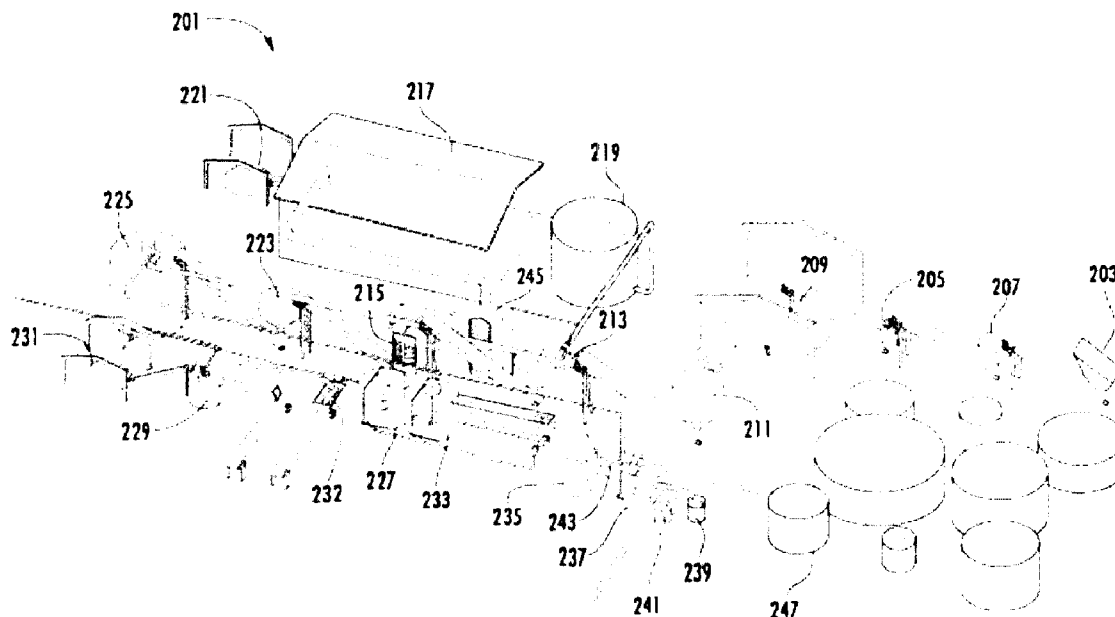


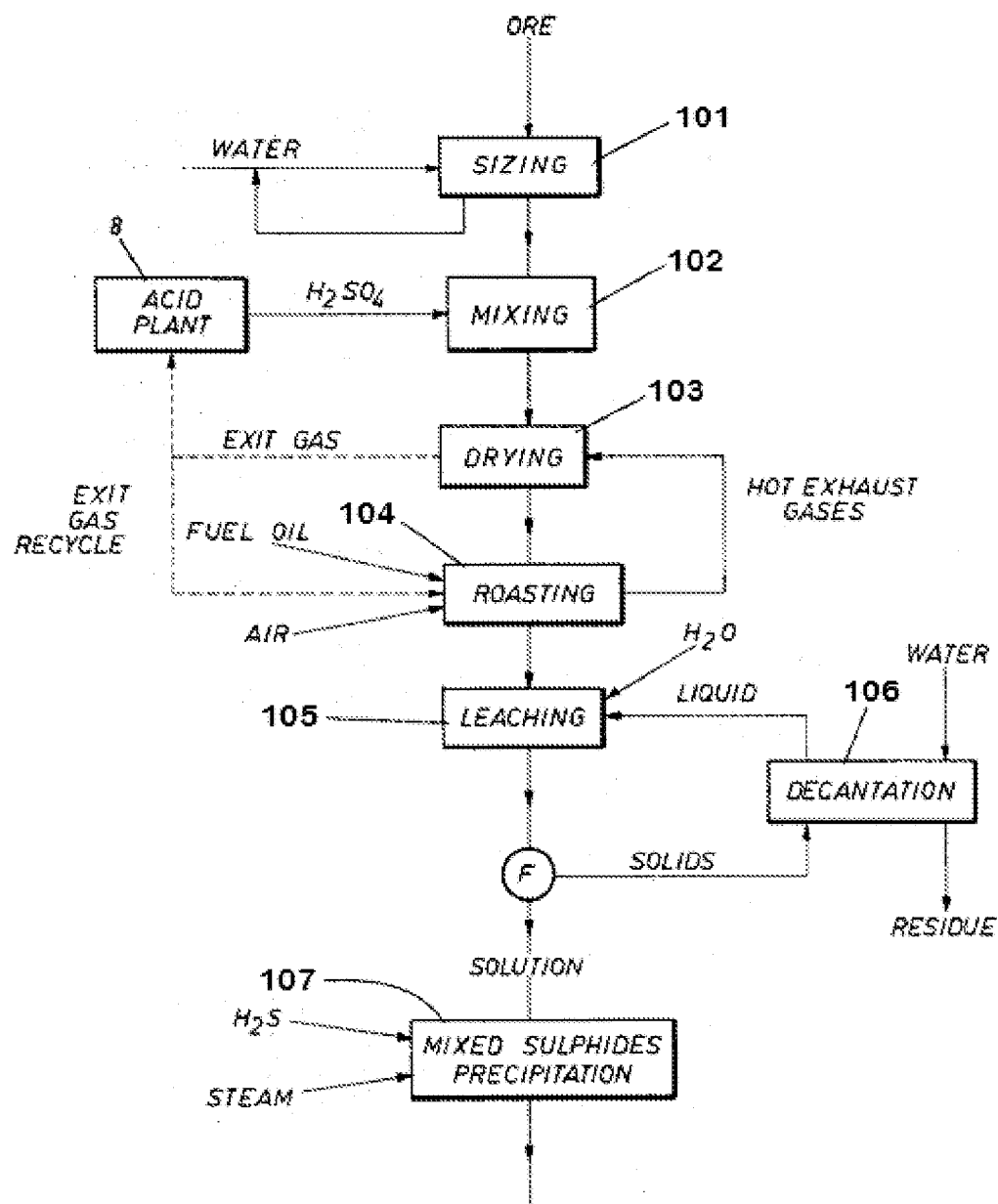


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Duyvesteyn(10) **Pub. No.: US 2012/0204680 A1**(43) **Pub. Date: Aug. 16, 2012**(54) **SYSTEM AND METHOD FOR RECOVERY OF
NICKEL VALUES FROM
NICKEL-CONTAINING ORES****Publication Classification**(51) **Int. Cl.**
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205/594**(75) **Inventor: Willem P. C. Duyvesteyn, Reno,
NE (US)**(73) **Assignee: EMC Metals Corporation**(21) **Appl. No.: 13/102,652**(22) **Filed: May 6, 2011****Related U.S. Application Data**(63) **Continuation-in-part of application No. 13/025,393,
filed on Feb. 11, 2011.**(57) **ABSTRACT**

