

ABSTRACT

The present disclosure provides a metallurgical extraction method for co-processing laterite ores and sulphide concentrates. In a first process step, a metalliferous sulphide concentrate is roasted in air to produce a sulphur dioxide containing gas and a calcine, whereafter the sulphur dioxide containing gas is processed to produce sulphuric acid. In a second process step, a laterite ore is subjected to HPAL processing using the sulphuric acid from the roasting process to extract base metals or value metals contained in the laterite ore. The calcine from the roasting process can be combined with the laterite ore at various stages, such as being added to the feed slurry for simultaneous leaching in the HPAL process or by being added to the HPAL discharge slurry for subsequent atmospheric leaching to extract base metals or value metals contained in the calcine. The disclosure also provides a metallurgical extraction plant in which the method is used.

A metallurgical extraction method for co-processing laterite ores and sulphide concentrates

FIELD OF INVENTION

The present invention relates to a metallurgical extraction method for co-processing
5 laterite ores and sulphide concentrates.

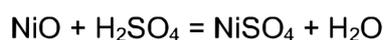
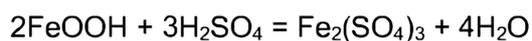
More particularly, the present invention relates to the metallurgical treatment of metal ores and concentrates to extract base metals via an acid leaching process.

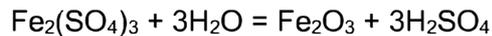
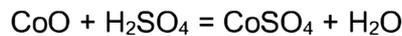
BACKGROUND ART

High-pressure acid leaching

10 A high-pressure acid leach (HPAL) process is a hydrometallurgical process for treatment of nickel laterite ores which has been used for many years. Since 1995, adaptations of the HPAL process have been used at a number of processing plants as nickel demand increased and nickel sulphide resources dwindled. Examples of these processing plants located in Australia include the Murrin Murrin, Bulong, Cawse and Ravensthorpe projects.

15 The HPAL process is typically applied commercially to treat limonitic nickel laterite ores that contain high concentrations of iron-rich goethite. Nickel is typically present in concentrations of the order of 0.8-1.5% and cobalt is also typically present at lower concentrations of the order of 0.2% or less and is co-extracted. The main features of the extraction of nickel and cobalt from laterite or oxide ores using the HPAL process are the
20 use of sulphuric acid, typically at addition rates of between 200 and 550 kg/ton ore, and leaching at high temperatures of between 200 and 280°C in an autoclave to digest the nickel and cobalt bearing minerals in the ore slurry and thereby releasing these value metals into an aqueous solution as dissolved sulphate salts. Iron is typically redeposited during the process as hematite, releasing acid back into solution. The following simplified
25 major reactions occur in this leaching process:





The production of sulphuric acid is often an integral part of the HPAL processing plant. While there are some exceptions where concentrated sulphuric acid is sourced from off-site, the major HPAL nickel laterite plants produce sulphuric acid on site by burning elemental sulphur. A typical schematic flow diagram of a HPAL process is shown in Figure 1.

Elemental sulphur is a by-product from oil and gas production and is typically shipped in to the mine site, often internationally from Vancouver or the Middle East. The exothermic combustion of elemental sulphur in air produces a large amount of heat that can be harvested to produce high pressure steam for use in the process and for electric power generation at the HPAL processing plant. The cost of elemental sulphur is one of the major components of the operating cost of a HPAL processing plant and this is dependent on both the spot market price thereof and the cost of transporting the elemental sulphur to the plant site.

Sulphide concentrates

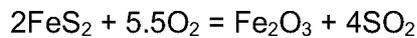
Historically the most economical extraction of base metals such as copper, zinc, cobalt and nickel has occurred through initial recovery of sulphide minerals from ores. Sulphide minerals are readily concentrated through gravity concentration and/or flotation following comminution of the ore. The sulphide minerals are compounds of sulphur and metals. Also, base metal concentrations in a sulphide mineral concentrate can be significantly higher than the concentrations of metals such as nickel and cobalt in laterite ores.

Sulphide concentrates have traditionally predominantly been processed through smelting and refining processes with smelting typically also producing sulphuric acid as a by-product. Alternative processes for treatment of sulphide concentrates include roasting and leaching and direct leaching, followed by hydrometallurgical recovery. The specific composition of these concentrates and other project related factors dictate whether they are amenable to such processing. Occasionally the sulphide minerals in a deposit are not present in sufficient abundance to make a concentrate of sufficiently high concentration to sell to a smelter or to economically process independently.

Roasting of Metalliferous Sulphide minerals

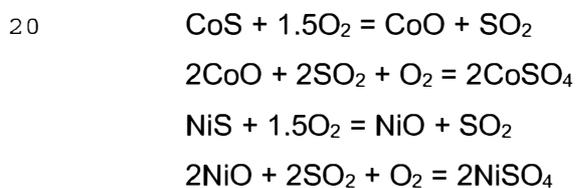
It is known to roast sulphide concentrates in air to process various sulphide concentrates and ores for the recovery of gold, copper, cobalt, nickel, zinc and others. The roasting process generates a large amount of heat and is autothermal at high temperatures in the
5 range of 500-1000°C. Roasting has been used as a pre-treatment process in these cases to remove sulphur from the concentrates and produce sulphuric acid.

A typical reaction of metalliferous sulphides is the oxidation of pyrite (iron sulphide) in air according to the following reaction:



10 This reaction is highly exothermic and can operate autogenously, i.e. without the need to input additional heat. The roasting of pyrite and pyrrhotite concentrates to generate sulphuric acid and steam has been used commercially as an alternative to sulphur burning acid plants and has been shown to be economically comparable in certain circumstances. Large pyrite and pyrite/pyrrhotite roasters can produce sulphuric acid and steam. Current
15 roasters operate at 850-900°C.

