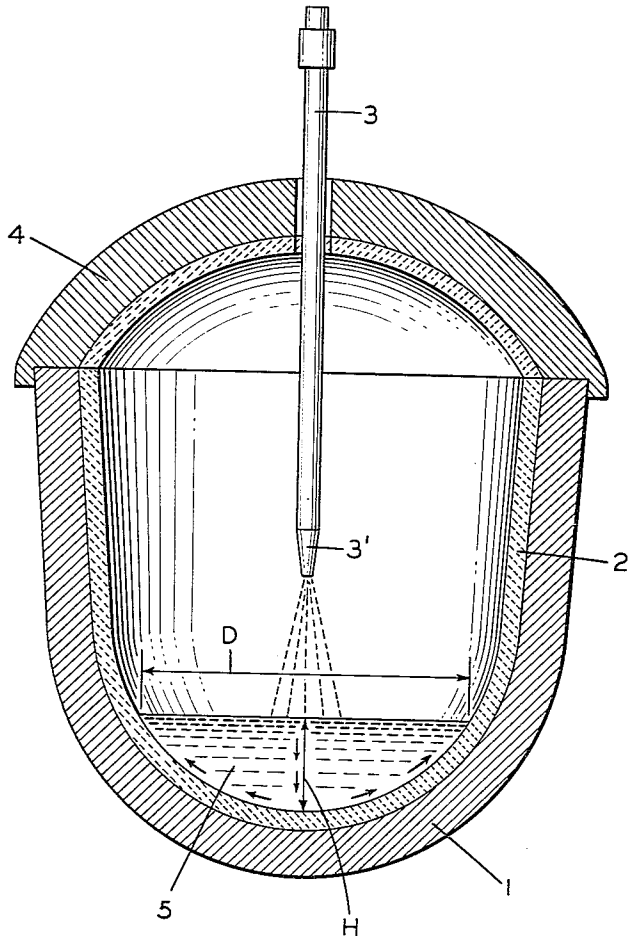
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PROCESS FOR REFINING PIG IRON

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# PROCESS FOR REFINING PIG IRON

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The invention relates to a process for refining pig iron in a converter or other suitable vessel, in which oxygen or other oxidizing gases or oxygen-containing gas mixtures are blown against the bath surface from above and the heat quantity required for the process is produced by the reaction of the oxygen with the impurities in the molten pig iron bath.

More particularly, the invention relates to a new process for refining primarily hot ferrous metal charges, for example, predominantly molten pig iron, with a jet of high purity gaseous oxygen directed downwardly through the slag cover onto the surface of the molten metal bath, generally at the central portion thereof, to produce steel at least equal in quality to basic open hearth steel, particularly with reference to nitrogen, oxygen and phosphorus content. The heat required for the refining is autogenous, being produced primarily by reaction of the oxygen gas with the impurities in the molten pig iron.

Processes for surface blowing with air or oxygen have been suggested previously as a possibility of refining primarily hot metal charges.

In the well-known Tropenas converter utilized in foundries, and suitable only for blowing relatively small metal charges, the air is blown onto the surface of the metal in an acid lined converter through tuyeres positioned above the melt level. In such a process, a large quantity of the heat developed is produced by combustion of the evolved carbon monoxide to carbon dioxide within the vessel. Thus, the Tropenas converter produced a much hotter blown metal from a charge of similar composition than can be attained in the bottom blown Bessemer converter, but this is necessarily at the expense of the oxygen efficiency in terms of total oxygen input compared to the theoretical oxygen consumption required in the refining reactions. It has been demonstrated that this burning of the carbon monoxide to carbon dioxide within the converter is caused by the high amount of available oxygen in the converter free space due to the low angle of inclination or impingement of the air jets on the melt surface.

When oxygen enriched air or oxygen is substituted for ordinary air in the above-mentioned type of surface blown process, it has been demonstrated that the low angle of impingement of the jet upon the melt surface produces excessively high temperatures above and at the melt-slag interface on the side of the vessel opposite the tuyeres or oxygen inlet so that a substantially rapid deterioration of refractory occurs. In addition, with an oxygen jet, the loss in oxygen efficiency due to this deflection of the gas from the melt surface cannot be tolerated, and further, the increase in temperature due to burning of a relatively large proportion (40 to 50 percent) of the evolved carbon monoxide to carbon dioxide above the melt is undesirable in further contributing to the short refractory life. The heat produced by the oxygen-molten metal reaction is more than sufficient to provide the necessary heat for completion of the refining reactions to the desired steel analysis, and for teeming.