A method is provided for extracting nickel values from nickel-containing ores. The method comprises (a) treating a nickel-containing ore with an acid, thereby producing an acid treated ore; (b) baking the acid treated ore, thereby producing a baked ore; (c) leaching nickel from the baked ore to form a leachate; and (d) extracting nickel values from the leachate through the use of an ion exchange resin.





- Prior Art -

FIG. 1

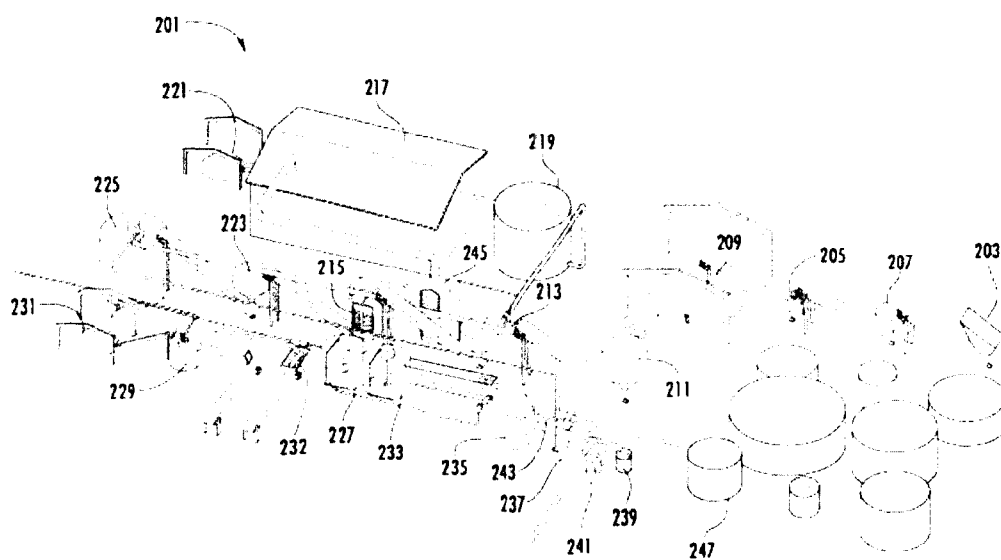
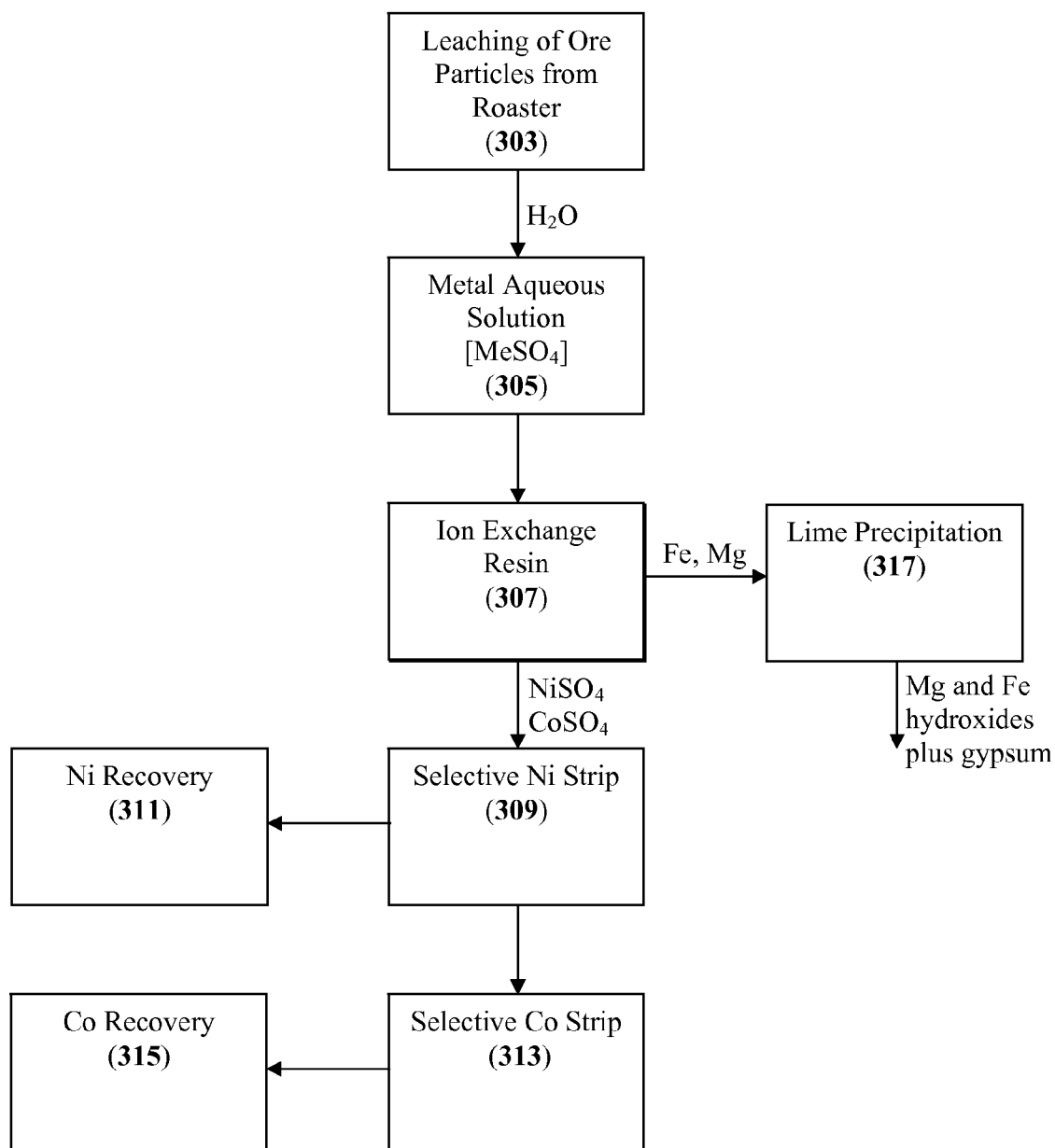


