The production of iron product uses a top-submerged lancing injection reactor system, having a reactor for containing a molten iron bath having a slag phase, and first and second top-submerged injection lances positioned in the reactor for top-submerged injection into the bath. The lances are at mutually spaced locations, such as with the first closer to a slag tapping region and the second closer to an iron product tapping region. With a molten bath having a molten iron phase, containing sulphur and phosphorus, and a molten slag phase in the reactor, free-oxygen-containing gas and fuel/reductant are injected into the slag, through each lance, at a respective ratio of free-oxygen to fuel/reductant. Additional reductant is charged to the slag through a charging port. The ratio of free-oxygen to fuel/reductant injected through each lance and the charging of further reductant are controlled whereby a respective reducing region is generated in the vicinity of second lance, and reducing conditions are provided substantially throughout the slag. The injecting and controlling of the respective ratios are maintained whereby more strongly reducing conditions are provided in the region in the vicinity of the first lance and less strongly reducing conditions are provided in the region in the vicinity of the second lance. Sulphur in the molten iron is taken-up by the slag, and iron in the slag is reduced, in the vicinity of the first lance, and phosphorous in the molten iron is taken-up by the slag in the vicinity of the second lance, thereby producing iron product having a reduced level of both sulphur and phosphorus.
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CONTINUOUS SMELTING AND REFINING OF IRON

This invention relates to a process and a reactor system for the smelting and/or refining of iron to produce an iron product.

The conventional iron smelting process involving smelting of lump ore, pellets or sinter in a blast furnace using metallurgical coke as both fuel and reductant produces liquid pig iron containing most of the sulphur and phosphorus in the feed to the furnace. Sulphur and phosphorus are removed by procedures carried out in either the steelmaking furnace or in subsequent ladle processes prior to casting of the steel. Phosphorus and sulphur cannot be removed together because the conditions required are different. Sulphur is best removed under strongly reducing conditions, while phosphorus removal requires a strongly basic slag and more oxidising conditions.

Direct smelting processes for production of iron from iron ore, using coal as fuel (rather than coke) are being developed. These processes involve a single reactor operating under one set of conditions, which means that either sulphur or phosphorus can be removed, but not both together.

One known direct smelting process is the subject of our International patent specification W093/06251. In the process disclosed in W093/06251, iron ore is smelted by top submerged lances utilised to inject coal, oxygen and air into a liquid slag to provide energy under non-oxidising conditions, and air and/or oxygen is blown in above the bath to completely burn the combustible CO and H₂ gases rising from the slag bath. The injection into the bath causes ejection of a “cascade” or “rain” of slag into the gas space above the bath, generating a very turbulent bath surface. The reactor for carrying out this process provides for lump coal and iron ore to be fed from the top of the reactor onto the turbulent top surface region, where iron ore is reduced to liquid iron metal containing 3 to 4% C. This metal falls through slag to the bottom of the reactor to form a liquid metal bath.

Combustible gases evolved from the bath in the process of W093/06251 are afterburnt by the above-bath injection to generate heat energy within the “rain” of slag, and thereby allow this heat energy to be transferred to a large extent to the bath via the splashed slag of W093/06251. The process involves
essentially almost complete combustion of the CO to CO$_2$ and the H$_2$ to H$_2$O, thereby maximising the available heat energy from afterburning. Metal is tapped from the furnace at one end of the reactor, while slag is tapped from the other end. The process, and reactor used for it, provides for only one set of conditions, so that either phosphorus or sulphur can be removed from the iron, but not both.

The present invention is directed to providing a process for the production of an iron product with a low content of each of phosphorous and sulphur.

The process of the invention enables the production of the iron product in which the content of each of phosphorous and sulphur are simultaneously reduced in the iron product. The process can be operated for the direct smelting reduction of iron-containing source material. However, it also can be used for the refining of an iron product, such as pig iron produced in a blast furnace.

The process of the invention utilises a top-submerged lancing injection reactor system having a reactor for containing a molten iron bath having a slag phase, and at least a first and a second top submerged injection lance. The lances are positioned in the reactor for top submerged injection into the bath of free oxygen containing gas and fuel/reductant at respective mutually spaced locations. Where there is more than two lances, the or each lance other than the first and second lance preferably is located intermediate the first and second lances.