In still other proposed surface blowing processes, intensive mixing of the oxygen jet and the molten metal has been deemed imperative. Thus, a supersonic velocity of the oxygen jet was proposed so that the jet would impinge upon the melt surface with such an impact energy that the jet would deeply penetrate the molten pig iron bath. As a result of such process, the high temperature oxygen-pig iron reactions were essentially uncontrolled, and proceeded at velocities which induced excessive temperatures and lack of control over the refining process in general so that over-oxidation of the blow metal resulted. In addition, the refractory bottom of the refining vessel was subject to rapid deterioration.

Attempts to bottom blow with high purity oxygen resulted in destruction of the refractory bottom in one heat. Accordingly, the invention is directed to an economical, commercially feasible process for refining primarily hot metal charges with high purity oxygen capable of producing a 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 composition.

It is accordingly 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 gaseous oxygen 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 melt 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 ordinary basic open-hearth practice, as well as those of higher silicon and phosphorus contents 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 25 minutes for charges of from 30 to 40 tons to carbon end points of 0.05 percent or below. These and other objects and advantages of the invention will be apparent from the following detailed description of the process.

The process of the invention generally comprises refining the molten pig iron metal in a converter-type or other suitable vessel with a high purity oxygen jet impinging on the melt surface, preferably at the central portion thereof, from directly above by means of a blast nozzle, or other suitable gas jet-producing means, under controlled conditions of jet impact pressure, hereinafter defined, to supply to the molten metal the required amount of oxygen for refining to the desired steel analysis, and to produce autogenous heat sufficient to insure completion of the refining and adequate temperature in the refined charge for subsequent handling.

The invention realizes the foregoing objects and other advantages, and in particular the avoidance of an oversupply of oxygen by an intentional limitation of the energy of the jet impinging on the bath surface, and essentially resides in that the pressure of the blast jet on a surface having from the blast nozzle a distance equal

to the distance of the bath surface from the blast nozzle is kept below 0.75 kg./sq. cm., (about 10.5 p. s. i.), preferably below 0.5 kg./sq. cm., (about 7 p. s. i.).

The foregoing expression for pressure measurement refers to the average impact pressure of the blast jet measured on a reference surface outside of the converter with the blast nozzle spaced from the reference surface at a distance equal to the spacing of the blast nozzle from the molten metal bath surface under operating conditions in the refining vessel. It is to be understood that the actual impact pressure of the oxygen jet upon the molten metal bath surface is not necessarily equal to the impact pressure measured on the reference surface. This expression, however, empirically determined, fully defines the limit to be observed on the impingement pressure of the oxygen jet on the bath surface for any given spacing of the blast nozzle, nozzle design, oxygen pressure at the blast nozzle and nozzle orifice diameter utilized in the process for supplying the calculated volume of oxygen at the rate required to complete the refining process within the predetermined time period. This expression eliminates the necessity of defining the characteristics of the oxygen jet in terms of factors which may be substantially varied, such as the aforementioned nozzle design, nozzle orifice diameter, and oxygen pressure at the nozzle, changes of which within rather wide limits are permissible, while still maintaining the impact pressure of the jet within the limit above-defined, and supplying the requisite quantity of oxygen to the molten metal charge at the proper rate.

The invention is based on the recognition that to ensure a perfect development of the reaction it is not necessary at all to conduct the blast jet against the bath with a kinetic energy so high that the blast penetrates deeply into the bath, but that it is sufficient when the blast contacts the bare metal surface of the bath to enable the oxygen to react with the metal. When a slag cover is utilized, the slag layer must be initially displaced or penetrated in the area of impingement. This is normally accomplished by the oxygen jet itself, and this function sets the lower limit for the energy of the oxygen jet, which may be as low as 0.75 pound per square inch (about 0.05 kg./sq. cm.). Where other means than the oxygen jet are employed for initial slag displacement impact pressures as low as about 0.28 pound per square inch (about 0.02 kg./sq. cm.) may be used, although this protracts the blowing time. The upper limit for the energy of the oxygen jet, however, is set thereby that the blast should not, or at least not deeply, penetrate into the metal bath, because it has been found by exhaustive tests that a deep penetration of the blast into the bath causes an oversupply of oxygen impairing the quality of the steel being produced, or causing excessive refractory wear on the refractory bottom. Thus, in accordance with the invention, the velocity of the jet impinging on the bath surface should be determined approximately in correspondence with the velocity of the reaction of the oxygen with the bath so that the oxygen required for the reaction is available whereas an oversupply of oxygen is avoided. It has been found that these conditions are fulfilled if the surface pressure of the blast jet on the bath surface is such that it corresponds to an impact pressure below 0.75 kg./sq. cm., preferably below 0.5 kg./sq. cm., measured on the reference surface outside of the converter at equal spacing of the blast nozzle, as set forth above. By conducting the blast process in accordance with the invention a subsequent treatment of the bath, to improve the quality, such as addition of ferromanganese, is generally rendered superfluous, with resulting savings in expense and time. The action of the jet on the bath surface is determined by the shape of the blast jet, by the distance of the nozzle from the blast surface, and by the velocity with which the jet escapes from the nozzle. Where the blast nozzle consists of a Laval nozzle (venturi-shaped), the nozzle velocity of the jet may