Essentially all metalliferous sulphide minerals can be roasted in air, converting the mineral to a metal oxide or, under particular conditions, to a metal sulphate, while producing sulphur dioxide gas. If the sulphides contain cobalt and/or nickel the following nominal reactions would occur:



After gas cleaning the sulphur dioxide can be converted to sulphuric acid using the
25 contact process or alternative available processes. To optimise metal extractions during subsequent leaching processes, the roasting reaction may have to be controlled within tight operating parameters to prevent the metal from becoming refractory to more benign leaching processes.

Where roasting involves recovery of base metals, traditionally a sulphatising roast has been employed to render the base metal sulphates so formed easily leachable from the calcine in a watery solution at atmospheric conditions. To achieve sulphatising conditions, the roast has to be run with excess oxygen and in a specific temperature range, typically
5 below 700°C. Sulphatising roasting requires large roasters due to the low operating temperature and excess air and generates less steam and sulphur dioxide than when operating at “dead roasting” conditions.

Pyrite (FeS_2) is likely the sulphide mineral most suited to roasting for the purpose of sulphuric acid production. Where this is the main purpose a “dead roast” can be
10 performed which essentially reaches the highest possible temperature (800-900°C) and removes nearly all the sulphur, forming a hematite rich calcine. If the pyrite is very pure the red hematite can be used as pigment. Under these roasting conditions contained value metals are likely to be present to a significant extent as ferrites, NiFe_2O_4 and CoFe_2O_4 , which are refractory to milder atmospheric leaching conditions. Thus, to
15 achieve high extractions of base metals from a dead roasted calcine, such calcine would ideally be treated with excess sulphuric acid and at temperatures above 220°C, more preferably at or above 250°C. These conditions are similar to the range of conditions used in the HPAL process used for nickel laterite leaching. Hence dead-roasted calcine can be leached under HPAL conditions with comparatively low acid consumption.

20 Co-Processing of Sulphide and Laterite Ores

Limited co-processing of nickel sulphide concentrates with laterite ore has been practiced at some of the Western Australian HPAL operations where highly oxidised and oxidising laterite ore has been combined with nickel sulphide concentrates as feed to the HPAL autoclave. Under HPAL conditions the oxidants in the laterite ore react with the reducing
25 sulphide minerals to form more sulphuric acid and this effectively dissolves nickel in both laterite and sulphide minerals. Typically the discharge oxidation reduction potential (ORP) should be above 300 mV vs Ag/AgCl and free sulphuric acid concentrations above 30 g/l to have sufficiently oxidising conditions so as not to damage a titanium autoclave. This limits the amount of sulphide concentrate that can be added to the HPAL process without
30 additional oxidant addition and requires addition of sulphuric acid from other sources to the HPAL.

Australian Innovation Patent 2008100563 describes a method to co-process nickel sulphide concentrates with laterites using HPAL conditions in Pachuca tanks and with the addition of oxygen or air to extend the amount of nickel sulphide that can be added to the laterite. Application of this method to conventional HPAL horizontal titanium autoclaves
5 would require consideration of the oxygen mass transfer and energy management requirements in the autoclave.

European Patent application EP2326737A1 describes a method of co-processing of nickel sulphide concentrates with laterite ore in an HPAL autoclave. The patent claims that sulphide co-processing can effectively be achieved as long as the HPAL discharge
10 contains between 30 and 60 g/l free sulphuric acid and the ORP is between 250-900 mV vs Ag/AgCl. At high addition rates of sulphide, the solution is likely to contain significant ferrous sulphate concentrations, the removal of which would have to be dealt with in downstream processing.

It is to be understood that, if any prior art publication is referred to herein, such reference
15 does not constitute an admission that the publication forms a part of the common general knowledge in the art, in Australia or any other country.

SUMMARY OF THE INVENTION

According to one aspect of the present invention, there is provided a metallurgical extraction method for co-processing laterite ores and sulphide concentrates comprising
20 the steps of:

- roasting a metalliferous sulphide concentrate in air to produce a sulphur dioxide containing gas and a calcine;
- processing the sulphur dioxide containing gas to produce sulphuric acid;
- combining the calcine with a laterite ore to form a feed slurry; and
- 25 processing the feed slurry and the sulphuric acid in a high-pressure acid leach process to extract base metals or value metals contained both in the laterite ore and in the calcine.

The metalliferous sulphide concentrate may be roasted at a temperature in the range of 500 – 1000°C. In one embodiment the metalliferous sulphide concentrate is submitted
30 to dead-roasting at a temperature in the range of 700 – 1000°C. In another embodiment

the metalliferous sulphide concentrate is submitted to partial-roasting by selecting a desired temperature and oxygen stoichiometry.

5 The metalliferous sulphide concentrate may be roasted in any one of a stationary fluidised bed roaster, a circulating fluidised bed roaster, a rotary kiln or any other suitable roasting equipment.

The metalliferous sulphide concentrate may be roasted in oxygen-enriched air.

10 The sulphur dioxide containing gas produced in the roaster may be passed through a heat recovery boiler to produce steam. The steam may be used to preheat the feed slurry prior to processing the feed slurry in the high-pressure acid leach process. The steam may be used to heat the slurry in an autoclave used in the high-pressure acid leach process.

The laterite ore may be a nickel laterite ore.

The density of the calcine may be higher than the density of the laterite ore so that combining these in the feed slurry results in the feed slurry having a higher solids concentration and improved rheological properties compared to that of the laterite ore.

15 In one embodiment the calcine is combined with the laterite ore prior to being passed through a thickener and whereby the thickener underflow forms the feed slurry. In an alternative embodiment the laterite ore is passed through a thickener whereafter the calcine is combined with the thickener underflow to form the feed slurry.

The sulphur content in the metalliferous sulphide concentrate may be above 30%.

20 In some embodiments a portion of the metalliferous sulphide concentrate may be added to the feed slurry to react with highly oxidised laterite ore and calcine in the high-pressure acid leach process, thereby to effect control of the discharge oxidation-reduction potential (ORP) of the high-pressure acid leach process. In such case the portion of the metalliferous sulphide concentrate added to the feed slurry may be less than 15% of the
25 total mass of metalliferous sulphide concentrate supplied for the step of roasting.