FIG. 2

301**FIG. 3**

SYSTEM AND METHOD FOR RECOVERY OF NICKEL VALUES FROM NICKEL-CONTAINING ORES

REFERENCE TO RELATED APPLICATIONS

[0001] The present application is a continuation-in-part of U.S. Ser. No. 13/025,393 (Duyvesteyn), entitled "System and Method for Recovery of Scandium Values From Scandium-Containing Ores", which was filed on Feb. 11, 2011, and which is incorporated herein by reference in its entirety.

FIELD OF THE DISCLOSURE

[0002] The present disclosure relates generally to systems and methods for producing nickel, and more particularly to systems and methods for recovering nickel values, alone or in combination with cobalt and scandium values, from laterite ore feedstocks.

BACKGROUND OF THE DISCLOSURE

[0003] Nickel is a silvery-white metal which is produced primarily from laterite deposits and magmatic sulfide deposits. In laterites, the primary ore minerals are nickeliferous limonite and saprolite or garnierite. Limonite has the general composition $(\text{Fe, Ni})\text{O}(\text{OH})$, while saprolite is a hydrous nickel silicate. Garnierite, which has the general composition $(\text{Ni, Mg})_3\text{Si}_2\text{O}_5(\text{OH})_4$, is not a single mineral, but is a mixture of Ni—Mg-hydrosilicates, namely serpentine, talc, sepiolite, chlorite and smectite. These minerals occur in garnierite ores both individually and in intimate mixtures. In nickel-bearing magmatic sulfide deposits, the principal ore mineral is pentlandite, having the general composition $(\text{Ni, Fe})_9\text{S}_8$.

[0004] At present, Canada produces approximately 30% of the world nickel supply, principally from the Sudbury Basin deposit in Ontario. Russia also contains significant nickel deposits, primarily at the Norilsk deposit in Siberia, which is thought to contain about 40% of all known nickel-bearing deposits. Significant nickel deposits have also been found in New Caledonia, France, Australia, Indonesia and Cuba.

[0005] A variety of methods have been developed in the art for the processing and extraction of metal values from nickeliferous ores. However, many of the existing methods must be implemented on feedstocks derived from ores that have already undergone some processing. In particular, many of these methods are designed to extract nickel from the products of other processes in which other metal values have already been extracted from the feedstock, or in which the chemical or physical structure of the original ore have been significantly modified. For example, the Mond process may be utilized to produce highly purified nickel by reacting partially purified nickel (obtained, for example, from froth flotation) with excess carbon monoxide at 50-60° C. to form nickel carbonyl:



The volatile nickel carbonyl is then removed as a gas, while any impurities (including other metals) present at this point in the process remain behind in the solid phase. The isolated nickel carbonyl may then be thermally decomposed to give highly pure nickel metal.

[0006] Some processes have also been developed for the extraction of metal values directly from nickeliferous ores. For example, the Sherritt-Gordon process, which is described in U.S. Pat. No. 3,244,513 (Zubryckyj), is a hydrometallurgical process for extracting nickel values from nickel laterite ores. An embodiment of this process is depicted in FIG. 1.

[0007] As seen therein, the Sherritt-Gordon process commences with a lateritic ore feedstock which is subjected to a preliminary sizing step **101** to separate oversized particles from the feedstock and produce finely divided ore particles. The sized feedstock is then mixed with water to form a slurry containing 25% to 35% solids. The slurry is mixed **102** with concentrated sulfuric acid in amounts at least sufficient, and preferably in slight excess of that required, to combine with the nickel, cobalt, manganese and magnesium values as sulfates, but less than that required to combine with the iron and the nonferrous metal values contained in the ore particles. The acidified slurry is then dried **103** and roasted **104** at a temperature within the range of 500° C. to 725° C. under controlled conditions to obtain sulfation of the nickel, cobalt and manganese values contained therein.

[0008] The sulfated particles are then leached **105** from the dried, roasted particles by dispersing the particles in an aqueous leaching solution to form a slurry. The nickel, cobalt and manganese sulfates are extracted in this process, and the undissolved residue is separated from the leach solution by decantation **106**. The solution is then reacted with a sulfidizing agent to convert the dissolved nickel and cobalt values to sulfides. The nickel and cobalt sulfides are then precipitated **107** from the solution. Nickel and cobalt sulfide concentrates recovered by the Sherritt-Gordon process can be further treated by either roasting or flash smelting, or else the sulfide concentrates may be treated by an ammonia solution pressure leach.

SUMMARY OF THE DISCLOSURE

[0009] In one aspect, a method is provided for extracting nickel values from nickel-containing ores. The method comprises (a) treating a nickel ore with an acid, thereby producing an acid treated ore; (b) baking the acid treated ore, thereby producing a baked ore; (c) leaching nickel from the baked ore to form a leachate; and (d) extracting nickel values from the leachate through the use of an ion exchange resin.

[0010] In another aspect, a method is provided for extracting nickel values from nickel-containing ores is provided. The method comprises (a) providing an ore which contains nickel; (b) treating the ore with an acid; (c) baking the ore, thus generating gaseous effluents; (d) recycling the gaseous effluents to reconstitute the acid; and (e) using the reconstituted acid in a second iteration of the method.

