Title: A FERRONICKEL PRODUCT AND A PROCESS FOR ITS PRODUCTION

Abstract: The invention relates to a process for the production of a ferronickel product from laterite ore or a concentrate made from nickel bearing laterite ore to yield the ferronickel product which contains in excess of 10% nickel when produced from limonite ore and in excess of 30% nickel when produced from saprolite ore and less than 0.5% carbon.
A FERRONICKEL PRODUCT AND A PROCESS FOR ITS PRODUCTION

FIELD OF THE INVENTION

This invention relates to the field of ferronickel production from laterite ores.

BACKGROUND TO THE INVENTION

Various metals are used in alloys to improve the properties of another metal. Examples include alloy steels and alloy brasses.

Nickel is an example of an alloy that is used in the production of various metals, including stainless steel. The cost of the ferronickel used for this is a major contributor to the high cost of, for example, stainless steel.

Nickel is typically found naturally in laterite ores. Compared with nickel sulphide deposits, nickel laterites are lower grade oxide nickel deposits that occur in highly weathered rock near the surface. The dominant crystalline component typically is serpentine, formed by the decomposition of olivine and/or pyroxene. These nickel bearing laterite deposits typically are divided into two types characterized geologically as limonite or saprolite. Limonite forms the top layer and is generally the more abundant of the two and is characterised by a high iron oxide and relatively low magnesia content. The main Ni-bearing minerals in limonite ores are goethite and other hydroxides. Saprolite is characterised by high silica and magnesia and relatively low iron oxide content. The main Ni-bearing mineral in saprolite ores typically are Mg-Fe rich silicates such as olivine and pyroxene. Transition zones between these two types of laterite deposits are common.

Limonite is conventionally processed in hydrometallurgical process routes while saprolite is processed pyrometallurgically. The hydrometallurgical processing involves significant environmental concerns and costs, which makes this the less attractive of the two options.

The pyrometallurgical route conventionally comprises processing in a blast furnace, or processing in an electric arc furnace, be it DC or AC.
In a blast furnace the ore needs to be melted, for which a significant amount of energy has to be added. This is done by way of coke which is fed into the furnace, along with the ore. Air is blown from the bottom to provide oxygen for the chemical reactions to proceed. For this a liquid slag is required, otherwise the speed at which the air is blown is impeded which reduces penetration of the air into the furnace.

These limitations dictate that the blast furnace be operated at a relative high temperature, which necessitates the use of external energy, typically added in the form of coke.

The nature of the blast furnace process is thus such that although the recovery of nickel from ore is good, whether it be limonite or saprolite, the reduction of iron is also very high. The amount of nickel in the ferro-nickel product from the blast furnace is thus relatively low, typically in the same ratio that it is present in the ore that loaded into the blast furnace.

Limonite typically has a Fe/Ni ratio of up to about 40:1 and saprolite a Fe/Ni ratio of about 10:1. Limonite therefore typically has nickel content in the region of about 0.5% to 2.0% and saprolite up to about 2.5% to 3.0% (at best). Processing either of these in a blast furnace will result in a low grade alloy.

Especially smelting limonite in a blast furnace will result in a very low grade alloy, generally known as nickel pig iron (NPI), which is a relatively new development, with production starting around 2005, especially in China utilising small blast furnaces.

It is insightful when considering that nickel finds a primary purpose in the manufacture of stainless steels. This may contain up to 8% Nickel in a so-called 18/8 stainless steel, which is a high nickel containing 300-series stainless steel, with 18% Cr which is provided from FeCr. The FeCr is provided typically with about only about 50% Cr. This means the FeNi that is used to add the Ni to the 18/8 stainless steel has to have in the region of about 15 % to 20% Ni to not dilute the Cr below 18%. Using a low grade FeNi, such as having in the region of 2.5% Ni will simply dilute the Cr below 18%. To be able to use such low grade FeNi for stainless steel production, a very high grade FeCr has to be used, which is also very costly.