be incerased within wide limits beyond the velocity of sound. However, this is not necessary at all for the process according to the invention. The velocity of sound, however, is reached in most cases without any special shaping of the nozzle. An ordinary nozzle or lance of straight line configuration may be utilized.

Suitable means for water cooling the lance or blast nozzle is provided since it is exposed to the high temperature existing within the refining vessel.

In accordance with the invention the jet may be conducted against the bath surface in the shape of a cone, the diameter of which at the level of the quiet bath surface is at least three times, suitably at least five times the orifice diameter of the nozzle. With such a ratio between the diameters, the condition can be fulfilled that the blast jet enters into reaction with the bath without substantially deeply penetrating into it.

The limitation of the energy of the blast jet impinging on the bath surface may be achieved by increasing the distance of the blast nozzle from the bath surface. In accordance with the invention the blast nozzle may be arranged so that the distance of its orifice from the bath surface when quiet is at least 150 mm. (about 6 inches), and not substantially in excess of 2000 mm. (about 80 inches), and preferably above 250 mm. (about 10 inches), through the operating ranges of nozzle pressures of from about 3 to 20 atmospheres and nozzle sizes the area of the smallest interior nozzle opening being selected to provide 32 square millimeters (about 0.5 square inch) per metric ton of metallic charge. By this measure it becomes possible to blow the gas at a higher velocity without exceeding the surface pressure on the bath surface beyond 0.75 kg./sq. cm. or 0.5 kg./sq. cm. Therefore, the nozzle cross section may be smaller so that smaller quantities of cooling water are sufficient for the nozzle, while the flow of gas is maintained at the same rate. Thereby, on the one hand, the cooling of the nozzle is facilitated because the quantity of cooling water is reduced, and on the other hand, owing to the larger nozzle spacing from the bath surface a smaller cooling effect is required because the nozzle is highly protected already by its larger distance from the bath surface. Tests have shown that in contradistinction to the previous assumptions the converter lining above the bath surface is not excessively affected even with such nozzle distance and that a fully sufficient action of the blast jet on the bath surface appears to be assured without involving increased losses of the oxidizing gases. In exemplary commercial practices with thirty ton converters utilizing oxygen pressures of about 8 to 10 atmospheres and nozzle diameters of from about 27.5 to 40 mm. (1.1 to 1.6 inches), nozzle spacings varying from 25 to 60 inches (about 650 to 1500 mm.) have been used, the preferred spacing being from 30 to 50 inches (about 750 to 1250 mm.). In general, it may be stated that as the oxygen pressure and nozzle diameter are increased, nozzle spacing is increased.

Since oxygen has a very high affinity to iron, the contact of oxygen with the bath causes a rapid combination of oxygen and iron to form FeO, part of which goes to the slag and part enters the bath by diffusion. The elements accompanying iron, that is, silicon, manganese and phosphorus, are also oxidized, whereby the bath is intensively warmed, temperatures in the direct oxidation reaction zone approaching the boiling point of iron. Subsequently the FeO formed reacts with carbon to form CO and the formation of CO causes a strong agitation of the bath by which unrefined metal is continuously presented to the oxygen gas reaction zone, and a slag-metal emulsion is formed. The stream of oxygen contacts the emulsion of bath and slag components so that the reactions are distributed over a large surface of iron and are accelerated. By the formation of the emulsion having a large surface, the rapid progress of the process is enabled though the jet blast does not penetrate deeply into the metal bath,

and the initially high FeO content of the slag is rapidly diminished.