[0011] In a further aspect, a method is provided for extracting nickel values from ores that contain both nickel and scandium. The method comprises (a) treating the ore with an acid, thereby producing an acid treated ore; (b) baking the acid treated ore, thereby producing a baked ore; (c) leaching nickel and scandium from the baked ore to form a leachate; and (d) recovering nickel and scandium values from the leachate.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. 1 is a flowchart depicting a prior art process (the Sherritt process) for recovering nickel values.

[0013] FIG. 2 is an illustration of a first embodiment of a method for extracting metal values from ores in accordance with the teachings herein.

[0014] FIG. 3 is an illustration of a second embodiment of a method for extracting metal values from ores in accordance with the teachings herein.

DETAILED DESCRIPTION

[0015] While the methods currently known to the art for recovering nickel values from ore feedstocks may be useful in certain applications, a need exists in the art for further improvements in these methods. In particular, it is found that some of these methods leave significant concentrations of nickel in the treated ore, especially when the ore being treated is a nickel laterite. Other methods, such as the Mond process, require the ore to undergo preliminary processing, and hence are not suitable for application to raw ore feedstocks. Still other methods are limited in that they do not provide for the efficient co-extraction of nickel with other metal values, such as scandium and cobalt; since these values frequently occur in commercially significant levels in many nickel laterite ores, the use of such methods diminishes the return on investment of the mining operation.

[0016] Finally, some of the processes currently utilized in the art for the extraction of metal values from nickeliferous ores, such as the high pressure acid leaching process, have very high capital and operating costs associated with them. These costs are primarily centered around the formation of aqueous slurries and the subsequent pressure leaching step, since these steps require significant infrastructure to process large volumes of slurry materials.

[0017] For example, in a typical implementation of the Sherritt-Gordon process, ore feedstock is ground in an aqueous medium to yield a slurry, which is then subjected to treatment with sulfuric acid. However, the use of a slurry has the effect of diluting the concentration of hydrogen ions in the solution. This frequently results in increased time required for the sulfation reaction, and/or increases in the amount of acid required for sulfation. Moreover, the use of a slurry significantly increases the amount of water that must be removed in the subsequent roasting step, and thus adds significantly to the cost of that process. Hence, although the Sherritt-Gordon process is often capable of extracting high percentages of nickel from lateritic ores, the value of extracted metals is partially offset by the significant capital and operating costs the process entails.

[0018] It has now been found that nickel and other metal values may be extracted efficiently, and in a manner requiring lower operating and capital costs, from nickel-bearing ores using the systems and methodologies disclosed herein. In particular, it has been found that nickel values may be efficiently extracted by subjecting dry ore to acid treatment, rather than treating an aqueous slurry with acid as is common in implementations of the Sherritt-Gordon process. Further improvements may be obtained by treating the dry ore with slightly diluted, rather than concentrated, sulfuric acid. Thus, while the ore feedstock may contain some water content, the percent by weight of sulfuric acid in the acid solution (after it is mixed with the ore) is preferably at least 75% by weight, more preferably within the range of about 85% to about 93% by weight, and most preferably within the range of about 87% to about 89% by weight.

[0019] Without wishing to be bound by theory, it is believed that utilizing sulfuric acid within the foregoing range of concentrations provides a high concentration of hydrogen ions, which optimizes the amount of nickel and other metal values in the ore feedstock that undergoes sulfation and improves the

reaction rate of the subsequent aqueous extraction step. Moreover, the lower water content inherent in this approach reduces the cost and overhead of the subsequent roasting process. In addition, this approach may be advantageously applied directly to raw ore feedstocks.

[0020] If the nickel-bearing ore also contains scandium and cobalt values, then these systems and methodologies may be used advantageously to extract the nickel, cobalt and scandium values, either separately or concurrently. In particular, after acid treatment, drying and roasting, a suitable leaching solution (preferably water, although in some embodiments, an aqueous solution of mineral acid or other solution may be utilized) may be utilized to extract these metal values from the ore, since these metals (in contrast to the iron that is contained in the ore) remain in a sulfated form after acid baking. The leaching solution may then be treated (as by passing it through ion exchange columns) to selectively extract nickel, alone or simultaneously with cobalt. The recovered nickel and cobalt values may then be isolated and converted into nickel or cobalt metal (e.g., via electrowinning), while the scandium values may be isolated using the methodologies disclosed herein to obtain a high-purity scandium oxide which may be further converted to scandium metal.

[0021] FIG. 2 depicts a first particular, non-limiting embodiment of a system and methodology for extracting nickel values from an ore feedstock, it being understood that this system and methodology may also be used to concurrently extract cobalt, scandium, and other metals of interest from the ore feedstock if such values are present. The system 201 depicted therein presumes a feedstock of a nickel-bearing ore. The feedstock may be derived from another process, but is preferably obtained directly from a mining operation, and will typically have a particle distribution which is reflective of the process it originated from or the type of mining procedure used to recover it. The use of ore feedstocks from laterite deposits is preferred in the systems and methodologies described herein. Moreover, the use of laterite ores containing both nickel and scandium values is further preferred, and the use of laterite ores containing nickel, cobalt and scandium values is especially preferred, due to the ability of these systems and methodologies to efficiently extract all three metals from the ore feedstock.

[0022] The feedstock may undergo preliminary processing in order to prepare it for metal extraction. For example, a particle size reduction step may be included if desired or necessary. Other preliminary processing steps may also be utilized. For example, fluoride or chloride content may be added to the ore feedstock, if desired. Alternatively, mechanical activation by fine grinding of the ore in the presence of these or other suitable fluoride or chloride sources may also result in the preferential formation of nickel, cobalt and scandium fluorides, which may be advantageous in some embodiments. Details of a device suitable for implementing such mechanical activation may be found, for example, in commonly assigned U.S. Ser. No. 12/874,460 (Duyvesteyn), entitled "LOW CARBON DIOXIDE FOOTPRINT PROCESS FOR COAL LIQUEFACTION", filed on Sep. 2, 2010, which is included herein by reference in its entirety.