The metalliferous sulphide concentrate may be combined with elemental sulphur prior to being roasted and so that subsequently the metalliferous sulphide concentrate and the elemental sulphur are roasted together.

5 The base metals contained in the metalliferous sulphide concentrate may comprise nickel and/or cobalt and these base metals may be co-extracted in the HPAL autoclave and recovered downstream thereof via conventional hydrometallurgical processes.

The base metals contained in the metalliferous sulphide concentrate may comprise base metals other than nickel and cobalt and these base metals may be co-extracted in the HPAL autoclave and recovered downstream thereof via conventional hydrometallurgical processes. In one embodiment, these base metals may be copper, cadmium or zinc.

10 The metalliferous sulphide concentrate may contain precious metals, such as gold or platinum group metals, and these may be selectively extracted (a) prior to combination of the calcine with the laterite ore, (b) in the HPAL autoclave, or (c) from the leach residue of the HPAL process using conventional hydrometallurgical processes.

15 According to a second aspect of the present invention, there is provided a metallurgical extraction plant for co-processing laterite ores and sulphide concentrates, the plant comprising:

a roasting unit for roasting a metalliferous sulphide concentrate in air to produce a sulphur dioxide containing gas and a calcine;

20 a sulphuric acid plant for receiving the sulphur dioxide containing gas from the roasting unit and processing the sulphur dioxide containing gas to sulphuric acid;

mixing equipment for combining the calcine with a laterite ore to form a feed slurry; and

25 a high-pressure acid leach autoclave arranged to process the feed slurry and the sulphuric acid to extract base metals or value metals contained both in the laterite ore and in the metalliferous sulphide concentrate.

According to a third aspect of the present invention, there is provided a metallurgical extraction method for co-processing laterite ores and sulphide concentrates comprising the steps of:

30 roasting a metalliferous sulphide concentrate in air to produce a sulphur dioxide containing gas and a calcine;

processing the sulphur dioxide containing gas to produce sulphuric acid;
processing a feed slurry of laterite ore and the sulphuric acid in a high-pressure acid leach process to extract base metals or value metals contained in the laterite ore;
combining the calcine with a discharge slurry from the high-pressure acid leach
5 process; and
leaching the calcine in a hot acidic atmospheric leach to extract the base metals or value metals contained in the calcine.

The step of roasting the metalliferous sulphide concentrate may comprise a sulphatising roast at a temperature in the range of 500-800°C.

10 According to a fourth aspect of the present invention, there is provided a metallurgical extraction plant for co-processing laterite ores and sulphide concentrates, the plant comprising:

a roasting unit for roasting a metalliferous sulphide concentrate in air to produce a sulphur dioxide containing gas and a calcine;
15 a sulphuric acid plant for receiving the sulphur dioxide containing gas from the roasting unit and processing the sulphur dioxide containing gas to sulphuric acid;
a high-pressure acid leach autoclave for processing a feed slurry of laterite ore and the sulphuric acid to extract base metals or value metals contained in the laterite ore; and
an atmospheric acid leach agitated tank configured to combine the calcine with a
20 discharge slurry from the autoclave and leach the calcine in a hot acidic atmospheric leach to extract the base metals or value metals contained in the calcine.

BRIEF DESCRIPTION OF DRAWINGS

The present invention will now be described, by way of example, with reference to the accompanying schematic drawings, in which:

25 Figure 1 is a flow diagram of a conventional high-pressure acid leach (HPAL) process wherein elemental sulphur is used as a feedstock for sulphuric acid generation;

Figure 2 is a flow diagram of a first embodiment of a metallurgical extraction method for co-processing of laterite ores and metalliferous sulphide concentrates wherein a metalliferous sulphide concentrate is roasted for sulphuric acid generation and a resultant
30 calcine is co-processed with the laterite ores in an HPAL autoclave;

Figure 3 is a flow diagram of a second embodiment of the metallurgical extraction method shown in Figure 2, wherein the resultant calcine is combined with a leach

discharge from the HPAL autoclave; and

Figure 4 is a flow diagram of a third embodiment of the metallurgical extraction method shown in Figure 2, wherein the resultant calcine is subjected to an intermediate precious metals recovery step prior to processing through the HPAL autoclave.

5 **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

Referring to Figure 2, there is shown a flow diagram 10 of a first embodiment of a metallurgical extraction method for co-processing of laterite ores and metalliferous sulphide concentrates. The metalliferous sulphide concentrate is roasted to produce steam and sulphuric acid for use in a high-pressure acid leach (HPAL) process, with the resultant roasted calcine being combined with the laterite ore and treated through the HPAL process to leach the contained base or value metals.

The method comprises the step of providing a feed (optionally from a storage hopper) of metalliferous sulphide concentrate 12 containing base or value metals to be processed and incorporated into a conventional HPAL process for treatment of nickel laterite ores. The metalliferous sulphide concentrate 12 is fed into and roasted in a fluidized bed roaster 14 or similar suitable equipment at temperatures in the range of 500-1000°C. The roaster 14 is preferably a stationary fluidised bed reactor, but it can also be a circulating fluidised bed roaster or a rotary kiln or other suitable roasting equipment, the selection of which is dependent on the properties of the sulphide feedstock. The roasting is conducted in air or in oxygen-enriched air to produce a gaseous product and a solid product.

The gaseous product is separated from the solid product via cyclones and a wet electrostatic precipitator. The gaseous product comprises a sulphur dioxide containing hot gas 16 that is subsequently passed through a heat recovery boiler 18 to recover heat therefrom by producing steam, e.g. high-pressure steam 26. The hot gas 16 is further passed through scrubbers as part of gas cleaning 20, before the sulphur dioxide gas is passed through a sulphuric acid plant 22 to produce sulphuric acid which is then subsequently fed to and used in a HPAL process or autoclave 24 to leach nickel laterite or oxide ore.

