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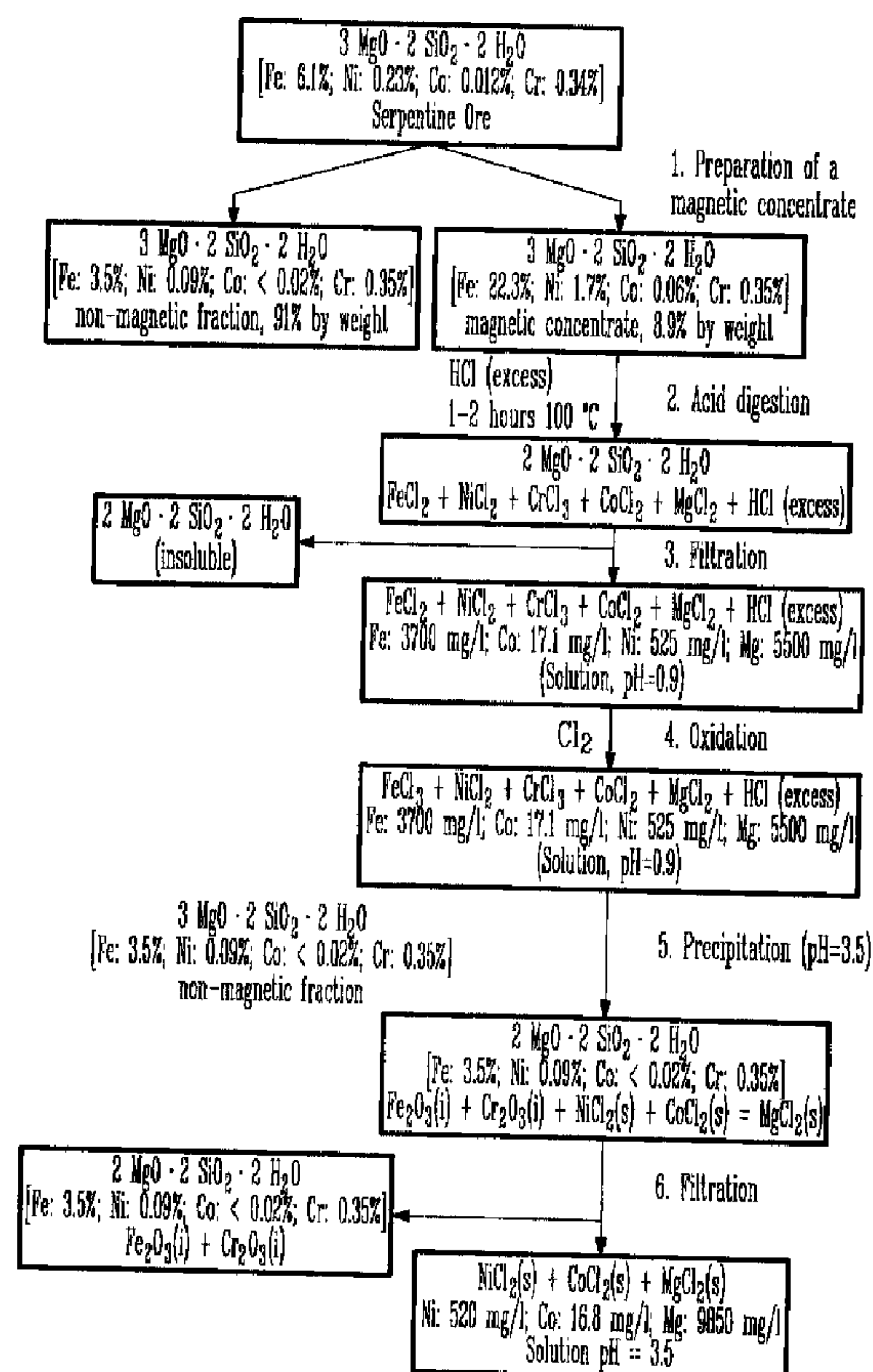
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(54) Titre : RECUPERATION DE METAUX DANS DES MINERAIS DE SERPENTINE