Even using a FeNi obtained from Saprolite using a blast furnace process will not be suitable for 18/8 stainless due to the dilution effect. The around 2.5% to 3.0% Ni that such FeNi can provide is simply not enough to be used economically with commercially available FeCr to produce a 300 series stainless steel.
As a general rule, it is therefore not cost efficient to produce FeNi from laterite, be it limonite or saprolite, using a blast furnace for use in high quality stainless steels.

An alternative to smelting laterite in a blast furnace is to smelt it in an electric arc furnace. A fundamental operational requirement of an electric arc furnace is that the liquidus temperature of the slag needs to be higher than (or close to) the liquidus temperature of the molten metal bath to ensure sufficient heat transfer from the slag to the alloy.

In an electric arc furnace the liquidus temperature of the slag decreases with increasing FeO content. It has been established that processing limonite, which typically has the higher Fe/Ni ratio of about 40:1, in an electric arc furnace results in a slag with a very high FeO content. The resulting slag liquidus temperature is too low. The slag liquidus temperature must be similar or higher than that of the metal liquidus, which for low carbon alloy is above 1450°C.

Limonite ores cannot be used because of difficulty to form a suitable slag, while ensuring reasonable nickel recovery. It is therefore effectively a non-starter to process limonite in an electric arc furnace.

Saprolite may well be conventionally processed pyrometallurgically in electric arc furnace. This is possible since saprolite contains significant amounts of magnesia and does not suffer from the same high Fe/Ni ratio as limonite. As mentioned above a typical saprolite ore has a Fe/Ni ratio of about 10:1. Saprolite ores are thus treated in electric arc furnaces, and for such are often blended with some limonite to provide a constant feed quality and to consume limonite.

Saprolite ores may also be processed in, for example, the RKEF (Rotary Kiln Electric Furnace). In this process saprolite ores are conventionally pretreated in a rotary kiln, followed by smelting in electric arc furnaces to produce either high carbon (higher than 1.5% carbon) or low carbon (0.15 to 0.3% carbon) ferronickel, depending on operating conditions. Nickel grade is determined by the Fe/Ni ratio in the ore and the extent of the iron reduction.

The process needs to be adapted to the particular slag which can be formed when smelting the ore. Mixing of different ore types in a laterite charge to a furnace is required to obtain a suitable slag composition. Electrical conductivity plays a role in tailoring the mix. The
melting temperature of the metal and the slag are also of great importance to ensure sufficient heat transfer from the slag to the alloy.

The carbon content is adjusted to obtain good nickel recovery without dilution of the nickel through excessive iron reduction and to control the slag properties. Excessive iron reduction also causes higher power consumption while customers generally do not pay for the iron content of the metal. Higher iron content also increases transport cost.

Some ores cannot be economically processed because of lack of sufficient power generating capacity in the region. Capital cost for power generation is extremely high, and without a base load in the region, cannot be justified.

A further complicating factor of using electric arc furnaces (AC and DC) for processing laterite, be it limonite (which as indicated above in any event is a non-starter due to the slag issues) or saprolite, is that all electric arc furnaces rely on transferring heat through the slag to the alloy. Electric arc furnaces operate with slag heights of up to one meter. The ore being smelted floats on the slag, so that the metal which is smelted from the ore needs to drop through the slag layer. When slag is tapped, significant quantities of metal and nickel oxide that are still present in the slag are tapped with the slag.

These difficulties make the production of ferronickel from laterite ores, especially limonite, using electric arc furnaces expensive and wasteful.

Since limonite is naturally more abundant than saprolite, and limonite is often found in the absence of any saprolite, there is almost always an excess limonite available and not enough saprolite. In many instances, there are stock piles of limonite at plants that cannot be processed pyrometallurgically. This negates the benefit that pyrometallurgical processing of saprolite offers, since only a minor portion of laterite ores can be processed in this manner.

The only option is therefore that limonite ores be treated hydrometallurgically.