The high-pressure steam 26 produced in the heat recovery boiler 18 is used for heating a feed slurry in the HPAL autoclave 24 and maintaining a target leach temperature inside

the autoclave 24. The high-pressure steam 26 may also be used for generating electric power via a steam turbine generator.

During the roasting process the solid product is produced by converting the metalliferous sulphide to an oxidised dry calcine 30. The calcine 30 may be optionally ground finer in a mill. The calcine 30 is then combined with a laterite ore 34 to form a feed slurry. In one embodiment the calcine 30 is combined with the laterite ore 34 in an ore preparation circuit prior to passing through a thickener 32, whereby the thickener underflow forms the feed slurry. Alternatively, the laterite ore 34 is first passed through the thickener 32 whereafter the calcine 30 is combined with the thickener underflow to form the feed slurry. A series of high-pressure pumps are used to introduce the dense feed slurry, via a series of pre-heaters 28, to the HPAL autoclave 24. The contained value metals, preferably cobalt and nickel, are co-extracted to a high extent under the aggressive HPAL leaching conditions. Finally, the leached slurry is discharged from the HPAL autoclave 24 and passes through a series of pressure let down valves and flash vessels 36 into one or more agitated atmospheric leach tank reactors 38 before proceeding to further downstream metal recovery stages 40. The additional value metals contained in the calcine are recovered together with the value metals present in the original laterite ore in this process.

Flash steam from the pressure letdown in the flash vessels 36 is used for heating the feed slurry during a pre-heating stage 28 before the slurry enters the HPAL autoclave 24.

In one embodiment the calcine 30 is coarser and has a higher specific gravity (density) than the laterite ore 34, so that combination of these results in formation of a feed slurry of higher solids concentration and improved rheological properties when compared to the laterite ore 34 alone. The higher concentration of solids in the feed slurry improves the productivity of the HPAL autoclave 24. The dry calcine 30 may be blended with the laterite thickener underflow to avoid other costlier thickening methods and typically the blending may include high shear mixing. A viscosity modifier may be optionally added to the feed slurry. In some embodiments the dry calcine 30 can be combined and mixed with the laterite ore 34 prior to thickening.

A typical HPAL processing plant is tailored to recover nickel and cobalt as saleable commodities via various downstream recovery processes 40. Such downstream processes 40 may comprise methods that result in production of intermediate mixed sulphide or mixed hydroxide products that require further refining, or they may comprise

processes that produce final LME grade metal or saleable metal salts. In one embodiment the contained value metals in the metalliferous sulphide concentrate and calcine are nickel and/or cobalt and they are present in concentrations of commercial interest, typically above 2% nickel equivalent.

- 5 Preferably the sulphur content in the metalliferous sulphide concentrate is above 30%.

In one embodiment the roast is a “dead roast” performed at temperatures of 700-1000°C with at- or near-total conversion of sulphide to sulphur dioxide containing gas to maximize the production of sulphuric acid and steam generation. The calcine produced by such a dead roast typically contains some base metal ferrites, which are refractory to
10 atmospheric acid leaching, but will typically be leached in HPAL conditions.

In essence the method 10 uses a metalliferous sulphide concentrate as an alternative feedstock to elemental sulphur for sulphuric acid production and also provides a means to extract additional value metals, preferably nickel and/or cobalt from the calcine.

The HPAL leach solution preferably consists of solubilised metal sulphate salts; optionally
15 and additionally it may contain chloride or other anions.

If desired, a minor portion of the metalliferous sulphide concentrate 12, typically less than 15%, optionally less than 10%, of the total mass of metalliferous sulphide concentrate supplied for the roasting process, can be added to the feed slurry to effect reaction in the HPAL autoclave 24 with the highly oxidised laterite and calcine feed
20 materials and effect control of the HPAL discharge oxidation-reduction potential (ORP), which can be important to ensure reduction of Cr(VI), Mn and Co containing minerals during the HPAL process, and so achieve the optimal discharge ORP, preferably between 300-600 mV vs Ag/AgCl, prior to further downstream treatment, which may include neutralisation, purification and metal recovery. As with the calcine 30, the minor portion of
25 the metalliferous sulphide concentrate may be added to the feed slurry before or after the thickener 32.

The cobalt and nickel value metals entering the system through the metalliferous sulphide concentrate 12 are subsequently co-extracted and refined with the same metals leached from the laterite ore feed passing through the HPAL autoclave 24.

In a further embodiment, the method 10 entails the partial roasting of the metalliferous sulphide concentrate 12, typically to an 85-95% extent, by modification of the temperature and oxygen stoichiometry. This may result in production of a calcine that is less refractory (resistant) to leaching and in such case the calcine and the remaining sulphides will likely
5 react indirectly with the lateritic oxides in the HPAL process in oxidation-reduction reactions.

Referring to Figure 3, there is shown a flow diagram 200 of a second embodiment of a metallurgical extraction method for co-processing of laterite ores and metalliferous sulphide concentrates. The method used in this second embodiment is largely the same
10 as that of the first embodiment and thus the respective parts and steps will be indicated using the same reference numerals. In this second embodiment the metalliferous sulphide concentrate 12 is subjected to sulphatising roasting in the roaster 14 at a temperature in the range of 500-800°C.

The second embodiment includes the optional step of including a sulphate salt 202 with
15 the metalliferous sulphide concentrate 12 for combined roasting in the roaster 14 to enhance the extent of subsequent extraction.

The base metals contained in the calcine 30 of the second embodiment are present predominantly as sulphates and oxides. Since these are more readily soluble, the calcine 30 can be added to or otherwise combined later in the process, namely with the
20 leached laterite slurry discharged from the HPAL autoclave 62, more typically after discharging from the flash letdown 36. Thus, the calcine 30 is not processed through the HPAL autoclave 24. Instead the combined leached laterite slurry and calcine 30 is subsequently leached in the hot acidic atmospheric leach 38 for extraction of the base metals and value metals contained in the calcine.

25 In an alternative embodiment, the methods 10 or 200 comprise a combination of a sulphur burner for burning elemental sulphur and a roaster 14 operating in parallel and feeding the combined off-gasses through the adsorption section of the sulphuric acid plant 22.