With use of such reactor system, the invention provides a process for the production of iron product which includes the steps of:
(a) providing in the reactor a molten bath having a molten iron phase, containing sulphur and phosphorous, and a molten slag phase,
(b) injecting free-oxygen-containing gas and fuel/reductant into the slag, through each of the first and second lances, at a respective ratio of free-oxygen to fuel/reductant for each lance;
(c) charging additional reductant to the slag through at least one charging port of the reactor;
(d) controlling the ratio of free-oxygen to fuel/reductant injected through each of the first and second lances and the charging of further reductant through the at least one charging port whereby a respective reducing region is generated in the vicinity of each of the first and second lance, and whereby reducing conditions are provided substantially throughout the slag; and

(e) maintaining the injecting of step (b) and the controlling of step (d) whereby more strongly reducing conditions are provided in the region in the vicinity of the first lance and less strongly reducing conditions are provided in the region in the vicinity of the second lance whereby:

(i) sulphur in the molten iron is taken-up by the slag, and iron in the slag is reduced, in the vicinity of the first lance, and

(ii) phosphorus in the molten iron is taken-up by the slag in the vicinity of the second lance,

thereby producing iron product having a reduced level of both sulphur and phosphorus.

The invention also provides a top-submerged reactor system for the production of iron product, wherein the system has a reactor for containing a molten iron bath having a slag phase; and first and second top-submerged injection lances positioned in the reactor at mutually spaced locations for top-submerged injection into the bath; and wherein each lance is adapted for injecting free-oxygen-containing gas and fuel/reductant into the slag at a respective ratio of free-oxygen to fuel/reductant, and the reactor is adapted for charging further reductant, whereby iron product having a reduced level of both sulphur and phosphorus is able to be produced by controlling the addition of further reductant and the top-submerged injection such that reducing conditions are able to prevail substantially throughout the slag and a respective reducing region is able to be generated in the slag in the vicinity of each lance, with more strongly reducing conditions provided in the region in the vicinity of the first lance and less strongly reducing conditions provided in the region in the vicinity of the second lance.

Thus, the process of the invention is operated with reducing conditions prevailing throughout the slag phase, but with a differential in the severity of the
reducing conditions at a respective region generated at the lower tip end of the first and second lances. The second lance is operated to generate a reducing region at its tip end, by control over the ratio of free oxygen to fuel/reductant injected into the bath by the second lance, whereby phosphorous in the bath is oxidised and taken into the slag phase. To facilitate this, a suitable addition most preferably is made to the bath in the vicinity of the second lance to ensure a more basic slag phase around the tip end of the second lance. In contrast, the first lance is operated to generate a reducing region at its tip end, by control over the ratio of free oxygen to fuel/reductant injected into the bath by the first lance, whereby sulphur in the bath is converted to sulphide and taken into the slag.

The process of the invention requires respective ratios of free oxygen to fuel/reductant for the first and second lances. It is necessary that more strongly reducing conditions prevail in the reducing region generated by the first lance than prevail in the reducing region generated by the second lance. In the reducing region generated by the second lance, the less strongly reducing conditions resulting in the take up of phosphorous by the slag phase are such that some oxidation of metallic iron also occurs with resultant of iron take-up by the slag phase in the vicinity of the second lance. This can result in the slag phase, in the vicinity of the second lance, containing Fe (as FeO) to a level of about 8% or higher. However, the more strongly reducing conditions in the reducing region generated by the first lance, in addition to causing the take-up of sulphur by the slag phase, also result in reduction of iron in the slag in the vicinity of the first lance, whereby the slag in that vicinity preferably contains no more than about 2% Fe (as FeO).

In the process of the invention, the respective ratio of free-oxygen to fuel/reductant injected by each lance is important in reducing both the sulphur and phosphorous content of the molten metal phase of the bath, to thereby provide required iron product low in both sulphur and phosphorous. However, the charging of further reductant, most preferably lump coal, also is important in maintaining reducing conditions substantially throughout the slag. Indeed, the further reductant, in combination with the respective injection ratio for each
lance, enables overall control over the oxygen potential of the bath and the FeO level in the slag and this control is highly desirable where, as detailed below, the process is operated to produce molten iron product by smelting iron oxide containing feed material. In the latter regard, such smelting is distinguished from use of the process for producing molten iron product by refining sulphur- and phosphorous-containing iron metal. However, even in the latter regard, control of the oxygen potential and the FeO level in the bath again is desirable, if less critical than when smelting iron oxide-containing feed material.