[0023] As seen in FIG. 2, the first step of the process of this embodiment utilizes a screening system 203. The screening system 203 operates to separate coarse or oversized material from the ore feedstock, so that the resulting feedstock is characterized by a maximum particle size that can be readily accommodated by the subsequent ore crushing equipment

205. The screening system **203** may include a plurality of subsystems. Thus, in a preferred embodiment, the screening system utilizes one or more devices known in the art as “grizzlies”, which act as scalpels for material about six inches and larger, in conjunction with a coarse screening station which removes materials from the feed which exceed some maximum threshold (typically 0.5 to 1 inch in the largest dimension). The materials removed from the feed by these devices can then be reduced in size (e.g., by crushing) and recycled into the system.

[0024] The screened ore is then passed through a hopper **207** which feeds it into the ore crushing equipment **205**. The ore crushing equipment **205**, commonly known in the art as a “jaw crusher”, produces an ore stockpile **209** in which the average particle size in the ore feedstock has been reduced to a level (typically 0.5 inches or less) suitable for subsequent treatment and ore extraction. If necessary, this ore stockpile may be stored in an ore bin **211** until it is subjected to subsequent processing.

[0025] The ore stockpile **209** is then treated in a pug mill **213**. Within the pug mill **213**, the ore is exposed to a suitable acid, which is preferably a mineral acid, and more preferably is sulfuric acid. Generally, sulfuric acid is sold as 98% sulfuric acid, since acid concentrations lower than 95% tend to freeze in winter time in colder climates. However, in some embodiments of the systems and methodologies described herein, the use of sulfuric acid which is slightly less concentrated than 98% may be utilized. This is especially preferable if the ore being processed contains scandium values in addition to nickel (and possibly cobalt) values, since the less concentrated sulfuric acid is still effective at leaching nickel and cobalt values, but is a much more potent leaching and de-structuring agent for scandium than 98% sulfuric acid. Preferably, the concentration of the sulfuric acid used for this purpose is within the range of about 85% to about 95%, more preferably within the range of about 87% to about 93%, and even more preferably within the range of about 89% to about 91%. Most preferably, 90% sulfuric acid is used. While the use of sulfuric acid is preferred, other acids (especially other mineral acids) may also be used. These include hydrochloric acid, nitric acid, and mixtures of the foregoing with each other or with sulfuric acid.

[0026] The treated ore output by the pug mill **213** is typically in the form of a thick paste. Preferably, the ore is subject to curing for an amount of time after the addition of acid and prior to the subsequent roasting step. This curing time is preferably within the range of about 30 minutes to about 72 hours, more preferably within the range of about 1 to about 48 hours, and most preferably within the range of about 1 to about 24 hours.

[0027] Next, the ore is processed in a roaster **215**, after which it is held in a calcine tank **223** until needed. The roaster **215** may be a vertical roaster (in which case it is preferably a multiple hearth roaster) or a horizontal roaster (in which case it is preferably a rotary kiln type roaster). If the ore was treated with sulfuric acid in the pug mill **213**, then during roasting, SO_2 will be evolved from the processed ore.

[0028] The SO_2 evolved from the treated ore is collected by a scrubber **245** and is fed into an acid plant **217**, where it is utilized to make reconstituted sulfuric acid. The sulfuric acid produced by the acid plant **217** is stored in a sulfuric acid tank **219**, where it is used as needed in the pug mill **213** in the manner described above. The acid plant **217** may draw from a sulfur pile **221** as necessary for the production of make-up

sulfuric acid. The provision of an acid plant **217** represents a significant cost savings for the process, because it allows for an almost complete recycle of the sulfates produced by the process. Of course, it will be appreciated that this feature also renders the process more environmentally friendly.

[0029] While the foregoing step has been described with reference to sulfuric acid, as noted above, other acids or mixtures of acids may be utilized to treat the ore in the pug mill **213**, and the acid reformulation process may be adjusted accordingly. For example, if nitric acid is used to treat the ore in the pug mill **213**, then the NO_x evolved from the treated ore is collected by the scrubber **215** and is fed into the acid plant **217**, where it is utilized to make reconstituted nitric acid.

[0030] Next, the ore is withdrawn from the calcine tank **223** and is placed in a leaching tank **225**, where the nickel (and possibly scandium and cobalt) values in the ore are extracted. Typically, the acidity (pH), redox potential (E_h), temperature, alkali concentration, iron concentration, seeding, the presence of impurities, and other such factors of the leaching solution in the leaching tank **225** will be closely monitored during this process, since these factors will typically determine whether the nickel values (and other metal values which may be present in the ore, such as scandium or cobalt) will dissolve completely in solution, or whether a portion of these metal values will re-precipitate.

[0031] While the foregoing conditions may vary from one application to another and may depend, for example, on the ore source and the particular metals of interest, in a typical application, the pH of the leaching solution is typically less than about 2.5, preferably in the range of about 1 to about 2.5, more preferably in the range of about 1 to about 2.0, and most preferably in the range of about 1 to about 1.5.

[0032] As explained previously, fluoride may be added in various forms to the ore feed. This may occur as a preliminary treatment of the ore, or during one of the later processing steps described herein. The use of a fluoride source may have several advantages. For example, fluoride concentration and pH may be adjusted as desired to achieve the predominance of certain metal ion species in the leachate, which may prevent the undesirable precipitation of metal values or, as the case may be, may induce the desirable precipitation of scandium species.

[0033] One skilled in the art will appreciate from the foregoing that the optimal operating conditions for the leaching operation may vary from one implementation to another, and may depend on a variety of factors. However, the foregoing parameters, and the relationships they entail, may be utilized to determine optimal operating conditions for a particular implementation of the leaching operation disclosed herein.

[0034] After treatment in the leaching tank **225**, the resulting mixture is passed through a filter press **227**, or any other suitable means or equipment adapted to separate the solids content of the mixture from the leachate. The nickel (and, if present, cobalt and scandium) values contained in the entrained leachate are recovered by washing with a solution that does not result in precipitation of the soluble metals. Control of both the Eh as well as the pH may be warranted.