In hydrometallurgical processing routes, magnesia and alumina in saprolite increases the acid consumption, limiting the saprolite content in the feed blend. The use of acid such as nitric acid and hydrochloric acid create environmental problems which increase the cost of processing limonite hydrometallurgically.
To be able to process a typical naturally occurring body of laterite it would therefore be required to use pyrometallurgical and hydrometallurgical processing plants to treat the saprolite and limonite respectively, and thus process the entire body of laterite ore. This is expensive and in most instances not economically viable.

In this specification the term "furnace" shall mean an electrically heated channel type induction furnace substantially as defined, described and claimed in patent applications numbers PCT/IB201 1/051 672 and PCT/IB201 2/050938 by the same applicant, the contents of which are fully included herein by reference.

For ease of reference, and without derogating from the scope of the inclusive reference of the above furnace, the so-referenced "furnace" and a so-called "ESS furnace" comprise a shell lined with refractory material, and having a floor and a wall extending from the floor to form a hearth, at least one channel type induction heater associated with the furnace and communicating with the hearth by means of a throat in the floor, the throat including a central passage serving as an inlet to the induction heater and two side passages on opposite sides of the central passage serving as outlets from the induction heater, the throat passages being complimentary shaped and configured to channels in the induction heater and each passage being in fluid communication with a complimentary channel, the furnace floor having a base on a first side of the hearth and a ramp which rises from the base to terminate in a plateau above the passages at a location distal from the first side, with the ramp and plateau extending at least partly between opposing end walls of the furnace, the plateau including a trench which extends at least partly between opposing ends of the plateau, with the trench being in fluid communication with the passages and the bottom of the trench being located in a plane higher than the plane in which the furnace floor is located, and the base of the furnace floor being in fluid communication with the central passage by means of a floor passage that extends from the base of the floor to the central channel of the heater.

The first side of the hearth is termed a "charge wall" with the charging ports located adjacent it, and the second opposite side is termed a "burner wall" with the burner ports located adjacent it, and the throat of the induction heater located proximate the burner wall.

OBJECT OF THE INVENTION

It is an object of the invention to provide a process for the production of a ferronickel product which at least partly overcomes the abovementioned problems.
SUMMARY OF THE INVENTION

In accordance with this invention there is provided a process for the production of a ferronickel product from a nickel bearing laterite ore or a concentrate made from nickel bearing laterite ore to yield the ferronickel product which contains in excess of 10% nickel when produced from limonite ore and in excess of 30% nickel when produced from saprolite ore and less than 0.5% carbon, preferably less than 0.2% carbon, the process comprising:

a. operating a furnace containing a liquid metal bath of the ferronickel at least partly covered by a slag layer, by charging feed material which includes the ore and reductant into the hearth proximate to its first side to substantially maintain the liquid metal meniscus above the plateau, with feed material at least partly floating on the liquid metal bath and slag layer;

b. introducing fuel and air into the furnace through burners along its second side for combustion of the fuel in the furnace operatively to partly reduce and to heat the ore in the charge by radiation heat transfer from the combusted gas resulting from combusting the fuel with the air;

c. heating the liquid metal bath by means of the induction heater;

d. discharging liquid metal from the furnace and charging feed material into the hearth to substantially maintain the plateau covered by liquid metal and to allow heated liquid metal to overflow from the trench in the plateau and melt the heated and partly reduced ore in the feed material floating on the liquid metal bath into the liquid metal bath; and

e. controlling the iron oxide content of the slag between 1% and 80% by adjusting the ratio of reductant to ore being charged into the furnace.

There is further provided for the process to include using hot exhaust gasses for air preheating and, optionally, for drying and preheating the ore.

There is further provided for the reductant to preferably comprise carbonaceous reductant, and more preferably coal or dried biomass.

According to a further feature of the invention there is provided a ferronickel product produced by smelting from limonite which contains in excess of 10% nickel, and preferably about 15% nickel; and less than 0.5% carbon, preferably less than 0.2% carbon.
According to a still further feature of the invention there is provided a ferronickel product produced by smelting from saprolite which contains in excess of 20% nickel, and preferably about 50% nickel; and less than 0.5% carbon, preferably less than 0.2% carbon.