The process may be operated on a batch-wise basis, but preferably is continuous. With continuous operation, the tapping of slag phase causes a flow of the slag from the vicinity of the second lance to the vicinity of the first lance. Thus, iron taken up by the slag phase in the vicinity of the second lance is able to be substantially recovered by its reduction to molten iron, in the vicinity of the first lance, to enable tapping of low iron slag. However, with both batch-wise and continuous operation, the top submerged injection by the at least two lances most preferably is such as to facilitate circulation of the slag phase between the first and second lances.

The reactor preferably has at least three top submerged injecting lances. The lances may be, and preferably are, laterally spaced in a direction extending from a slag tapping region to an iron product tapping region. The reactor may be of elongate form, with each tapping region at a respective end of the reactor and the lances laterally spaced from each other along the reactor between those ends.

Where the lances are laterally spaced in a direction extending between the respective regions for slag and iron product tapping, it is preferred that the first lance is relatively closer to the slag tapping region and that the second lance is relatively closer to the iron product tapping region. Thus, where for example the reactor is of elongate form, with each tapping region at a respective end of the reactor, the first lance may be adjacent to the end of the reactor provided with the slag tapping region and the second lance adjacent to the end with the iron product tapping region.
The reactor may have an inclined base which extends downwardly from the slag tapping region to the metal product tapping region. Where this is the case, the inclination may be such that, in the vicinity of the first lance and the slag tapping region, the bath substantially predominantly comprises slag phase.

That is, while some molten metal phase will be present in the vicinity of the first lance, where metal is reduced from the slag phase, the bath at least in a quiescent condition (such as if injection is terminated) may have a substantially lesser depth of molten metal in the vicinity of the first lance and the slag tapping region than at the metal product tapping region.

Prior to or during the process, feed material is supplied to the reactor. In the case of a batch-wise operation, the feed material can be supplied at the commencement of operation and, if required, supplemented during the course of operation. In a continuous operation, the feed material can be supplied continuously or at required intervals throughout the operation.

The feed material may include phosphorous- and sulphur-containing metal to be refined and, in this case, the metal preferably is charged with slag or slag forming constituents prior to the commencement of a batch-wise operation. Alternatively, the feed material may include suitable iron-containing material such as iron concentrate or iron ore, such as iron sands, iron ore fines and iron-rich dusts. In the latter case, the material may be supplied with slag or slag forming constituents prior to the commencement of a batch-wise operation or, as is preferred, the material is supplied to a slag phase containing bath during the course of a smelting operation. The feed material additionally includes reductant, preferably lump coal, and material suitable for maintaining a basic slag. The material for maintaining a basic slag may be lime or limestone and it, and the reductant, preferably is added during the course of a batchwise or continuous operation, either continuously or intermittently as required.

In one suitable mode of operation, the reactor is provided with at least three top submerged injecting lances which are laterally spaced from each other along a line, such as a line in a direction from the slag tapping region to the iron product tapping region. Feed material is supplied to the bath through a series of charging ports located in an upper region of the reactor, such as in a...
roof of the reactor. A charging port preferably is provided between the first lance and the second lance or, where there are at least three lances, a respective charging port preferably is provided between successive lances. Also, a further charging port most preferably is provided between the second lance and the metal product tapping region. The ratio of feed material constituents can be substantially the same for each charging port. However, the feed material supplied to the further charging port may have a higher proportion of lime, limestone or other constituent for maintaining a basic slag, whereby a suitably basic slag for take-up of phosphorous is ensured in the vicinity of the second lance and the iron product tapping region.

Where the invention is used for the smelting of iron oxide-containing feed material, such material may comprise iron ore, iron sands, iron fines, iron-rich dusts and mixtures thereof. With iron oxide-containing feed material, the process of the invention in one embodiment includes feeding the further reductant, preferably coal and most preferably lump coal, and that feed material in a ratio which varies from the metal product tapping region to the slag tapping region. This ratio varies so as to facilitate maintenance of more strongly reducing conditions in the vicinity of the first lance and less strongly reducing conditions in the vicinity of the second lance. By this means, overall control of both the oxygen potential and the FeO content of the slag is able to be achieved. Thus, for example, when the first lance is adjacent to the slag tapping region and the second lance is adjacent to the metal product tapping region, phosphorous is removed from the iron phase of the bath and the FeO content of the slag is increased adjacent to the metal product tapping region, while sulphur is removed from the iron phase and the FeO content of the slag is reduced adjacent to the slag tapping region. The FeO content of the slag at the metal product tapping region can be increased to about 8% Fe or more. However, at the slag tapping region, the FeO content of the slag can be reduced to about 2% or less.