Owing to the high affinity of oxygen with iron and the elements accompanying it in the pig, the jet blast conducted in the manner according to the invention consumes by performing its oxidizing work before it can deeply penetrate into the metal bath. By the formation of the oxides, extremely high temperatures are generated locally. The reactions taking place at these high temperatures have not been definitely explained yet scientifically. Tests have shown that at the beginning of the blast process a combustion of iron takes place to form FeO. The emulsion is not formed at the beginning of the blast process; this can be shown by the fact that the bath level initially does not rise, although a short visible flame is formed immediately after start of blowing. The emulsion will be formed only when with rising temperatures the rapid combustion of carbon starts, usually about the second or third minute with starting of the carbon boil. Only from this time will the rapid development of the entire process begin. An oversupply of oxygen, therefore, will have adverse effects primarily during the further development and in the final phases of the blast process because on the one hand the bath surface available for the reaction will not have been increased before by the formation of the emulsion, and because on the other hand any over-oxidation of the bath taking place only initially may be compensated to the highest possible degree during the later stages of the blasting. Therefore, in accordance with the invention, it is possible, if desired, to start the reaction between the oxygen of the blast jet and the bath vigorously and to reduce only subsequently the energy of the blast jet so that the surface pressure of the blast jet on the bath surface will correspond to an impact pressure on the reference surface below 0.75 kg./sq. cm. or below 0.5 kg./sq. cm., as set forth above.

The advantages of high oxygen efficiency and high refractory life are obtainable according to the process of the invention when the oxygen jet impinges on the central portion of the bath surface from directly above, that is, approximately vertically with specific surface pressures, as above set forth. Oxygen efficiencies calculated on the basis of total oxygen input compared to oxygen consumed in the bath reactions is approximately 95 percent. This is demonstrated by an average high purity oxygen consumption, when refining pig iron of basic open hearth analysis of only 57 normal cubic meters (measured at standard conditions of temperature and pressure) per ton of ingots 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 percent 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 percent to carbon monoxide, the analyses showing on the average over 90 percent CO and less than 10 percent $CO_2$, 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. 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.

In conducting the process in the manner set forth above, the zone of direct oxygen reaction is effectively confined to the central portion of the bath, and the endothermic reduction of FeO by carbon to form CO encompasses this zone affording protection to the vessel lining. In this regard, the blowing conditions are maintained such that the diameter of the area of jet impingement is at least one twenty-fifth of the total bath surface diameter, and preferably one tenth, while it should not substantially exceed about one fifth. When operating within the limits of surface pressure set forth above, preferably a diameter of the impingement area of about one tenth the bath surface diameter should be observed. Thus, exceptionally high refractory life is obtained at high production rates. 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 $SiO_2$ 12–17 percent, CaO 38–44 percent, MgO 5–10 percent, MnO 9–13 per cent, $P_2O_5$ 1.2–1.8 percent, and Fe 12–17 percent, 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, 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, or less.

The process has as one of its major advantages the applicability to pig iron of analyses used in ordinary open-hearth practice, for example, within the composition limits above set forth, 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. In addition, the process is fully applicable to pig irons having analyses of the type which are normally utilized either by the acid Bessemer (high silicon-low phosphorus) or the basic Thomas converter processes (high phosphorus).

In the usual operation of the process, it is preferred to employ oxygen of a purity of at least 98 percent (by volume), preferably above, since this results in negligible nitrogen pick-up in the metal bath as shown by frequency curves based on the produced steel analyses indicating a peak or maximum at a nitrogen content of from 0.002 to 0.003 percent, with 95 percent of all heats blown showing a nitrogen content of 0.004 percent or less.

In addition to the low nitrogen contents, the steel produced is characterized by its high purity with respect to the undesired elements phosphorus, sulfur, and oxygen.

In application of the process to basic refining, the effective heating of the slag cover and metal bath from above, the FeO formed initially absorbed into the slag, and the boiling action setting in at an early stage of the process, are highly beneficial in that they promote the formation of an early fluid and highly oxidizing slag relatively high in reactive lime. This condition provides an accelerated rate of phosphorus and sulfur removal from the bath, leaving the steel very low in both elements. With normal open hearth pig irons having phosphorus contents ranging from about 0.1–0.35 per cent, and with correct lime additions, final phosphorus contents not higher than about 0.025 percent, and as low as 0.010 percent are obtained at the time the carbon end point is reached with a single slagging operation. With sulfur contents in the pig iron of from 0.045 to 0.08 per cent, the sulfur content is decreased to 0.2–0.025 per cent, and on the lower range of sulfur in pig iron to values as low as 0.012 percent.

In addition, the process has proven itself capable of removal of phosphorus to well below 0.05 percent at the desired carbon end point on basic Bessemer pig iron having phosphorus contents from 1.5 to about 2 percent.

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 over-oxidation 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 low impact pressure of 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 contents of 0.04 percent maximum for heats that were blown to a carbon end point of from 0.05 to 0.10 percent 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.