These and other features of the invention are described in more detail below.

**BRIEF DESCRIPTION OF THE DRAWINGS**

Figure 1 is a graphical representation of Iron Nickel recoveries in an electric furnace and in an induction heated furnace operated according to the invention; and Figure 2 is a graphical representation of alloy grade at increasing Fe/Ni ratios in a laterite resulting from processing in a blast furnace with 90% Fe reduction, and electric arc furnace with 20% Fe reduction, and an induction heated furnace operated according to the invention with 6% Fe reduction.

**DETAILED DESCRIPTION OF THE INVENTION**

As mentioned above nickel is typically found naturally in laterite ores, which are typically divided into limonite and saprolite. As mentioned, limonite is characterised by a high iron oxide and relatively low silica content, and saprolite is characterised by high silica and magnesia and relatively low iron oxide content.

Under controlled reducing conditions nickel can be selectively reduced from a laterite ore. The intention of such controlled processing is to recover most of the nickel from the ore into a nickel containing alloy while reducing a minimum amount of the iron to act as collector - this forms a ferro nickel alloy.

This minimum amount of iron reduction can be calculated assuming equilibrium conditions. Conventionally this is seldom achieved in practice. This equilibrium can be calculated using the reaction between nickel and iron in the alloy, [Ni] and [Fe] and nickel oxide and iron oxide in the slag, (NiO) and (FeO):

\[ (\text{NiO}) + [\text{Fe}] \rightleftharpoons [\text{Ni}] + (\text{FeO}) \]  

The equilibrium constant \( K \) of reaction (1) is only dependent on operating temperature, namely:
Activities \( a \) can be expressed in terms of activity coefficients \( \gamma \) and mole fractions \( x \):

\[
K = \frac{a_{Ni} \cdot a_{FeO}}{a_{NiO} \cdot a_{Fe}} \quad \ldots \quad (2)
\]

The activity coefficients can be combined as \( \gamma \) and can reasonably be assumed not to vary much with composition:

\[
\gamma = \frac{\gamma_{NiO} \cdot \gamma_{FeO}}{\gamma_{Ni} \cdot \gamma_{Fe}} \quad \ldots \quad (3)
\]

The equilibrium relationship between nickel and iron recovery can be calculated from equations (3) and (4), as shown in equation (5) and can be expressed as number of moles in equation (6):

\[
K \gamma = \frac{x_{Ni} \cdot x_{FeO}}{x_{NiO} \cdot x_{Fe}} \quad \ldots \quad (5)
\]

\[
K \gamma = \frac{n_{Ni} \cdot n_{FeO}}{n_{NiO} \cdot n_{Fe}} \quad \ldots \quad (6)
\]

If the amount of nickel and iron in the feed are denoted by \( n^o \), then the mass balances are as follows:

\[
n_{Ni} = n^o_{Ni} + n^0_{NiO} - n_{NiO} \quad \ldots \quad (7)
\]

\[
n_{Fe} = n^o_{Fe} + n^0_{FeO} - n_{FeO} \quad \ldots \quad (8)
\]

The iron and nickel recoveries can now be defined as:

\[
R_{Ni} = \frac{n_{Ni}}{n^o_{Ni} + n^0_{NiO}} \quad \ldots \quad (9)
\]

\[
R_{Fe} = \frac{n_{Fe}}{n^o_{Fe} + n^0_{FeO}} \quad \ldots \quad (10)
\]

Combining equations (7) to (10):

\[
n_{NiO} = (1 - R_{Ni})(n^o_{Ni} + n^0_{NiO}) \quad \ldots \quad (11)
\]

\[
n_{FeO} = (1 - R_{Fe})(n^o_{Fe} + n^0_{FeO}) \quad \ldots \quad (12)
\]

And equations (9) to (12) in (6):
\[ K\gamma = \frac{R_{Ni}}{R_{Fe}} \left( \frac{n_{Ni}^0 + n_{NiO}^0 (1-R_{Fe}) (n_{Fe}^0 + n_{FeO}^0)}{n_{Fe}^0 + n_{FeO}^0} \right) (1-R_{Ni}) \] 