The free-oxygen containing gas injected by each lance may be air, oxygen-enriched air or oxygen. The free-oxygen containing gas most preferably has an oxygen content of from about 40% to about 100%. The
injected fuel/reductant preferably is fine particulate coal. However the fuel/reductant may be at least one of fuel oil, natural gas, LPG or other suitable carbonaceous material, with or without particulate coal.

As indicated, reducing conditions are to prevail throughout the slag phase. Attainment of these conditions is facilitated by additional reductant supplied to the bath, that is by reductant such as lump coal additional to the top submerged injection of fuel/reductant. However, each lance is operated so as to generate a respective reducing region at its lower tip end. Preferably each lance is operated with a ratio of free oxygen to fuel/reductant providing for combustion of from about 40% to about 60% of the fuel/reductant, such as from about 40% to about 55%. The first lance is operated at the lower end of the range, such as with a ratio of free oxygen to fuel/reductant of less than about 47%, for example about 45% or lower. The second lance is operated at the higher end of the range, such as with a ratio of free oxygen to fuel/reductant in excess of about 47%, for example about 49% or higher.

Where the reactor is provided with more than two lances, the or each lance other than the first and second lances can be operated with a ratio of free oxygen to fuel/reductant similar to that used for the first lance. That is, the or each other lance also may generate a reducing region at its lower tip end which is more strongly reducing than the region generated by the second lance. However, the ratio for each lance may be such that there is a step-wise reduction in the reducing strength in the reducing region generated by successive lances, from the first lance through to the second lance. Particularly in the latter case, a concentration profile can be developed in the slag phase which, in terms of iron content, decreases from the second lance to the first lance.

The lances can be of any form suitable for top submerged injection. However, the process of the invention necessitates relatively high reactor temperatures of from about 1350°C to about 1500°C, particularly in the case of direct smelting reduction. Each lance preferably is of a suitable alloy steel, such as stainless steel. The alloy steel preferably is of a high quality, to be corrosion resistant and, in particular, resistant to oxidation and dissolution in the
slag phase at high temperatures. ASTM 321, 316 or other high chromium steels are suitable. Also, cooling of the lances generally is desirable, by supply of coolant fluid thereto during operation. The lances may be in accordance with our International patent application PCT/AU90/00466 (WO 91/05214) filed 26 September 1990. Most preferably, the lances are of the form disclosed in our Australian patent specification AU-B-24505/92 (corresponding to the United States patent 5308043). The disclosures of each of the specifications WO 91/05214 and AU-B-24505/92 are incorporated herein and to be read as part of the disclosure of the present invention.

The process of the present invention most preferably is conducted with post-combustion (or afterburning) of CO and H₂ generated in the smelting and/or refining operation, as well as with combustion of any carbon dust carried out of the bath by combustion gases. For this, free oxygen-containing gas, whether oxygen, air or oxygen-enriched air, is blown into the reactor space above the bath. The post-combustion preferably is close to the bath surface, such as close to the reducing region generated by at least one (but preferably each) lance, to achieve a high level of heat energy transfer to the slag phase. The oxygen-containing gas for post-combustion can be blown in by at least one lance having its lower discharge end located above the bath surface. However, it is preferred that the gas is blown into the reactor space by a shroud pipe through which a lance for top submerged injection extends, with the shroud pipe terminating above the bath surface. A shrouded lance as disclosed in WO 91/05214 or in AU-B-24505/92 (USP 5308043) is suitable for use as the or each lance required for this purpose in the present invention.

Post-combustion, as determined by the ratio of (CO₂ + H₂O) to (CO + H₂ + CO₂ + H₂O) in exhaust gases, preferably is conducted so as to achieve an oxidation degree in excess of 0.2. The oxidation degree preferably is not in excess of 0.95, but can be up to 1.0. The oxidation degree is controlled so as to achieve a maximum suitable level of heat energy transfer to the slag phase, consistent with any use of post-combusted exhaust gases and avoidance of re-oxidising of the bath. Gases from the reactor may be used for general heating purposes, such as for steam production. However, while the
gases can be used to achieve partial pre-reduction of iron concentrate or iron ore to be smelted, prior to charging the such iron source to the reactor, the economics of operation generally do not favour pre-reduction.

While reference is made to iron-concentrate or iron ore, in use of the process for smelting, the feed material for smelting may comprise or include iron-containing source material in the form of pellets, pellet fines, iron sands, iron residues and/or scale, steel plant flue dust, ferrous scrap and/or high iron slag.

