone resulting in refining of the iron and gas evolution and in the production of high temperature in the reaction zone away from the refractory lining, said reaction producing a circulatory movement in the molten metal, which circulatory movement brings those portions of the molten metal bath which are remote from the reaction zone into the reaction zone whereby those portions are subjected to said reaction with minimum injury to the refractory lining.
2. The gaseous oxygen process set forth in claim 1 in which the oxygen is blown into said vessel under pressure in a range between about five and about twenty-five atmospheres above normal atmospheric pressure.

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