[0035] After the residual metal values are removed, lime is added to the isolated solids, by way of a lime slaker **229** and associated lime pile **231**, to reduce the acidity of these materials (e.g., to a pH of about 7) and to produce tailings that are suitable for disposal as dry stackable tailings. The tailings may be processed in a pug mill **232**, either during or after this

process. If needed, the lime solution can be heated to facilitate impurity precipitation; this will also typically provide enhanced filtration rates.

[0036] The clear filtrate, which at this point comprises chiefly the desired metal ions in an aqueous medium, is then subjected to further processing (as described below with respect to FIG. 3) to isolate the desired metal values. This may be accomplished, for example, by contacting the solution with a resin selective to nickel (and possibly cobalt) absorption, as taught in U.S. Pat. No. 5,626,648 and U.S. Pat. No. 6,350,420. The nickel is then extracted from the resin using an acidic stripping solution, and may be recovered from the pregnant stripping solution using suitable techniques, some of which are described below. Other metal values present in the raffinate may then be recovered by passing the raffinate through one or more ion exchange resins adapted to recover specific target metals, through pyro-hydrolysis, or through other methods as are known to the art.

[0037] FIG. 3 illustrates a particular, non-limiting embodiment of a process which may be used within the context of the system of FIG. 2 to recover metal values from roasted ore particles of the type obtained from the roaster 215. The process 301 depicted therein commences with leaching 303 of the metal values from the roasted ore particles with water or an aqueous solution of mineral acid to yield an aqueous solution 305 containing the metal values, typically as a mixture of metal sulfates. The solids may be removed by a suitable filtration process (such as with a filter press 227; see FIG. 2) or by decantation. Following leaching and the removal of solids, the pH of the solution is adjusted, if necessary, to a range of about 1 to 3.

[0038] The aqueous solution of metal sulfates is then passed through an ion exchange resin 307. In the particular embodiment depicted, the resin is selective to Ni and Co, and hence these metals are co-extracted by the ion exchange resin 307. However, in other embodiments, only Ni is extracted by the resin, and any cobalt values, if present, may be subsequently recovered through a separate ion exchange process, through pyro-hydrolysis, or through a combination of the two. In still other embodiments, metals in addition to Ni and Co (such as scandium) are extracted by the resin, and separate stripping and recovery steps may be utilized to isolate each metal. In the event that a scandium extraction step is included, scandium can be removed by a scandium selective ion exchange resin of the type disclosed in U.S. Pat. No. 4,988,487 and U.S. Pat. No. 4,965,053.

[0039] The resulting raffinate, which will typically contain magnesium and iron sulfates, is then subjected to lime precipitation 317 to yield hydrated MgO and Fe₂O₃ plus gypsum. These materials may also be utilized as neutralizers for controlling the pH of the leachate to a level of about 1 to 3 in preparing the pregnant solution for extraction of nickel and cobalt by ion exchange. In some embodiments, a portion of the raffinate, after re-acidification, may be recycled to the leaching stage.

[0040] Meanwhile, the absorbed nickel is stripped 309 from the ion exchange resin by contacting the resin with a mineral acid (HCl, H₂SO₄ or HNO₃) to form a nickel solution as an eluate thereof from which the nickel is thereafter recovered 311. Similarly, the absorbed cobalt is stripped 313 from the ion exchange resin by contacting the resin with a mineral acid to form a cobalt solution as an eluate thereof from which the cobalt is thereafter recovered 315. An analogous step may

be used to strip scandium from a scandium selective resin if a scandium extraction step is used in the process.

[0041] Various ion exchange resins may be used in the foregoing nickel, cobalt (and, if applicable, scandium) recovery processes. Preferably, however, the ion exchange resin used for nickel extraction is a chelating resin containing bis-picolylamine as the active functional group, such as a resin based on bis(2-picolyl) amine or N-(2-hydroxyethyl)-2-picolylamine. Such resins are available commercially from the Dow Chemical Company (Midland, Mich.) as Dow XFS-4195, and may be used to selectively recover nickel from mineral acid column leachates. Since the resin is an amine, the resin is protonated in an acid solution. Reference is made to TABLE 1, which lists the absorption constants for the different elements. The theoretical capacity for nickel is about 30 grams nickel per liter of well-settled resin.

TABLE 1

The Absorption Constants (K l/mol) of XFS-4195 (Sulfate Solution pH = 2)										
	Cu	Ni	Fe + 3	Cd	Zn	Co	Fe + 2	Ca	Mg	Al
K	700	190	80	70	60	30	3	<2	<1	<1

Another nickel-absorbing resin that may be used for this purpose is based on a macroporous polystyrene copolymer with a weakly basic chelating picolylamine derivative attached, i.e., specifically N-(2-hydroxypropyl)-2-picolylamine.

[0042] Referring again to FIG. 2, if the raffinate resulting from nickel (and possibly cobalt) extraction contains significant scandium values, then the raffinate is passed to an ion exchange system as taught in U.S. Pat. Nos. 4,988,487 and 4,965,053, or to a solvent extraction system 233. Alternatively, a neutralizing agent may be added to produce an impure scandium oxide precipitate for further refining.

[0043] In the solvent extraction system 233, the scandium values are selectively loaded into an organic phase having a high efficiency to selectively extract scandium from the raffinate. Such an organic phase preferably comprises an organic solvent dissolved into an organic carrier liquid (or diluent). For example, the organic solvent may comprise thenoyltrifluoroacetone or a mixture of alkyl primary amines, and is present in an amount sufficient to extract the bulk of the scandium content without extracting appreciable amounts of iron and other minerals. The organic carrier may be, for example, an aromatic solvent. Co-loaded impurities such as iron, manganese, and the like are crowded off by the incoming scandium that is contained in fresh raffinate. Suitable scandium solvent extraction systems are disclosed, for example, in U.S. Pat. No. 4,898,719 and U.S. Pat. No. 4,808,384.

[0044] Once the organic phase is fully loaded with scandium, it is stripped with a mineral acid such as, for example, hydrochloric acid, to yield a pregnant solution that contains the stripped scandium as well as some residual mineral acid. The stripped organic phase is then recycled back to the loading section where leachate solution is contacted with the organic phase.