Resulting in:

\[ K\gamma = \frac{R_{Ni}}{R_{Fe}} \left( 1-R_{Fe} \right) \] 

Thus:

\[ R_{Ni} = \frac{K\gamma R_{Fe}}{1 - (1-K\gamma)R_{Fe}} \]

Therefore, under ideal equilibrium conditions the minimum amount of iron reduction or iron recovery that will be required to achieve a desired degree of nickel recovery is dependent on the equilibrium value of \( K\gamma \) for the specific furnace. The equilibrium value of \( K\gamma \) is only dependent on operating temperature of the furnace.

The equilibrium value of \( K\gamma \) at an operating temperature of about 1550°C of an induction heated furnace operated according to the invention is approximately 150. The nickel recovery at increased iron reduction at \( K\gamma =150 \) as shown in Figure 1. Thus, to achieve a 90% nickel recovery, a minimum of 6% of iron must also be reduced.

In electric arc furnaces, smelting saprolite ores with a Fe/Ni ratio of 10, it is empirically known that generally a minimum of 20% iron must be reduced to achieve a 90% nickel recovery, corresponding to a \( K\gamma \) value of 36, as shown in Figure 1. This is probably not only equilibrium driven but likely also due to inefficient nickel collection from the thick layer of slag.

It is apparent from Figure 1 that to achieve 90% recovery of nickel from a nickel bearing ore, the process according to the invention requires only 6% Fe reduction whilst in an electric arc furnace it requires 20% Fe reduction. Stated differently, if both processes could be limited to only 6% Fe reduction, then the process according to the invention would result in 90% recovery of nickel form the laterite ore and the electric arc furnace process would result in only about 68% recovery of nickel form the laterite ore.

Since a recovery of only 68% is too low to economically justify using a process, an electric arc furnace in any event has to be operated to the 20% Fe reduction level to achieve a commercially acceptable degree of recovery of nickel from its ore.
As described above at least for limonite this leads to a very high level of FeO in the slag. This reduces the liquidus temperature of the slag by too much to still ensure sufficient heat transfer from the slag to the alloy.

The problem with the final grade of the FeNi product is graphically shown in Figure 2. Reducing 20% of the iron from a saprolitic ore with a Fe/Ni ratio of 10, the alloy grade is approximately 30% Ni. The alloy grade under complete equilibrium conditions (K_γ = 36) is 30%. This is the case in an electric arc furnace. As mentioned above such FeNi grade will be suitable for use in stainless steel manufacturing.

As a comparison, the FeNi grade from a blast furnace with about 90% Fe reduction for the same saprolitic ore yields a FeNi product with about 10% Ni. As mentioned above such FeNi grade will not be suitable for use in high quality stainless steel manufacturing, such as 18/8 stainless steels. In any event, due to slag viscosity being too high, this is not a material suitable for processing in a blast furnace. It is also uneconomical to add fluxes to reduce the viscosity of such slag.

Using the process according the invention to operate an ESS furnace, a minimum of 6% Fe has to be reduced to ensure a 90% Ni recovery from the laterite ore to yield a FeNi product with about 50% Ni. This is suitable for the manufacture of any stainless steel grade, including the highest quality stainless steel grade and other high nickel containing alloys, without having to resort to more expensive quality ferrochrome (FeCr) with higher chrome contents.

Processing limonite, with a Fe/Ni ratio of up to 40:1 (compared with a value of around 10:1 for saprolite) in respectively the same three furnace processes is also shown in Figure 2. The calculated alloy grades at 6%, 20% and 90% iron reduction are respectively about 21%, 9%, and 2.5%.