Regarding scrap additions, the process advantageously may utilize scrap charges of up to 30 percent, depending primarily upon the silicon content of the pig iron and the temperature of the hot metal. For lower ranges of silicon, such as 0.6 to 0.7 percent, scrap charges of 12 to 18 percent are permissible. With silicon in amounts from 1 to 1.2 percent, scrap charges of 20 to 25 percent may be utilized.

In the normal range of phosphorus in basic open hearth pig iron of about 0.1 to 0.35 per cent, the required slag volume with from 3 to 8 percent lime charge is advantageously much lower than the slag volume in the bottom blown basic Thomas process. The iron content of the slag ranges between about 9 to 17 percent. On high phosphorus pig iron of the basic Bessemer type, due to the required increase in slag volume, the total iron content lost to the slag may be increased when blowing to a low phosphorus percentage of 0.015–0.02 percent. Thus, in treating "steel making" pig iron, i. e. pig iron of basic open hearth analysis, the slag volume amounts to only from 8 to 16 percent and averages 14 percent iron. Consequently, the iron loss does not exceed normal values, for example only about 2 percent per ton of steel.

In regard to output, the combustion of the impurities of "steel making" pig iron and the iron content of the slag total a loss of about 8.0 percent with an additional 0.8 percent 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 percent comparable to the yield with the basic open hearth process.

While observing the limits of impact pressure of the jet upon the melt surface, as above set forth, the oxygen flow rate in the process is maintained to provide an average such that blowing is completed and the carbon end point reached within a time period of from 12 to about 30 minutes, preferably 17 to 20 minutes, depending, of course, upon the particular pig iron charge, scrap to hot metal proportions, and the specific steel analysis to which the metal is blown.

The accompanying drawing diagrammatically illustrates a device for carrying out the process of the present invention. A converter type vessel with a closed bottom is shown having a metallic wall **1** and a refractory lining **2**. An oxygen supply lance **3** is inserted through an opening of the cover **4** of the refining vessel. The lance is centrally positioned and overhung above the charge, being provided with a nozzle **3'** for directing a jet of oxygen gas onto the surface of the charge. The molten material charge is indicated at **5**, the depth and diameter of the surface of the molten material being denoted by H and D, respectively.

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 converter of symmetrical design with a centrally located mouth, through which gases are passed directly into a stack and provided with a removable bottom is utilized, the outside diameter of the converter being about 14 feet and overall height of about 20 feet. The converter provides bath dimensions of about 8½ feet inside diameter having a bath area of approximately 57 square feet, and a bath depth of about 3 feet. An overhung movable water cooled oxygen lance is connected to a high purity oxygen plant, producing oxygen of 99 percent purity, through an oxygen accumulator and an oxygen supply line in which a pressure reducing valve of usual type is inserted, the pressure prevailing in the said accumulator being about 355 p. s. i. In operation, the lance is inserted through the centrally located converter mouth to the adjusted distance above the surface of the charge after initial charging. As set forth below, the typical cycle of operations from charging to teeming is given on a time table basis.

| Time, Hours | |
|---|---|
| 15.30 | 2,400 kg. plant return scrap charged to converter. |
| 15.38 | 26,100 kg. hot metal charged having the following analysis: 3.73% C, 1.98% Mn, 0.12% Si, 0.075% P, 0.052% S, about 0.01% N. |
| 15.43 | Addition of 1,200 kg. burned lime, 300 kg. mill scale, and 300 kg. fire-clay bats. This material was charged from the pit side through a retractable gravity chute with the converter tilted to the charging bay side. |
| 15.45 | Positioning of jet nozzle, blowing commenced at a nozzle pressure of 128 p. s. i. (which means the pressure prevailing between the pressure reducing valve and the nozzle), with a nozzle diameter of 1.10 inches, and a nozzle spacing from the bath of 31.5 inches (800 millimeters). Within three-tenths of a minute the oxygen was ignited, and a flame of 1 to 2 meters was projected over the converter mouth. At the end of about one minute the flame was elongated to about 7 meters. |
| 15.58 | After 13 minutes of blowing time, the nozzle pressure was reduced to 114 p. s. i. |
| 16.05 | The converter flame became transparent, the oxygen jet nozzle was retracted and the oxygen flow shut off to end the blow in 20 minutes. |
| 16.06 | The converter was tipped to the horizontal, sampled, and slag condition noted as well as fluid. |
| 16.07 to 16.14 | About three quarters of the slag was allowed to run into a slag thimble, the remaining slag was stiffened by addition of about 20 shovelfulls of burned lime through the converter mouth. |
| 16.15 | Teeming of the ladle after adding 3 kgs. of aluminum, the teeming temperature being 2,894° F. A group of four ingots of about 6.3 tons (metric) was cast. Ingot teeming temperature measured 2,696° F. and the yield in sound ingot steel was 88.1% having a composition as follows: 0.07% C, 0.37% Mn, 0.0% Si, 0.016% P, 0.023% S, 0.002% N. |

Total oxygen input was 1297 cubic meters measured at standard conditions, compared to the theoretical oxygen requirement for the pig iron analysis, scrap charged, and the analysis of finished steel obtained calculated at 1212 cubic meters (measured at standard conditions). This indicates an oxygen efficiency of 93.4%.