(54) Title: METALS RECOVERY FROM SERPENTINE ORES



(57) Abrégé/Abstract:

A method for the recovery of nickel, cobalt and magnesium oxide from serpentine ores, such as the mine tailings from asbestos mines, in one type of operation by a series of steps including grinding the serpentine ores to yield granules; magnetically

(57) Abrégé(suite)/Abstract(continued):

enriching the granules to produce a magnetic concentrate; digesting the magnetic concentrate in concentrated hydrochloric acid to produce an acidic reaction mixture comprising water soluble metal chlorides and an insoluble residue; filtering the acidic reaction mixture to provide a filtered solution of the water soluble metal chlorides; precipitating and filtering ferric oxide and chromium oxide from the filtered solution providing a second filtered solution; selectively recovering nickel, cobalt and magnesium oxide from the second filtered solution with the concomitant formation of gaseous hydrochloric acid which is recycled to the acid digesting step.

ABSTRACT

A method for the recovery of nickel, cobalt and magnesium oxide from serpentine ores, such as the mine tailings from asbestos mines, in one type
5 of operation by a series of steps including grinding the serpentine ores to yield granules; magnetically enriching the granules to produce a magnetic concentrate; digesting the magnetic concentrate in concentrated hydrochloric acid to produce an acidic reaction mixture comprising water soluble metal chlorides and an insoluble residue; filtering the acidic reaction mixture to provide a filtered solution
10 of the water soluble metal chlorides; precipitating and filtering ferric oxide and chromium oxide from the filtered solution providing a second filtered solution; selectively recovering nickel, cobalt and magnesium oxide from the second filtered solution with the concomitant formation of gaseous hydrochloric acid which is recycled to the acid digesting step.

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TITLE OF THE INVENTION

METALS RECOVERY FROM SERPENTINE ORES

FIELD OF THE INVENTION

5 The present invention pertains to a method for the recovery of nickel, cobalt and magnesium oxide from serpentine ores, such as the mine tailings from asbestos mines.

BACKGROUND OF THE INVENTION

10 Serpentine ore bodies are known to contain small amounts of base metals such as iron, nickel, cobalt and chromium. This is generally the case with asbestos-bearing serpentine deposits, found across southern Quebec (Canada), from the Vermont border all the way up to the Gaspé peninsula.

 Asbestos mines have been in operation in Quebec for more than
15 a hundred years. The volume of tailings generated by this mining activity is estimated to be in the order of several billion tons. The existence of such a huge amount of ground serpentinic rock is readily understood from the fact that for many years, the province of Quebec was producing one and a half million tons of asbestos fiber per year, from ore bodies containing no more than 3 to 4% of
20 economically recoverable fiber. Therefore, for each ton of fiber produced, 25 to 30 tons of serpentinic tailings were generated. These tailings, made mostly of hydrated magnesium silicates, contain some iron and traces (0.1 - 0.3%) of nickel and chromium.

 It has been known since the beginning of asbestos mining, that
25 ground serpentine ores can be subjected to magnetic enrichment which is achieved by exposing the ores to a permanent magnet. This magnetic exposure has been used in order to achieve improved fiber recovery, and to produce magnetic concentrates from the ores. This concentrate, comprising iron and nickel, was intended to be used for the production of ferro-nickel by arc furnace
30 reduction. This project however has never been implemented, possibly because of the presence of very large amounts of magnesium oxide in the magnetic concentrate (roughly 30%), creating problems of slag composition during the arc furnace reduction.

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The magnetic enrichment of asbestos tailings has been examined in view of recent technologies involving nickel/cobalt extraction, more specifically, solvent extraction. With modern reagents like Cyanex 300, Cyanex 302 and Cyanex 272, it is possible to separate a nickel/cobalt mixture from other base metals like iron and chromium. These reagents furthermore permit the separation of the nickel portion from the cobalt portion. However, the presence of magnesium in the asbestos tailings creates a problem, since the extractability of magnesium by cyanex reagents is intermediate between nickel and cobalt.