In order that the invention can more readily be understood, description now is directed to the accompanying drawings in which:

Figure 1 is a top plan view of a reactor system, suitable for use with the present invention; and

Figure 2 is sectional view of the system of Figure 1, taken online II-II.

In Figures 1 and 2, the reactor system 10 includes a reactor 12 of elongate form in which a centrally disposed laterally spaced series of four lances 14a to 14d is mounted. The series of lances 14a to 14d is disposed along a longitudinal central line of reactor 12 for top submerged injection into the slag phase layer 16 of a molten bath which also includes a molten iron layer 18.

At one end of reactor 12, there is a tap hole 20 for tapping slag from layer 16, while a tap hole 22 is provided at the other end for tapping iron product from layer 18. Reactor 12 also has a base 12a which is inclined downwardly from tap hole 20 to tap hole 22. Despite this inclination of base 12a, the interface between layers 16 and 18 extends from to tap hole 20 to tap hole 22, although the inclination is such that molten iron produced during operation with system 10 drains along base 12a towards tap hole 22.

Above tap hole 20, reactor 12 has an off-take flue 23 by which off gases generated during operation in reactor 12 are able to be exhausted for suitable processing. Also, in a roof 12b of reactor 12 there is a respective opening 24 for each lance 14, such that the lances 14 are able to be raised or lowered by suitable means (not shown) located above reactor 12. Each opening 24 has a
fitting (not shown) which, while enabling vertical movement of a respective lance 14, substantially precludes the passage of off-gases therethrough.

Reactor 12 is refractory lined, and may have an external steel shell. At least in hotter regions of its peripheral wall, such as along the sides thereof where heating effects are high, the peripheral wall may be water-cooled, if required.

Between each opening 24, there is a respective feed material charging port 26 in roof 12b. A further port 26 is provided in roof 12b between the end of reactor 12 provided with top hole 22 and a second lance 14d which is nearest to that end. Each port 26 is provided with suitable means (not shown) enabling the charging of feed material to the bath in reactor 12 while substantially precluding the passage of off-gases therethrough.

System 10 is suitable for smelting iron-containing feed material, or for the refining of phosphorous- and sulphur-containing molten iron feed, to provide an iron product low in phosphorous and sulphur. The iron-containing feed material or molten iron feed can be high in phosphorous and sulphur, while the process also is able to accommodate sulphur resulting from fuel and/or reductant used in the process.

In operation with system 10 of Figures 1 and 2, for the smelting of iron-containing feed material, a suitable molten slag layer 16 is established. There preferably also is at least a small quantity of iron present as layer 18, such as a heel volume from a previous operation. With such molten bath established, lances 14 are positioned for top submerged injection into the slag of layer 16. Preferably the lances 14 are progressively lowered, as described in specifications WO 91/05214 and AU-B-24505/92 (USP 5308043) to form and maintain a protective coating of solidified slag thereon.

The lances 14 are operated to provide injection of free-oxygen containing gas and fuel/reductant into layer 16. For each lance, the gas has an oxygen content of from 40% to 100% of the stoichiometric requirements for full combustion of its fuel/reductant and is to provide in a suitable ratio of oxygen to fuel/reductant. Preferably the oxygen content and the rate of injection of the free-oxygen containing gas is the same for each lance 14, with the rate of
injection of fuel/reductant being varied between the lances 14 to achieve a required ratio of oxygen to fuel/reductant. However, other control is possible to achieve those ratios.

At least lance 14a nearest to tap hole 20 is operated at a different ratio of injected oxygen to fuel/reductant to the lance 14d nearest to tap hole 22. The lance 14a is operated to provide reducing conditions at its tip which are sufficiently strongly reducing to cause substantially complete take-up of sulphur in the slag phase, with reduction of iron in the slag to molten metal. For this, lance 14a is operated with a ratio of oxygen to fuel/reductant of less than about 47% of stoichiometric requirements for full combustion of the fuel/reductant injected by lance 14a, such as about 45%. The lance 14d is operated to provide reducing conditions at its tip which are less strongly reducing than for lance 14a, and sufficient to cause substantially complete take-up of phosphorous into the slag, with some oxidation of metallic iron and its take-up by the slag. For this, lance 14d is operated with a ratio of oxygen to fuel/reductant of more than about 47% of stoichiometric requirement for full combustion of fuel/reductant injected by lance 14d, such as about 49%.