In the foregoing example, the nozzle pressure, nozzle orifice diameter and nozzle spacing provided an impact pressure of the oxygen jet on the melt surface such that the impact pressure of the jet measured on a reference surface outside the converter was 0.184 and 0.164, respectively kilograms per square centimeter (2.62 and 2.42 p. s. i., respectively) utilizing the same nozzle spacing, nozzle pressure and nozzle orifice diameters.

In this as well as in all other cases in which impact pressure is referred to in this application the following method of measurement is used to determine the average impact pressure:

To determine the average impact pressure the first step consists in measuring outside the converter the diameter of the unobstructed jet emerging into air at such a distance from the nozzle orifice as is equal to the distance of

the metal bath surface in the converter from the nozzle orifice during operation. In Example 1 this distance is 31.5 inches (about 800 mm.). To perform this measurement a Pitot tube such as is conventionally used for aerodynamical measurements, is moved in a plane normal to the jet axis. If a nozzle having a circular cross-section is used the Pitot tube is moved on two straight lines which intersect the jet axis at right angles to each other. The resulting pressure pattern decreases from a maximum lying in the jet axis towards the boundaries of the jet. The boundary of the jet is considered to be disposed at those points where the pressure measured with the Pitot tube (Pitot pressure) is 1 mm. water column. This limiting value has been chosen because lower values cannot be measured with the required accuracy under practical conditions. The mean diametrical spacing of two pairs of diametrically opposite points having a Pitot pressure of 1 mm. water column will give the diameter of the jet at a given distance from the nozzle orifice. Using this diameter the cross-sectional area of the jet, considered as of circular cross section, at the respective point is calculated. This cross-sectional area of the jet is considered the impact area.

Then the total pressure exercised by the gas jet is determined as follows: The jet is blown against a plate having a diameter at least twice the jet diameter measured as described hereinbefore. The arrangement is such that the jet axis intersects the plate at the center and the jet axis is at an angle of 90 degrees to the plate. The plate is connected to a weighing device arranged to indicate the total pressure exercised by the gas jet on the plate. The jet axis extends vertically and the plane of measurement extends horizontally. To calculate the pressure exercised by the blast jet on this surface, whose spacing from the nozzle corresponds to the distance of the nozzle from the quiescent bath surface when the nozzle is in operating position, the measured total pressure on the plate (in kg.) is divided by the area (in sq. cm.) of the jet cross-section measured in this manner. According to the invention the pressure thus calculated should be in any case less than 0.75 kg./sq. cm. (about 10.5 p. s. i.).

If another than a circular nozzle cross-section is chosen the same method of measurement is employed. In that case, however, it is not sufficient, to scan two mutually orthogonal straight lines in the plane of measurement with the Pitot tube but it is necessary to scan the jet cross-section in the plane of measurement around its entire periphery; the line where a Pitot pressure of 1 mm. water column prevails is considered the boundary of the jet cross section and of the impact area.

As will be seen, this impact pressure of the jet on the reference surface falls within the values set forth above. The oxygen nozzle pressure reduction during the latter portion of the blow reduces the oxygen feed rate and aids in low oxygen recovery in the steel by reducing oxygen input as the carbon boil nears completion.

*Example 2*

The applicability of the process of the invention to grades of pig iron having analyses between that of typical basic open hearth and basic Bessemer iron is clearly shown by reference to the following steel production in which a hot metal charge analyzing as follows was blown under conditions similar to those set forth in Example 1: 3.61% C, 2.16% Mn, 0.46% Si, 0.856% P, 0.06% S. The blowing of this charge of rather unfavorable chemistry both with respect to normal open hearth practice and basic Bessemer yielded a steel having the following composition: 0.04% C, 0.15% Mn, 0.0% Si, 0.014% P, 0.04% S.