As stated above, the 2.5% FeNi product achievable from a blast furnace is not useful for the manufacture of any high nickel containing stainless steel. The 9% FeNi product calculated for an electric arc furnace theoretically using limonite ore, can in any event not be smelted in electric arc furnace since the slag liquidus, with a very high FeO content in the slag, is too low; the slag liquidus temperature must be similar or higher than that of the metal liquidus, which for low carbon alloy is above 1450°C.
However, as will be seen from Figure 2 using the process according to the invention laterite ore can be smelted to produce a FeNi grade of higher than 10% for limonite ore and higher than 20% for saprolite ore can be achieved. Specifically, a FeNi grade of as high as about 15% for limonite and a FeNi grade as high as about 50% Fe for saprolite is achievable, both a recovery of about 90% nickel from the ore. As will be seen from Figure 2, these figures, i.e. about 15% for limonite (an ore with Fe/Ni ratio of about a 40:1) and about 50% for saprolite (an ore with a Fe/Ni ratio of about 10:1) are somewhat less than indicated on the curve. The reason for this is that the curves in Figure 2 represent the calculated maximum values. In practice, a slightly lower value is expected. Hence, the calculated value of about 21% for limonite is reduced to a practical expected maximum value of about 15%, and the calculated value of about 67% for saprolite is reduced to a practical expected maximum value of about 50%.

The area in Figure 2 indicated by reference "D", which lies above the calculated maximum FeNi alloy grade using an electric arc furnace process (line "B") and the calculated maximum FeNi alloy grade using the process according to the invention (line "A"), indicates the FeNi alloy grades possible with the process according to the invention, for the range of Fe/Ni ratios indicated in Figure 2. For the sake of clarity, the calculated maximum FeNi alloy grade using the blast furnace process is indicated as line "C".

It should be reiterated that whilst lines "B" and "C" in Figure 2 indicates calculated maximum values, for the reasons mentioned already, the only practical FeNi produced by a blast furnace is low grade FeNi using limonite (an ore with Fe/Ni ratio of about a 40:1), and from an electric arc furnace FeNi product using saprolite (an ore with a Fe/Ni ratio of about 10:1).

The reduction and melting is performed in a furnace similar to ones as described in patent applications numbers PCT/IB2011/051672 and PCT/IB2012/050938 by the same applicant. For ease of reference side perspective views of the furnace is provided in Figures 1 and 2.

Ore and reducing agent, generally coal (but not restricted to coal), is fed along one long wall of the furnace (the feed wall of the furnace) while fuel and preheated air is introduced through burners along the opposite long wall (the burner wall of the furnace). The ore is partly reduced and heated to high temperature by radiation.

Proximate to the burner wall a channel induction heater is mounted below the floor of the furnace in a similar way as described in PCT/IB2012/050938. Heated liquid metal from the
channel heater is introduced into a trench along the burner wall, from where it overflows to melt metal and slag from the heated and partly reduced ore which is partly floating on the liquid metal.

Hot exhaust gasses are used for air preheating and some excess heat from this could be available for drying and preheating the ore.

Nickel and iron recovery is controlled by monitoring the iron oxide content of the slag. Heat for melting is introduced to the metal and not to the slag (which is the case in in electric arc furnaces). Therefore, the electrical conductivity of the slag has no influence on the working of the process. The requirement for a large quantity of slag to be present in the furnace is removed.

A small area of the furnace is covered by maximally about 100mm of slag, while the rest of the surface is covered by much less slag. The low volume of slag retained in the furnace is beneficial to the working of the process. Openings for tapping metal and slag are positioned close to each channel heater and the centre of the trench where heated metal from the channel heater exits passages leading from the channel heater. The openings are arranged in such a manner that the metal forms a pool which extends to the outside of the furnace, and slag floating on the metal also reaches the outside of the furnace at all times. This arrangement ensures that metal samples can be taken at any time (not restricted to metal tapping time) and slag can be tapped continuously if sufficient slag is being melted. The slag thickness in the tapping spout and above the metal in the trench is controlled to less than 100mm by adjusting the weir height in the spout.