Lances 14b and 14c may be operated at the same oxygen to fuel/reductant ratio as lance 14a. Alternatively, lances 14b and 14c may be operated at respectively the same ratios as lances 14a and 14d. In a still further alternative, each lance 14 can be operated at a respective ratio with the ratio varying progressively from that used for lance 14d to that used for lance 14a.

During smelting, iron source material, and lump coal additional reductant with lime or limestone is charged to the bath through each port 26. However, with these feed materials, the proportion of lime or limestone is increased for the port 26 located between lance 14d and tap hole 22. This is to ensure a sufficiently basic slag in the vicinity of lance 14d and tap hole 22, to facilitate the take-up of phosphorous by the slag of layer 16.

The injected fuel/reductant preferably is particulate coal. The feed material of iron source material, lump coal and lime or limestone can be charged continuously or intermittently. Iron product low in sulphur and
phosphorous, and also slag low in iron, can be tapped from respective holes 22 and 20 continuously, or intermittently as required.

During smelting, the ratio of iron-containing feed material to further reductant is controlled, but varies along the reactor, to enhance the attainment of the required strongly and less strongly reducing regions provided by the top-submerged injection. Such ratios will vary with both the iron oxide content of the feed material and the coal type. Also, the top submerged injection causes circulation of slag from one to the other end of reactor 12. At the location of each lance 14, substantial turbulence is created by the top-submerged injection, causing droplets of slag to be splashed upwardly and a “cascade” or “rain” of slag back to the bath.

Operation with system 10 of Figures 1 and 2 for the refining of phosphorous- and sulphur-containing molten iron feed is similar to that for smelting iron feed material. In each case, the process of the invention is suitable for producing molten iron product which is low in both phosphorous and sulphur. Each of the latter elements is able to be reduced to a level of about 0.02% or less, with slag tapped from the reactor able to have a low iron content of about 2% or less.

In Figures 1 and 2, at least one, preferably each, of lances 14a to 14d provides for the discharge of free-oxygen containing gas within the interior space of reactor 12 above the slag phase layer 16, to provide for post-combustion. However, other arrangements for such supply of oxygen can be provided. The degree of post-combustion of CO and H₂ generated by a smelting and/or refining operation can be controlled so as to achieve a suitable take-up of resultant heat energy by the slag. Any coal dust present in the gases generated also can be post-combusted. Most preferably at least one lance 14 is in accordance with the disclosures of WO 91/05214 or AU-B-24505/92 (USP 5308043), and thus includes a shroud through which the lance extends, with the shroud providing for the supply of post combustion oxygen.

The top submerged injection causes circulation of slag in reactor 12 which most preferably minimises longitudinal mixing of the slag and metal in the
reactor. By operating the lance at the metal tapping end of the reactor under conditions less reducing than the lance at the slag tapping end of the reactor, a concentration profile is developed along the reactor which allows the removal of phosphorus at the less strongly reducing (more oxidising) metal tapping end, whilst sulphur is removed at the more reducing slag-tapping end of the reactor. Additional lime is fed into the reactor at the metal tapping end to ensure optimal phosphorus removal to slag at that end.

This invention allows the simultaneous separation of both phosphorus and sulphur from the iron smelting system in a single reactor.

This process and reactor provides the means to minimise phosphorus and sulphur levels in iron product, irrespective of the levels in the feed before the iron is processed through to steel. This also minimises the cost of removal of these elements from iron, since the steelmaking process does not need to be operated to remove either of them. Low phosphorus and sulphur steel is a premium product, which has higher value and is more readily marketed than steel with higher phosphorus and/or sulphur levels.

The invention also allows feed materials with higher levels of phosphorus and sulphur to be processed through to marketable steel, and therefore enhances the value of these iron resources.

Finally, it is to be understood that various alterations, modifications and/or additions may be introduced into the constructions and arrangements of parts previously described without departing from the spirit or ambit of the invention.
Claims:

1. A process for the production of iron product, using a top-submerged lancing injection reactor system, the system having a reactor for containing a molten iron bath having a slag phase, and first and second top-submerged injection lances positioned in the reactor for top-submerged injection into the bath at respective mutually spaced locations, the process including the steps of:

(a) providing in the reactor a molten bath having a molten iron phase, containing sulphur and phosphorous, and a molten slag phase,

(b) injecting free-oxygen-containing gas and fuel/reductant into the slag, through each of the first and second lances, at a respective ratio of free-oxygen to fuel/reductant for each lance;

(c) charging additional reductant to the slag through at least one charging port of the reactor;