Steel produced by the process of the invention as above-described is comparable with, and in some applications superior to open hearth steel. As indicated above, this high purity oxygen blown steel has low phosphorus and sulfur contents, and its nitrogen content shows even lower average values than are found in open hearth steels. The metallurgical conditions, above described, eliminate excessive oxygen pick up by the bath during the refining period. An after-blow as in standard basic converter practice is, of course, not required, since the phosphorus is removed before the removal of carbon is completed. The boil period with carbon monoxide evolution, therefore, lasts up to the last minute of the refining period indicated by the flame drop and transparency, thus preventing an over-oxidation of the steel. This condition makes for low oxygen contents in the steel as blown, a fact which is indicated by the exceptionally good pourability of the steel without the aid of additions of manganese and by the absence of red shortness even at rather low carbon contents.

In the production of rimming steels, the high temperatures developed in the high purity oxygen blowing cause a manganese throwback from the slag into the metal bath as shown by a hump in the manganese curve for the latter portion of refining period. Manganese content does not thereafter decrease until carbon drops to its end point. Under such characteristics of comparatively high content of manganese in the finished heat, it is possible to pour rimming steels of relatively very low carbon contents without any additional manganese and deoxidizing agents. In addition, such rimming steels as produced by the process pour more easily than open hearth heats of identical manganese and carbon. Ingots are accordingly, relatively free from blow holes near the skin that would give rise to surface defects on blooms. Rimming ingots, as shown by test on four ton specimens, are characterized by uniformly good density and purity in the center and bottom parts of the ingot, the deviations from ladle analyses being limited mainly to the top 15% of the ingot. This compares more than favorably with open hearth steel ingots (4 ton) in which the phosphorus and sulfur content over the entire cross sectional area of the ingot deviated materially from the ladle analysis through the top ⅓ of the ingot.

The forming properties of the high purity oxygen blown steels should meet any requirement, as indicated by a large number of heats subjected to rolling in the hot strip mill. They stood up exceptionally well to rolling under normal shop conditions, the strip presenting perfectly smooth edges in the as-rolled condition with fine regularity. Testing for red shortness behavior yielded excellent results even in heats that were finished with a carbon content of 0.05% C and below.

The marked degree of cold formability of the high purity oxygen blown steels compares equally, and in some cases is superior, to those of open hearth steels. The rimming low carbon steels exhibit a low susceptibility to strain hardening, and accordingly exhibit excellent cold forming properties, which makes them particularly applicable for cold rolling, wire drawing and deep drawing. For example, production from heats of rimming low carbon steel of 0.08 max. carbon was subjected to drawing to reduce rods of 5.5 millimeters diameter down to 0.35–0.40 millimeters diameter with no intermediate anneal of stock being required. The cold work applied was 99.6%, a larger reduction than obtainable in open hearth steel under identical operating conditions.

The steels exhibit very favorable deep drawing properties, tests indicating the range of Erichsen—cupping—test values obtained from a large number of heats of cold and annealed strip to exhibit a lower limit well above accepted standard values. The deep drawing property of hot rolled and annealed high purity oxygen blown sheet steel is equally excellent.

The excellent characteristics of rimming steels produced by the present invention comparable to open hearth grades also permit production of high grade killed steels using silicon or other agents for deoxidation in the ladle.

The degree of purity as in the case of rimming steel, for killed high purity oxygen blown steel can meet the most exacting requirements. Results obtained from notch breaking tests in the blue shortness range from examination of step turned test pieces representing a large number of heats indicate that any degree of purity that might be specified for plain carbon high grade steels and high strength-structural steels can be met with the steel produced by the process of the invention. In regard to hot and cold forming properties, these killed steels are on a par with killed open hearth material. Regarding mechanical properties in the as-rolled and in the normalized condition, it should be emphasized that the yield point-tensile strength relation is generally higher for the steels of the present process than for killed open hearth steels. Tests also indicated creep strength for silicon killed steels blown by the high purity oxygen method to be somewhat higher than silicon killed open hearth steel of equal strength.

In many other instances, the steels produced by the present invention have been proven by test to be at least comparable to open hearth steels, among which may be mentioned killed low carbon plate steel having good weldability and resistance to aging, heat-treatment (hardenable) steels, case hardening steels, and rail steels.

It is also an advantage of the present invention that plain carbon steels may be produced directly by the process, since it is possible to "catch" the heat at higher carbon contents due to the rapid removal of phosphorus and sulfur, although such steels may also be produced by blowing to the normal carbon end point of .05 to 0.10 percent C and recarburizing.

Considering refining capacity alone, and refining rates as given above for the process of the invention, one continously operating 30 ton (metric) converter will produce from 35 to 55 tons (metric) per hour, depending upon hot metal analysis. To achieve an equal tonnage of steel per hour in an open hearth plant, two large size units of about 250 tons charging capacity would have to be operated continuously. These figures establish that the process of the invention provides a definite capital cost advantage over the conventional open hearth process, even including the relatively high cost of the oxygen plant.