The carbon and iron content of the metal is effectively controlled by monitoring the iron oxide content of the slag and adjusting the ratio of reductant to ore being charged. It has been found that the carbon content of the metal remains almost constant at below 0.5%, and can be below 0.2%C, as long as the iron oxide content of the slag is greater than about 30%. Iron oxide content of up to 80% could be maintained without adversely affecting nickel yield, producing a metal containing around 15% Ni. The iron content in the slag is determined by the ore composition, which in the case of limonite can be as high as about 50% Fe, in for example New Caledonia limonite.
Electrical power consumption

All this makes it possible for laterite ore to be smelted to produce a FeNi grade of higher than 10% for limonite ore (an ore with a 40:1 Fe/Ni ratio) and higher than 30% for saprolite ore (an ore with a 10:1 Fe/Ni ratio) can be achieved. Specifically, a FeNi grade of as high as about 21% for such limonite and a FeNi grade as high as about 58% Fe for such saprolite is theoretically achievable, both at a recovery of about 90% nickel from the ore.

The carbon content may be as low as 0.1%, making the alloy well suited to adjusting the chemistry of stainless steel at the end of the steel making process, i.e. trimming it, which will not introduce unwanted carbon or other unwanted elements into the steel at such time. The alloy will also require less energy for melting in the steel process, so that it could be added later in the blow, resulting in less nickel losses from the stainless steel operation. The product will therefore be highly regarded by customers and could fetch a premium over the normal ferronickel alloy.

In the event that trace elements like copper, cobalt and platinum group elements make an ore unsuitable for nickel recovery by melting, then the high concentration of these elements and lower iron content could result in profitable use of the ore in a smelting operation followed by hydrometallurgical extraction of nickel and cobalt from the metal.

Because of the use of fuel for reduction and heating of the ore to temperatures higher than 1000°C and even as high as 1300 °C, much less electrical power is required. This could lead to unlocking ores that otherwise could not be treated because of lower capital cost required for power generation and the use of portable power generation installations.

Although the benefits of the current process has been described with reference to the specific advantages gained over the current hydrometallurgical and pyrometallurgical processes as routes to produce ferronickel for the manufacture of stainless steel, there are further advantages. The process according to the invention makes it possible to produce high grade ferronickel which was previously not possible. This high quality high grade ferronickel can be produced in one induction heated furnace using the process of the invention, and using either limonite or saprolite, or any combination thereof.

This holds costs benefits not only for the manufacture of stainless steel, but for most processes that uses nickel.
CLAIMS

1. A process for the production of a ferronickel product from laterite ore or a concentrate made from nickel bearing laterite ore to yield the ferronickel product which contains in excess of 10% nickel when produced from limonite ore and in excess of 30% nickel when produced from saprolite ore and less than 0.5% carbon, the process comprising:
   a. operating a furnace containing a liquid metal bath of the ferronickel at least partly covered by a slag layer, by charging feed material which includes the laterite ore and reductant into the hearth proximate to its first side to substantially maintain the liquid metal meniscus above the plateau, with feed material at least partly floating on the liquid metal bath and slag layer;
   b. introducing fuel and air into the furnace through burners along its second side for combustion of the fuel in the furnace operatively to partly reduce and to heat the ore in the charge by radiation heat transfer from the combusted gas resulting from combusting the fuel with the air;
   c. heating the liquid metal bath by means of the induction heater;
   d. discharging liquid metal from the furnace and charging feed material into the hearth to substantially maintain the plateau covered by liquid metal and to allow heated liquid metal to overflow from the trench in the plateau and melt the heated and partly reduced ore in the feed material floating on the liquid metal bath into the liquid metal bath; and
   e. controlling the iron oxide content of the slag to between 1% and 80% by adjusting the ratio of reductant to ore being charged into the furnace.

2. A process as claimed in claim 1 which includes using hot exhaust gasses for air preheating and, optionally, for drying and preheating the ore.

3. A process as claimed in claim 1 or claim 2 in which the reductant comprises carbonaceous reductant, and more preferably coal or dried biomass.

4. A ferronickel product produced by smelting from limonite, which contains in excess of 10% nickel and less than 0.5% carbon.