[0045] The volume of the pregnant solution is subsequently reduced, preferably through evaporation of a portion of the solvent, to yield a scandium oxide slurry 135, and the evaporated solvent is recycled to the filter press 227. The scandium oxide slurry 235 is then treated with oxalic acid to precipitate

scandium oxalate from it, and the precipitated oxalate is passed through a Nutsche filter **237** to produce a filter cake. The filter cake is then treated in a tray oven **239** to thermally decompose the oxalate and to remove the hydrocarbon content from it, thus yielding scandium oxide **241**. The oxide is then re-dissolved in a portion of solvent (this may be recovered solvent from the solvent extraction system **233**) and is processed in a centrifuge **243** to remove any precipitates or finely suspended solids, since the presence of these materials may adversely affect the purity of the final product. The final product from the centrifuge **243** is high purity scandium oxide. The mother liquor from the centrifuge **243** may be stored in a tank farm **247** for further treatment.

[0046] Various modifications to the foregoing process are possible. For example, an ion exchange step may be utilized in addition to, or in lieu of, the solvent extraction system used to extract scandium. In some implementations of the process, the use of oxalic acid to precipitate scandium oxalate may result in the precipitation of other undesirable materials. In such implementations, the use of an ion exchange resin to purify the solution prior to precipitation may improve the purity of the final product. It will also be appreciated that solvent extraction of scandium may be performed before the use of ion exchange to extract nickel and/or cobalt from the leachate.

[0047] Though not preferred, in some implementations of the systems and methodologies described herein, fractional sublimation or distillation may be utilized as part of the process to separate nickel, scandium and cobalt from other metals and materials or to purify these metals. By way of example, in some embodiments of the methodologies disclosed herein, an ion exchange resin may be utilized which extracts more than one metal of interest from the leachate. The extracted metals may be converted to their corresponding chlorides or other halides, and subsequently separated by sublimation or distillation. For example, nickel chloride (NiCl_2) has a boiling temperature of 973°C ., and scandium chloride (ScCl_3) has a boiling temperature of 967°C . These chlorides are thus readily separated from the chlorides of other metals and materials occurring in nickel and scandium bearing ores such as yttrium chloride (YCl_3 ; b.p.= 1507°C .), cobalt chloride (CoCl_2 ; b.p.= 1049°C .), zirconium chloride (ZrCl_4 ; b.p.= 331°C .), iron chloride (FeCl_3 ; sublimes at 310°C .), aluminum chloride (AlCl_3 ; b.p.= 180°C .), titanium chloride (TiCl_4 ; b.p.= 136°C .), and silicon chloride (SiCl_4 ; b.p.= 57°C .). Of course, it will be appreciated that similar methods of separation or purification which are based on the conversion of nickel and scandium into other compounds (including various salts, such as the fluorides or other halides, and various oxides) may also be utilized.

[0048] In some embodiments, various preliminary processes may be employed to concentrate nickel, cobalt or scandium in the feedstock before it is subjected to processing in accordance with the teachings herein. For example, chlorination of the ore feedstock can have the effect of preferentially volatilizing the chlorides of other metals from the feedstock, thus concentrating nickel and scandium (and possibly cobalt) in the remaining ore solids. The volatilized materials may then be harvested as additional products of the ore recovery process.

[0049] In some implementations of the systems and methodologies described herein, solvent extraction may also be utilized to separate nickel, cobalt or scandium from other metals. For example, nickel and scandium may be separated

from iron and manganese in the leachate by extracting essentially all of these metals from the solution with a solvent system consisting essentially of an extracting agent (such as, for example, a dialkyl phosphoric acid) in a solvent (such as an aromatic solvent). The extracting agent is preferably present in an amount sufficient to extract essentially all of the nickel and scandium without extracting appreciable amounts of iron and manganese. The resulting organic solution may then be stripped of its nickel and scandium content with, for example, an aqueous ammonium carbonate solution which is separated from the stripped organic.

[0050] In some embodiments of the systems and methodologies described herein, a source of fluoride or chloride ions may be added to the leaching solution. For example, in some embodiments, especially those involving the leaching of nickel from laterites with acidic leaching solutions, the addition of a source of fluoride ions may facilitate the leaching process. Nickeliferous laterites consist mainly of nickel-substituted garnierite or lizardite having the chemical formula $\text{Mg}_3(\text{Si}_2\text{O}_5)(\text{OH})_4$, with trace amounts of magnetite and phlogopite. Under some conditions, fluoride ions are found to react with silicon in the lizardite crystal structure to form metal-fluoride complexes, and also increase the equilibrium constant of the lizardite dissolution in the acid solution significantly. Hence, the addition of fluoride salts can significantly enhance the metal extraction rate. Suitable fluoride ion sources may include, for example, NaF , NH_4F and CaF_2 . Frequently, only catalytic quantities of these materials are required such as, for example, 0.2 wt. % NaF ; indeed, in some cases, larger quantities of fluoride salts will actually reduce the yield of nickel in extraction from laterite ores, possibly by precipitating MgF_2 .

[0051] The above description of the present invention is illustrative, and is not intended to be limiting. It will thus be appreciated that various additions, substitutions and modifications may be made to the above described embodiments without departing from the scope of the present invention. Accordingly, the scope of the present invention should be construed in reference to the appended claims.

1. A method for extracting nickel values from nickel-containing ores, the method comprising:

treating a nickel-containing ore with an acid, thereby producing an acid treated ore;

baking the acid treated ore, thereby producing a baked ore;

leaching nickel from the baked ore to form a leachate; and extracting nickel values from the leachate through the use of an ion exchange resin.

2. The method of claim 1, further comprising:

electrolytically depositing the extracted nickel values.

3. The method of claim 2, wherein electrolytically depositing the extracted nickel values includes electrowinning.

4. The method of claim 1, wherein the acid treated ore is baked in an oxidizing environment.

5. The method of claim 4, wherein the baked ore contains an iron content of at least 15% by weight.

6. The method of claim 5, further comprising adding an iron ore to the acid treated ore prior to baking the acid treated ore.