With the development of the new refining process of the invention, there is made available a new steel making tool which permits steels of excellent quality to be produced under favorable conditions, including high productivity per unit, comparatively low capital outlay for plant, and low cost of production, and good flexibility with regard to available resources of charging materials.

Various modifications may be made to the process without departing from the spirit of the invention. For example, in certain instances where nitrogen contents of greater than .003–.004 percent may be tolerated, oxygen somewhat below 98% may be utilized to produce steels having nitrogen contents of from 0.010 to 0.015 exhibiting the characteristic of relatively high strain hardening. Also, the process may be conducted with use of oxygen of from 95 to 98 percent in the first portion of the blow followed by finishing of the blow with high purity oxygen of 98 percent or higher, the vigorous boiling action of the bath up to the carbon end point insuring removal of nitrogen under such conditions. The term "high purity oxygen" is intended to mean at least 97 percent oxygen.

In the foregoing specification and in the appended claims, the term "directly above" with respect to the impingement of the oxygen jet on the bath surface is intended to mean that the oxygen jet issues from an overhung blast nozzle or other oxygen jet producing means in contradistinction to the disposition of lances or tuyeres positioned in the sidewalls of the refining vessel above the melt line for relatively low angle impingement on the melt surface.



As indicated above, the energy of the jet in the initial stages or first few minutes of the blow, may exceed the defined specific surface pressure of the jet on the melt surface, particularly where an unusually thick or stiff slag cover is encountered. However, the impact pressure of the jet is maintained in accordance with the foregoing teachings throughout the major portion of the blow, and particularly during the later stages thereof. Reference to "tons" where not indicated is to be interpreted as metric tons, and percentages, except as otherwise indicated, are percentages by weight.

This application is a continuation-in-part of our copending application Serial Number 277,061 filed March 17, 1952.

We claim:

1. A process for refining molten ferrous metal by surface blowing with gaseous oxygen in which the heat required for the refining is produced by reaction of the oxygen with the impurities in the molten metal, which comprises introducing into a reaction zone solid ferrous metal and a predominant proportion of molten carbon-containing ferrous metal, providing the molten metal with a slag cover, initially displacing the slag cover to provide direct contact of oxygen with said molten metal, blowing a jet of high purity oxygen from a blast nozzle substantially vertically downwardly onto the surface of said molten metal, said blast nozzle being spaced between about 150 millimeters and about 2000 millimeters above the surface of the molten metal, and controlling the impingement of the oxygen jet on the surface of said molten metal such that the impact pressure of the blast jet on a reference surface spaced from the blast nozzle a distance equal to the distance of the molten metal surface from the blast nozzle is maintained below about 0.75 kg./sq. cm., and above about 0.02 kg./sq. cm., while supplying the oxygen at a rate sufficient to complete the refining in about 12 to about 30 minutes.

2. A process according to claim 1 in which the pressure of the oxygen at the blast nozzle is reduced in the latter portion of the said refining period to reduce the rate of oxygen feed as the carbon end point is approached.

3. A process according to claim 1 in which the impact pressure of the blast jet on said reference surface is maintained below about 0.5 kg./sq. cm.

4. A process according to claim 1 in which the solid ferrous metal is scrap and is charged in amount up to about 30% of the total metallic charge.

5. A process according to claim 1 in which the slag cover is initially displaced by directing the oxygen jet against the slag-covered metal with an impact pressure on the reference surface of at least about 0.1 kg./sq. cm.

6. A process for refining predominantly pig iron-containing molten metal with gaseous oxygen in which the heat required for the refining is produced by reaction of the oxygen with the impurities in the molten metal, which comprises introducing into a reaction zone solid ferrous metal and a predominant proportion of molten pig iron, providing the molten metal with a slag cover, blowing a jet of high purity oxygen gas from a blast nozzle substantially vertically onto the surface of the slag covered molten metal at the central portion thereof to initially displace the slag in the area of jet impingement and to establish direct contact of the oxygen with the molten metal, said blast nozzle being spaced from about 150 millimeters to about 2000 millimeters above the surface of said molten metal, and controlling the impingement of the oxygen jet on the surface of said molten metal such that the average impact pressure of the blast jet in the impingement area measured on a reference surface equally spaced from the blast nozzle with respect to the distance of the blast nozzle from the surface of said molten metal is maintained below about 0.75 kg./sq. cm. and at least about 0.1 kg./sq. cm., while

supplying the oxygen at a rate sufficient to complete the refining in from about 12 to 30 minutes.

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