5. A ferronickel product produced by smelting from limonite, which contains about 15% nickel and less than 0.5% carbon.
6. A ferronickel product as claimed in claim 4 or 5 which contains less than 0.2% carbon.

7. A ferronickel product produced by smelting from saprolite, which contains in excess of 20% nickel and less than 0.5%.

8. A ferronickel product produced by smelting from saprolite, which contains in about 50% nickel and less than 0.5% carbon.

9. A ferronickel product as claimed in claim 7 or 8 which contains less than 0.2% carbon.
### INTERNATIONAL SEARCH REPORT

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC: C22B 4/06 (2006.01); C22B 4/08 (2006.01); C22C 33/04 (2006.01); C22C 38/40 (2006.01); C21C 5/36 (2006.01); C21C 7/04 (2006.01); F27D 11/06 (2006.01)

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)

- C22B, C22C, C21C, F27D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

- EPDOC, WPI, X-FULL

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>CN 101285129 A (AUTOMATICALLY TRANSLATED BY THE INTELLECTUAL PROPERTY PUBLISHING HOUSE OF SIPO) (MA HEPing ET AL.) 15 October 2008 (15.10.2008) abstract; description, specific embodiment: claim 1</td>
<td>4 - 6</td>
</tr>
<tr>
<td>X</td>
<td>CN 102650002 A (AUTOMATICALLY TRANSLATED BY THE INTELLECTUAL PROPERTY PUBLISHING HOUSE OF SIPO) (YUNNAN TIN GROUP HOLDING CO., LTD.) 29 August 2012 (29.08.2012) abstract; description, embodiments; claims 1 - 5</td>
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<td>A</td>
<td>CN 101886231 A (AUTOMATICALLY TRANSLATED BY THE INTELLECTUAL PROPERTY PUBLISHING HOUSE OF SIPO) (CHUNDE LI ET AL.) 17 November 2010 (17.11.2010) abstract; description; claim 1</td>
<td>1 - 9</td>
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[X] Further documents listed in the continuation of Box C.

- **X** See patent family annex

* Special categories of cited documents:

  - **A** document defining the general state of the art which is not considered to be of particular relevance
  - **E** earlier application or patent but published on or after the international filing date
  - **L** document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
  - **O** document referring to an oral disclosure, use, exhibition or other means
  - **P** document published prior to the international filing date but later than the priority date claimed

**Date of the actual completion of the international search**

22 September 2014 (22.09.2014)

**Date of mailing of the international search report**

29 September 2014 (29.09.2014)

**Name and mailing address of the ISA/AT**

Austrian Patent Office
Dresdner StraBe 87, A-1200 Vienna

Facsimile No. +43 / 1 / 534 24-535

**Authorized officer**

AIGNER M.

Telephone No. +43 / 1 / 534 24-458
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<td>CN 101338354 A (AUTOMATICALLY TRANSLATED BY THE INTELLECTUAL PROPERTY PUBLISHING HOUSE OF SIPO) (UNIV. KUNMING SCIENCE &amp; TECH. ET AL.) 07 January 2009 (07.01.2009) abstract; description; claims 1, 4</td>
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<td>A199923544 B2 (BILLITON S.A., LTD.) 14 October 1999 (14.10.1999) abstract; description, page 2, lines 19 - 22, page 3, line 29, page 5, line 11 - page 9, line 1; claims 1, 4, 12,</td>
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**INTERNATIONAL SEARCH REPORT**

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<td>1. ☐ Claims Nos.: because they relate to subject matter not required to be searched by this Authority, namely:</td>
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<td>2. ☐ Claims Nos.: because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:</td>
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<td>3. ☐ Claims Nos.: because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).</td>
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<td>Claims 1 - 3; claims 4 - 6; claims 7 - 9</td>
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<td>1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.</td>
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<td>2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.</td>
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<td>3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:</td>
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<td>4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:</td>
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**Remark on Protest**

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (continuation of first sheet (2)) (July 2009)
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