7. The method of claim 6, wherein adding an iron ore to the acid treated ore includes recycling an iron-containing residue from another ore extraction process.

8. The method of claim 1, wherein leaching nickel from the baked ore is catalyzed by a material selected from the group consisting of fluorides and chlorides.

9. The method of claim 1, wherein leaching nickel from the baked ore includes leaching scandium from the baked ore such that the leachate contains nickel and scandium values.

10. The method of claim 1, wherein the pH of the leaching solution is maintained at a value less than 2.5 during leaching.

11. The method of claim 1, wherein the pH of the leaching solution is maintained within the range of about 1.0 to about 2.0 during leaching.

12. The method of claim 1, wherein the pH of the leaching solution is maintained within the range of 1.0 to 1.5 during leaching.

13. The method of claim 1, wherein the acid is sulfuric acid.

14. The method of claim 1, wherein the acid is nitric acid.

15. The method of claim 13, wherein baking the ore releases SO_2 from the ore.

16. The method of claim 15, further comprising:

collecting the SO_2 generated by the baking step in a first iteration of the method; and

using the SO_2 to make sulfuric acid which is used in treating the ore with an acid in a second iteration of the method.

17. The method of claim 16, wherein the SO_2 is collected with a scrubber.

18. The method of claim 14, wherein baking the ore releases NO_x from the ore.

19. The method of claim 18, further comprising:

collecting the NO_x generated by the baking step in a first iteration of the method; and

using the NO_x to make nitric acid which is used in treating the ore with an acid in a second iteration of the method.

20. The method of claim 19, wherein the NO_x is collected with a scrubber.

21. The method of claim 1, wherein leaching nickel from the baked ore results in a solution containing a mixture of nickel and scandium ions.

22. The method of claim 1, further comprising:

extracting nickel from the leachate by contacting the leachate with an ion exchange resin which is selective to the absorption of nickel, thereby forming a nickel-loaded resin and a raffinate;

separating the raffinate from the resin;

extracting the nickel from the nickel loaded resin by contacting the resin with an acid and forming a soluble nickel salt thereof as an eluate; and

recovering nickel from said eluate.

23. The method of claim 22, wherein recovering nickel from said eluate comprises salting out the nickel by crystallization of nickel sulfate heptahydrate.

24. The method of claim 23, wherein salting out the nickel includes the addition of concentrated sulfuric acid to the eluate.

25. The method of claim 24, further comprising:

recycling the crystallization mother liquor with residual acid values back to the acid treatment step of the process.

26. The method of claim 22, wherein the raffinate comprises iron, magnesium and the acid.

27. The method of claim 22, further comprising:

prior to extracting nickel from the leachate, adjusting the pH of the leachate to a range of about 1 to 3.

28. The method of claim 22, wherein contacting the resin with an acid involves contacting the resin with a mineral acid.

29. The method of claim 22, wherein the nickel-containing ore is a lateritic ore containing at least about 3% magnesium, at least about 10% iron and at least about 0.5% nickel.

30. The method of claim 22, wherein the nickel-containing ore has a particle size less than about one inch.

31. The method of claim 22, wherein the pH of said leachate is adjusted by adding a neutralizing agent to said leachate; and wherein any residue remaining in said pH-adjusted leachate is removed prior to the extraction of nickel therefrom.

32. The method of claim 22, wherein the absorbed nickel is extracted from the nickel-loaded resin with a solution of HCl to form a nickel chloride solution, wherein said nickel chloride solution is subjected to pyro-hydrolysis to form a nickel oxide.

33. The method in claim 32, wherein said nickel oxide is further processed to metallic nickel.

34. The method of claim 22, wherein contacting said leachate with said ion exchange resin provides a raffinate containing iron and magnesium, wherein said nickel is separated from said resin with a mineral acid to form a soluble nickel salt as an eluate thereof, and wherein substantially pure nickel is recovered from said eluate.

35. The method of claim 22, wherein said leachate contains Ni, Fe and Mg, wherein said leachate is passed through a bed of the ion exchange resin to produce a raffinate deficient in nickel and containing Fe and Mg, and wherein nickel is extracted from said the nickel loaded resin with HCl to provide an eluate of nickel chloride.

36. The method of claim 35, wherein said eluate is subjected to pyrohydrolysis to form NiO, and wherein said raffinate is subjected to pyro-hydrolysis to form MgO/FeOH_3 for recycle.

37. The method of claim 36, wherein MgO/FeOH_3 is recycled into the leaching system as a neutralizing agent.

38. The method of claim 36, wherein the MgO/FeOH_3 is also used to produce HCl for recycle into the leaching system.

39. The method of claim 38, wherein the HCl produced is further used to recycle to said ion exchange resin as a stripping agent.

40. The method of claim 22, wherein said leachate contains iron and magnesium, and further comprising:

contacting said leachate with the resin so as to form a nickel-loaded resin and a raffinate which is deficient in nickel and which comprises Fe and Mg;

passing mineral acid through a bed of the nickel loaded resin to extract the nickel as a soluble salt of the mineral acid as an eluate thereof; and

recovering said nickel from said eluate.

41. The method of claim 40, wherein the resin is a bis(2-picolyl)amine resin.

42. The method of claim 40, wherein said mineral acid is H_2SO_4 , wherein said nickel-containing eluate is a nickel sulfate solution, and wherein said nickel sulfate solution is subjected to electrowinning to form substantially pure electro-nickel.

43. A method for extracting nickel values from nickel-containing ores, the method comprising:

providing an ore which contains nickel;

treating the ore with an acid;

baking the ore, thus generating gaseous effluents;

recycling the gaseous effluents to reconstitute the acid; and using the reconstituted acid in a second iteration of the method.

44.-84. (canceled)

85. A method for extracting nickel values from ores that contain both nickel and scandium, the method comprising:

treating the ore with an acid, thereby producing an acid treated ore;
baking the acid treated ore, thereby producing a baked ore;
leaching nickel and scandium from the baked ore to form a leachate; and

extracting both the nickel and scandium values from the leachate.

86.-131. (canceled)

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