(d) controlling the ratio of free-oxygen to fuel/reductant injected through each of the first and second lances and the charging of further reductant through the at least one charging port whereby a respective reducing region is generated in the vicinity of each of the first and second lance, and whereby reducing conditions are provided substantially throughout the slag; and

(e) maintaining the injecting of step (b) and the controlling of step (d) whereby more strongly reducing conditions are provided in the region in the vicinity of the first lance and less strongly reducing conditions are provided in the region in the vicinity of the second lance whereby:

(i) sulphur in the molten iron is taken-up by the slag, and iron in the slag is reduced, in the vicinity of the first lance, and

(ii) phosphorus in the molten iron is taken-up by the slag in the vicinity of the second lance,

thereby producing iron product having a reduced level of both sulphur and phosphorus.

2. The process of claim 1, further including the step of charging to the reactor, in the vicinity of the second lance, slag forming constituents providing a
more basic slag at the region in the vicinity of the second lance, whereby oxidation of phosphorous and its take-up by the slag is facilitated.

3. The process of claim 2, wherein said constituent is lime, limestone or a mixtures of lime and limestone.

4. The process of any one of claims 1 to 3, wherein the less strongly reducing conditions result in oxidation of metallic iron, and its take-up by the slag as iron oxide, in the region in the vicinity of the second lance.

5. The process of claim 4, wherein the take-up of iron oxide by the slag results in the slag, in the vicinity of the second lance, having an iron content (as FeO) of at least about 8%.

6. The process of any one of claims 1 to 5, wherein the more strongly reducing conditions in the region of the first lance result in reduction of iron in the slag whereby the slag in the vicinity of the first lance contains not more than about 2% iron (as FeO).

7. The process of any one of claims 1 to 6, wherein the injecting of step (b) generates circulation of slag between the first and second lances.

8. The process of any one of claims 1 to 7, wherein the process is operated on a batch-wise basis in which the molten iron of the bath is refined to provide a refined iron product low in both sulphur and phosphorous.

9. The process of any one of claims 1 to 7, wherein the process is operated on a batch-wise basis and further includes the step of charging iron-containing feed material to the bath before and/or during steps (a) to (e).

10. The process of any one of claims 1 to 7, wherein the process is operated on a continuous basis and further includes the steps of:

- charging iron-containing feed material to the bath during steps (a) to (e), and
- tapping slag at a slag tapping region whereby slag in the vicinity of the second lance is caused to flow to the vicinity of the first lance.

11. The process of claim 9 or claim 10, wherein the iron-containing feed material contains or comprises phosphorous- and sulphur-containing iron metal which is taken-up by the molten bath and refined to provide refined iron product.
12. The process of claim 9 or 10, wherein the iron-containing feed material is iron ore or concentrate which is smelted to provide iron product low in both sulphur and phosphorous.

13. The process of claim 12, wherein said first lance is nearer to a slag tapping region and said second lance is nearer to a metal product tapping region, and wherein said feed material and further reductant are charged at a ratio which varies between said tapping regions whereby maintenance of said more strongly reducing conditions in the vicinity of said first lance and said less strongly reducing conditions in the vicinity of said second lance is facilitated, thereby providing control over the overall oxygen potential and the FeO content of the slag.

14. The process of any one of claims 9 to 13, further including charging slag or slag-forming constituents to the reactor with the iron-containing feed material.

15. The process of any one of claims 9 to 14, wherein at least part of the feed material and further reductant are charged through a charging port, in a roof of the reactor, intermediate the first and second lances.

16. The process of claim 15, wherein at least part of the feed material and of the further reductant is charged through a charging port, in the roof of the reactor, intermediate the second lance and the metal tapping region.

17. The process of any one of claims 1 to 16, wherein there is at least one further top-submerged injection lance intermediate the first and second lances, by which free-oxygen-containing gas and fuel/reductant is injected into the slag at a ratio of free-oxygen to fuel/reductant similar to the ratio for the first lance.

18. The process of any one of claims 1 to 17, wherein the free-oxygen-containing gas is air, oxygen-enriched air or oxygen.

19. The process of any one of claims 1 to 18, wherein the free-oxygen containing gas has a free-oxygen content of from about 40% to about 100%.

20. The process of any one of claims 1 to 19, wherein the injected fuel/reductant is fine particulate coal, fuel oil, natural gas, LPG or a mixture thereof.
21. The process of any one of claims 1 to 20, wherein the further reductant is lump coal.

22. The process of any one of claims 1 to 21, wherein each of the first and second lances is operated at a respective ratio of free-oxygen to fuel/reductant providing for combustion of from about 40% to about 60% of the fuel/reductant.