It is also envisaged that the feed to the roaster 14 can comprise more than one sulphide or sulphur feedstock. For example, the feed can comprise a combination of elemental
30 sulphur prills together with metalliferous sulphide concentrate. This has the advantage in

that should the metalliferous sulphide concentrate be totally depleted, the fluidised bed roaster 14 can be operated with the sulphur prills and a calcine substrate.

In some embodiments of the method 10 a different sulphide feedstock may be fed to the roaster 14 than is used in the HPAL process. For example, the feedstock for the
5 roaster 14 can comprise a cobaltiferous pyrite concentrate, while the sulphide that is blended with the feed slurry to be fed into the HPAL autoclave 24 can comprise a nickel-rich pentlandite/pyrrhotite concentrate.

In the event that the metalliferous sulphide concentrate 12 also contains other value metals, such as copper, cadmium or zinc, the downstream metal recovery stages may be
10 modified for effective recovery of such metals. For example, hydrometallurgical recovery techniques such as solvent extraction may be used to affect such separations.

Referring to Figure 4, there is shown a flow diagram 300 of a third embodiment of a metallurgical extraction method for co-processing of laterite ores and metalliferous sulphide concentrates. Again, the same respective parts and steps will be indicated using
15 the same reference numerals as in Figures 2 and 3. In this third embodiment the roasted calcine 30 is subjected to an intermediate treatment step 302 for recovery of certain precious metals, such as gold or platinum group metals, contained in the calcine 30 before the calcine is fed into the HPAL autoclave 24 (as per the first embodiment 10) or into the atmospheric leach 38 (as per the second embodiment 200).

20 Alternatively, the precious metals entering the process may be recovered as part of downstream metal recovery 40. In such a case the precious metals may typically be recovered subsequent to the base metals by treatment of the leach residue.

Using the methods 10, 200 or 300 enables the production of sulphuric acid, steam and electric power from roasting of a metalliferous sulphide concentrate, which may be
25 sourced at a lower equivalent cost than elemental sulphur. Accordingly, the methods 10, 200 and 300 provide the flexibility of producing sulphuric acid from either metalliferous sulphide concentrate or elemental sulphur in a fluidised bed operation, depending on commercial cost considerations.

The methods 10, 200 and 300 enable extraction of additional value metals from the
30 roasted calcine 30, increasing the overall yield of cobalt, nickel and or other value metals.

The addition of the dry calcine 30 to the wet laterite ore 34 can be used to modify the properties of the HPAL feed slurry such as density, temperature and rheology and thereby permit optimisation of the operation of the HPAL autoclave 24. Similarly, the addition of a fraction of the metalliferous sulphide concentrate 12 to the feed slurry for the HPAL autoclave 24 can be used to control the HPAL discharge conditions.

The methods 10, 200 and 300 can be incorporated into existing nickel laterite HPAL processing facilities that are encountering depleting laterite ore grades, whereby the roasting of metalliferous sulphide concentrates will enrich the HPAL feed slurry and extend the operational life of the processing facility.

The metallurgical extraction methods 10, 200 and 300 thus allow for the synergistic co-processing of laterite ores and sulphide concentrates to reduce overall operating cost and increase metal recoveries.

Example

A mining company owns the rights to a nickel laterite deposit and, based on a number of factors, is planning to utilise a conventional HPAL process, as shown in Figure 1, to process the laterite ore at a rate of two million tonnes per annum. The laterite ore contains 1.0% Ni and 0.2% Co and has a specific gravity (SG) of 3.3. The HPAL feed slurry density is 38 wt/wt% solids and the process requires 300 kg/t sulphuric acid addition to the HPAL autoclave. Downstream recovery for the nickel and cobalt entails separation methods to produce a nickel-cobalt mixed sulphide intermediate product for further refining in a dedicated nickel-cobalt refinery with spare capacity. It is assumed that 90% recovery of cobalt and nickel are achieved to the final product.

However, a suitably sized semi-massive sulphide deposit, 100 km away by road, contains a combination of cobalt, nickel and iron sulphide minerals. The predominant minerals are pyrite and pyrrhotite, with cobalt and nickel being intergrown in these sulphide minerals, so that production of smeltable high-grade nickel and/or cobalt concentrate is not possible. Nevertheless, a bulk metalliferous sulphide concentrate with a specific gravity of 4.5 can be produced using a comminution circuit in combination with gravity concentration and froth flotation to have the following composition: 3.0% Ni, 0.5% Co, 47.5 % Fe and 40.5% S.

This concentrate is too high in sulphur and too low in base metals to treat economically in conventional pyrometallurgical or hydrometallurgical circuits. However, it would be viable to utilise the method 10 as depicted in Figure 2, i.e. roasting the sulphide concentrate prior to incorporation into the HPAL process. The following assumptions are made for such operation:

- A mine and concentrator will be operated to produce the bulk sulphide concentrate.
- The bulk sulphide concentrate will be transported by road trains to the location of the laterite deposit and the proposed HPAL Plant.
- The process uses a concentrate roasting acid plant without a sulphur burner.
- 10 • The concentrate is dead roasted in a stationary fluidised bed roaster at a temperature of 750-850°C.
- The resultant calcine is blended with the thickened laterite slurry and treated through the HPAL autoclave together with the laterite ore, also yielding >90% cobalt and nickel extraction.
- 15 • Following neutralisation of the residual acid with limestone and liquid-solids separation by counter current decantation, nickel and cobalt are precipitated as a mixed sulphide intermediate that is transported to the refinery.

For comparative purposes it is assumed that the process is constrained by the HPAL autoclave's volumetric throughput. Autoclave volume, temperature and residence time typically provide the key "setpoint" for the entire HPAL processing plant design.

The following Table 1 compares calculation of the two operating scenarios, whereby the first column represents the operation of the plant according to the conventional HPAL process of Figure 1 and the second column represents conversion of the plant according to the HPAL process of Figure 2:

Aspect	Units	(A) Sulphur Burning HPAL Plant	(B) Concentrate Roasting HPAL Plant
Laterite Feed			
Ore Feed Rate	tpa	2,000,000	1,863,400
Nickel Grade	%	1.00	1.00
Cobalt Grade	%	0.20	0.20
Acid Plant			
Acid Plant Type		Sulphur-burning	Sulphide Roaster
Acid Plant Production	tpa H ₂ SO ₄	600,000	603,230
	tpd H ₂ SO ₄	1,730	1,740
Elemental Sulphur for acid	tpa S	193,939	None
Sulphide Concentrate			
Concentrate Feed Rate	tpa	None	476,840
Sulphur Content	%		40.5
Nickel Grade	%		3.00
Cobalt Grade	%		0.50
Calcine Produced	tpa	None	385,720
Combined Autoclave Feed			
Solids Mass Flowrate	tpa	2,000,000	2,250,000
Nickel Grade	%	1.00	1.46
Cobalt Grade	%	0.20	0.27
Solids Concentration	wt/wt%	38.0	41.1
Relative Density	t/m ³	1.36	1.41
Volumetric Flowrate	m ³ /h	520	520
Total Metal Recovery			
Nickel	tpa	18,000	29,650
Cobalt	tpa	3,600	5,510
Revenue	%	100	160

Table 1: Comparison of leaching plants operating (A) a conventional HPAL process and (B) a process according to the present disclosure

The following observations on this comparison illustrate that:

- 5 • The calcine makes up approximately 17% of the solids mass of the autoclave feed.
- The addition of calcine (SG = 4.85) to the autoclave laterite feed ore (SG = 3.3) slurry allows the density of the feed slurry to increase from 1.36 t/m³ to 1.41 t/m³ and allows for a 12% increase in solids mass flow through the autoclave.
- The contribution of nickel and cobalt in the calcine increases the feed grade to the
10 autoclave by over 40%.

- The contribution of nickel and cobalt from the calcine result in a 60% overall increase in revenue from the combined process.

The new synergistic process enables harnessing essentially all the potential included in the metalliferous sulphide concentrate:

- 5
- Sulphide sulphur is converted to sulphuric acid and energy for steam, and
 - Nickel and cobalt in the coarse and high density calcine is extracted by the HPAL processing plant and refined with additional marginal operating cost and without the need for excessive additional capital expenditure.

10 In this example the additional revenue from cobalt and nickel contained in and extracted from the calcine significantly increases the attractiveness of the sulphide roasting option over conventional sulphur burning. It follows that the benefit is proportional to the concentration of contained value metals in the calcine.

15 While not included in the example, the addition of a fraction of the metalliferous sulphide concentrate to the feed slurry could also be considered, potentially contributing further to the profitability of the project.

While most metalliferous sulphide minerals can be considered for co-processing with laterite ore via the disclosed method, examples of sulphide mineral assemblages that may be of particular interest for application of the disclosed method include the following:

- 20
- Pyrite with Cobalt Enrichment (Cobaltiferous Pyrite)
 - Pyrrhotite/Pentlandite intergrowths that are difficult to separate and concentrate (Nickeliferous Pyrrhotite)
 - Combinations of pyrrhotite, pyrite and other minor sulphide minerals that contain valuable base metal sulphides in various and varying concentration
 - Nickel sulphide deposits with high talc concentrations, making the concentrates
- 25 unsuitable for smelting.

Naturally, nickel or cobalt sulphide concentrates of higher grade, including smelter grade could also be considered for inclusion.

In the claims which follow and in the preceding description of the invention, except where the context requires otherwise due to express language or necessary implication, the word "comprise" or variations such as "comprises" or "comprising" is used in an inclusive sense, i.e. to specify the presence of the stated features but not to preclude the presence
5 or addition of further features in various embodiments of the invention.

CLAIMS

1. A metallurgical extraction method for co-processing laterite ores and sulphide concentrates comprising the steps of:
 - roasting a metalliferous sulphide concentrate in air to produce a sulphur dioxide containing gas and a calcine;
 - processing the sulphur dioxide containing gas to produce sulphuric acid;
 - combining the calcine with a laterite ore to form a feed slurry; and
 - processing the feed slurry and the sulphuric acid in a high-pressure acid leach process to extract base metals or value metals contained both in the laterite ore and in the calcine.
2. A metallurgical extraction method as claimed in claim 1, wherein the metalliferous sulphide concentrate is roasted at a temperature in the range of 500 – 1000°C.
3. A metallurgical extraction method as claimed in claim 2, wherein the metalliferous sulphide concentrate is submitted to dead-roasting at a temperature in the range of 700 – 1000°C.
4. A metallurgical extraction method as claimed in claim 2, wherein the metalliferous sulphide concentrate is submitted to partial-roasting by selecting a desired temperature and oxygen stoichiometry.
5. A metallurgical extraction method as claimed in any one of claims 1 to 4, wherein the metalliferous sulphide concentrate is roasted in any one of a stationary fluidised bed roaster, a circulating fluidised bed roaster, a rotary kiln or any other suitable roasting equipment.
6. A metallurgical extraction method as claimed in any one of claims 1 to 5, wherein the metalliferous sulphide concentrate is roasted in oxygen-enriched air.
7. A metallurgical extraction method as claimed in any one of claims 1 to 6, wherein the sulphur dioxide containing gas produced in the roaster is passed through a heat recovery boiler to produce steam.