23. The process of claim 22, wherein the ratio for the first lance is less than about 47%, and the ratio for the second lance is in excess of about 47%.

24. The process of claim 23, wherein the ratio for the first lance is less than about 45%.

25. The process of claim 23 or claim 24, wherein the ratio for the second lance is in excess of about 49%.

26. The process of any one of claims 1 to 25, wherein the process is conducted at a reactor temperature of from about 1350°C to about 1500°C.

27. The process of any one of claims 1 to 26, wherein CO and H₂ are generated during the process and evolve from the molten bath, and wherein the CO and H₂ are subjected to post-combustion or after-burning in the reactor, above the molten bath by free-oxygen-containing gas blown into the reactor, above the bath.

28. The process of claim 27, wherein the free-oxygen-containing gas blown into the reactor space above the bath is oxygen, air or oxygen-enriched air.

29. The process of claim 27 or claim 28, wherein the post-combustion is conducted to a post-combustion degree, as determined by the ratio of \((CO_2 + H_2O)\) to \((CO + H_2 + CO_2 + H_2O)\), which is in excess of 0.2, and wherein the degree of post-combustion is controlled to regulate the transfer to the slag of heat energy generated by the post-combustion.

30. The process of any one of claims 1 to 29, wherein the top-submerged injection is conducted to generate substantial turbulence in the slag, whereby droplets of slag are splashed upwardly and fall back to the bath.

31. A top-submerged lancing injection reactor system for the production of iron product, wherein the system has a reactor for containing a molten iron bath having a slag phase; and first and second top-submerged injection lances positioned in the reactor at mutually spaced locations for top-submerged
injection into the bath; and wherein each lance is adapted for injecting free-oxygen-containing gas and fuel/reductant into the slag at a respective ratio of free-oxygen to fuel/reductant, and the reactor is adapted for charging further reductant, whereby iron product having a reduced level of both sulphur and phosphorous is able to be produced by controlling the addition of further reductant and the top-submerged injection such that reducing conditions are able to prevail substantially throughout the slag and a respective reducing region is able to be generated in the slag in the vicinity of each lance, with more strongly reducing conditions provided in the region in the vicinity of the first lance and less strongly reducing conditions provided in the region in the vicinity of the second lance.

32. The reactor system of claim 31 wherein there is at least one further lance intermediate the first and second lances.

33. The reactor system of claim 31 or claim 32 wherein the reactor includes means for blowing free-oxygen-containing gas into a space in the reactor above the bath.

34. The reactor system of claim 33, wherein at least one lance extends through a shroud which has a lower end terminating above the bath, whereby the free-oxygen-containing gas to be blown into the reactor is able to be supplied through the shroud for discharge from said lower end.

35. The reactor system of any one of claims 31 to 34, wherein the reactor has a molten iron tapping region and a slag tapping region at respective locations spaced around the perimeter of the reactor, and wherein the lances are spaced in a direction extending between said tapping regions with the first lance closer to the slag tapping region and the second lance closer to the iron tapping region.

36. The reactor system of claim 35, wherein the reactor is of elongate form with each tapping region at a respective end of the reactor.

37. The reactor system of claim 35 or claim 36, wherein the reactor has a base which is inclined downwardly from the slag tapping region to the iron product tapping region.
38. The reactor system of any one of claims 31 to 37, wherein said reactor has at least one port intermediate the first and second lance whereby iron-containing feed material and further reductant can be charged to the reactor.

39. The reactor system of any one of claims 35 to 37, or of claim 38 when appended to any one of claims 35 to 37, wherein said reactor has a port intermediate the second lance and the metal tapping region.
**INTERNATIONAL SEARCH REPORT**

International Application No.
PCT/AU 96/00830

### A. CLASSIFICATION OF SUBJECT MATTER

Int Cl:
C21C 1/02, 5/32, C21B 13/00

According to International Patent Classification (IPC) or to both national classification and IPC

### B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C21C 1/-, 5/-, C21B 13/-

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU: IPC C21C 1/02, 5/32, 5/35, C21B 13/00

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
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### C. DOCUMENTS CONSIDERED TO BE RELEVANT

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* Special categories of cited documents:
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Date of the actual completion of the international search
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Date of mailing of the international search report
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Telephone No.: (06) 283 2052

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**INTERNATIONAL SEARCH REPORT**

**DOCUMENTS CONSIDERED TO BE RELEVANT**

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