8. A metallurgical extraction method as claimed in claim 7, wherein the steam is used to preheat the feed slurry prior to processing the feed slurry in the high-pressure acid leach process.
9. A metallurgical extraction method as claimed in claim 7 or 8, wherein the steam is used to heat the slurry inside an autoclave used in the high-pressure acid leach process.
10. A metallurgical extraction method as claimed in any one of claims 1 to 9, wherein the laterite ore is a nickel laterite ore.
11. A metallurgical extraction method as claimed in any one of claims 1 to 10, wherein the density of the calcine is higher than the density of the laterite ore so that combining these in the feed slurry results in the feed slurry having a higher solids concentration and improved rheological properties compared to that of the laterite ore.
12. A metallurgical extraction method as claimed in any one of claims 1 to 11, wherein the calcine is combined with the laterite ore prior to being passed through a thickener and whereby the thickener underflow forms the feed slurry.
13. A metallurgical extraction method as claimed in any one of claims 1 to 11, wherein the laterite ore is passed through a thickener whereafter the calcine is combined with the thickener underflow to form the feed slurry.
14. A metallurgical extraction method as claimed in any one of claims 1 to 13, wherein the sulphur content in the metalliferous sulphide concentrate is above 30%.
15. A metallurgical extraction method as claimed in any one of claims 1 to 14, wherein a portion of the metalliferous sulphide concentrate is added to the feed slurry to react with highly oxidised laterite ore and calcine in the high-pressure acid leach process, thereby to effect control of the discharge oxidation-reduction potential (ORP) of the high-pressure acid leach process.

16. A metallurgical extraction method as claimed in claim 15, wherein the portion of the metalliferous sulphide concentrate added to the feed slurry is less than 15% of the total mass of metalliferous sulphide concentrate supplied for the step of roasting.
17. A metallurgical extraction method as claimed in any one of claims 1 to 16, wherein the metalliferous sulphide concentrate is combined with elemental sulphur prior to being roasted and wherein subsequently the metalliferous sulphide concentrate and the elemental sulphur are roasted together.
18. A metallurgical extraction method as claimed in any one of claims 1 to 17, wherein base metals contained in the metalliferous sulphide concentrate comprise nickel and/or cobalt and these base metals are co-extracted in the HPAL autoclave and recovered downstream thereof via conventional hydrometallurgical processes.
19. A metallurgical extraction method as claimed in any one of claims 1 to 18, wherein base metals contained in the metalliferous sulphide concentrate comprise base metals other than nickel and cobalt and these base metals are co-extracted in the HPAL autoclave and recovered downstream thereof via conventional hydrometallurgical processes.
20. A metallurgical extraction method as claimed in claim 19, wherein the base metals comprise copper, cadmium or zinc.
21. A metallurgical extraction method as claimed in any one of claims 1 to 20, wherein the metalliferous sulphide concentrate contains precious metals, such as gold or platinum group metals, and these are selectively extracted (a) prior to combination of the calcine with the laterite ore, (b) in the HPAL autoclave, or (c) from the leach residue of the HPAL process using conventional hydrometallurgical processes.
22. A metallurgical extraction plant for co-processing laterite ores and sulphide concentrates, the plant comprising:
 - a roasting unit for roasting a metalliferous sulphide concentrate in air to produce a sulphur dioxide containing gas and a calcine;
 - a sulphuric acid plant for receiving the sulphur dioxide containing gas from the roasting unit and processing the sulphur dioxide containing gas to sulphuric acid;
 - mixing equipment for combining the calcine with a laterite ore to form a feed

slurry; and

a high-pressure acid leach autoclave arranged to process the feed slurry and the sulphuric acid to extract base metals or value metals contained both in the laterite ore and in the calcine.

23. A metallurgical extraction method for co-processing laterite ores and sulphide concentrates comprising the steps of:

roasting a metalliferous sulphide concentrate in air to produce a sulphur dioxide containing gas and a calcine;

processing the sulphur dioxide containing gas to produce sulphuric acid;

processing a feed slurry of laterite ore and the sulphuric acid in a high-pressure acid leach process to extract base metals or value metals contained in the laterite ore;

combining the calcine with a discharge slurry from the high-pressure acid leach process; and

leaching the calcine in a hot acidic atmospheric leach to extract the base metals or value metals contained in the calcine.

24. A metallurgical extraction method as claimed in claim 23, wherein the step of roasting the metalliferous sulphide concentrate comprises a sulphatising roast at a temperature in the range of 500-800°C.

25. A metallurgical extraction plant for co-processing laterite ores and sulphide concentrates, the plant comprising:

a roasting unit for roasting a metalliferous sulphide concentrate in air to produce a sulphur dioxide containing gas and a calcine;

a sulphuric acid plant for receiving the sulphur dioxide containing gas from the roasting unit and processing the sulphur dioxide containing gas to sulphuric acid;

a high-pressure acid leach autoclave for processing a feed slurry of laterite ore and the sulphuric acid to extract base metals or value metals contained in the laterite ore; and

an atmospheric acid leach agitated tank configured to combine the calcine with a discharge slurry from the autoclave and leach the calcine in a hot acidic atmospheric leach to extract the base metals or value metals contained in the calcine.

Figure 1 (Prior Art)

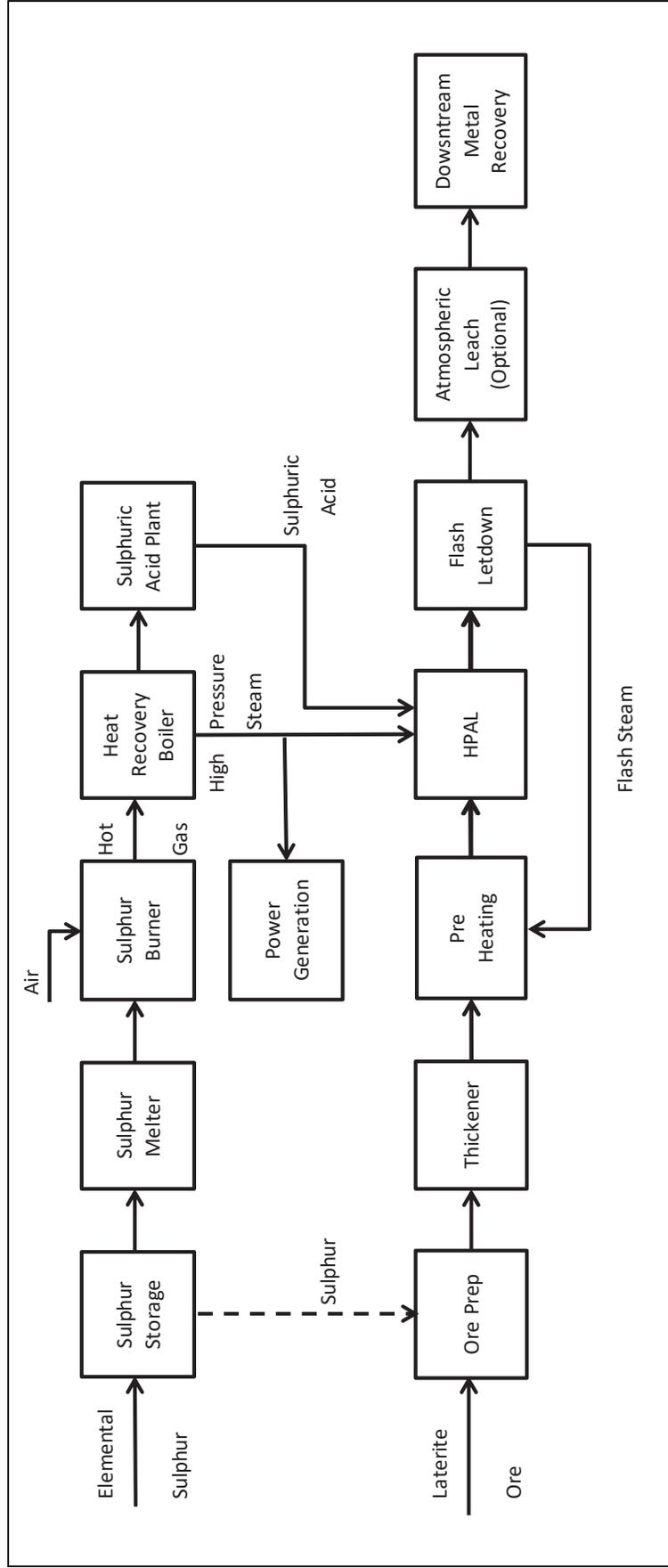


Figure 3

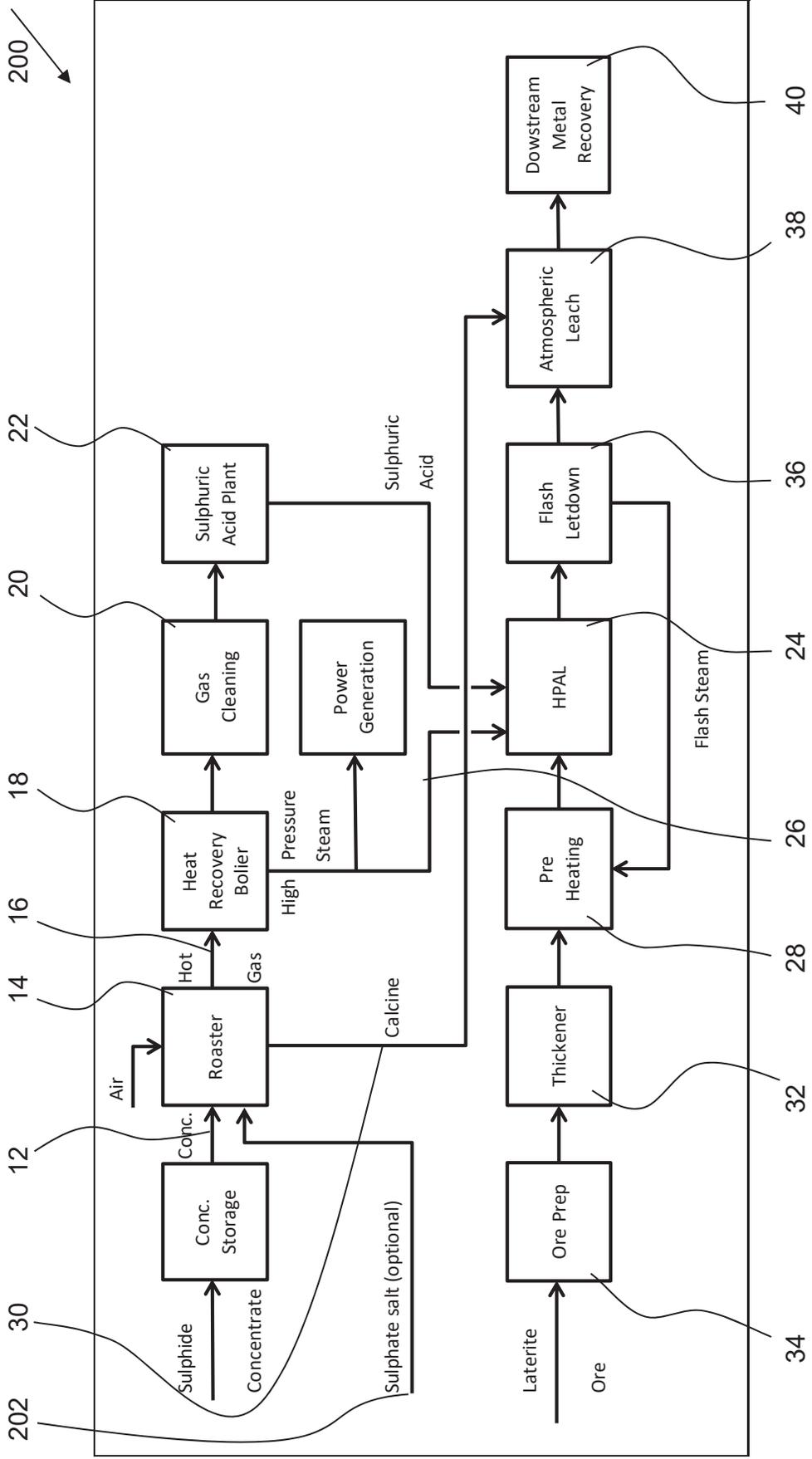


Figure 4