There remains a need for a method for the recovery of nickel, cobalt and magnesium oxide from serpentine ores, such as the mine tailings from asbestos mines. The present invention seeks to meet these and other needs.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method for the recovery of nickel, cobalt and magnesium oxide from serpentine ores, such as the mine tailings from asbestos mines, in one type of operation. The interest for such a procedure stems from the billions of tons of serpentine ores produced by asbestos mining operations and comprising the above mentioned elements. This is achieved by a series of steps including:

- (a) grinding the serpentine ores to yield granules;
- (b) magnetically enriching the granules to produce a magnetic concentrate;
- (c) digesting the magnetic concentrate in concentrated hydrochloric acid to produce an acidic reaction mixture comprising water soluble metal chlorides and an insoluble residue;
- (d) filtering the acidic reaction mixture to provide a filtered solution of the water soluble metal chlorides;
- (e) precipitating and filtering ferric oxide and chromium oxide from the filtered solution providing a second filtered solution;
- (f) selectively recovering nickel, cobalt and magnesium oxide from the second filtered solution with the concomitant formation of gaseous hydrochloric acid which is recycled to the acid digesting step.

It is another object of the present invention to provide a method for the recovery of base metals (nickel and cobalt) from serpentine ores, such as the

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mine tailings from asbestos mines containing common metals (iron, chromium and magnesium), wherein the method embodies a closed circuit allowing for the recycling of reagents.

5 The chemical composition of the serpentinitic tailings will vary somewhat from mine to mine, but will generally contain about 36-41% of magnesium oxide (MgO), about 5-7% of iron (Fe), mainly as ferrous oxide (FeO); traces of about 0.1-0.3% of nickel (Ni); traces of about 0.01 to 0.05% of cobalt (Co); and traces of about 0.05-0.3% of chromium (Cr).

10 Experiments, as described were conducted with Mine Jeffrey tailings having the following composition: MgO, 38.1%; Fe, 6.1%; Cr, 0.34%; Ni, 0.23%; and Co, 0.012%.

The material was ground to an appropriate mesh size, ranging from about -12 to -200 mesh. A magnetic concentrate was then prepared by circulating a 20% slurry of the ground material over a permanent magnet. The magnetic fraction was then collected, re-suspended in water and again submitted to magnetic separation. The final magnetic concentrate, after drying, represented about 8 to 12% of the weight of the starting material tailings. The chemical composition of the final magnetic fraction was as follows: Fe, 22.3%; Co, 0.06%; Ni, 1.70%; Cr, 0.35%; Mg, 17.1%. This composition indicates that 65% of the nickel and 44% of the cobalt have been removed from the tailings and are now present in the magnetic fraction. The chromium content in the magnetic fraction is substantially identical to the chromium content observed in the starting material tailings. However, the iron content in the magnetic fraction is substantially more concentrated as compared to the starting material tailings.

25 In order to separate these various metallic entities, the magnetic concentrate needs to be dissolved. A preferred solvent system is composed of a concentrated hydrochloric acid (HCl) solution (about 20 to 22% HCl content). This choice of solvent is mainly based on its ability to generate water soluble metal chlorides with the above mentioned metallic entities. Additionally, hydrochloric acid gas is readily recycled from the metal recovery process of the present invention, and can therefore be recycled to regenerate the concentrated hydrochloric acid solution, essential to the formation of the water soluble metal chlorides.

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The dissolution of the metallic entities in the concentrated hydrochloric acid solution, also called acid digestion, is essentially carried out over a period ranging from one to two hours. The magnetic fraction is treated with the concentrated hydrochloric acid solution at a temperature of about 100°C, such that a slurry comprising about 20% solids is obtained. An excess amount of acid is used such that an appropriate acid digestion can be achieved. More specifically, an excess of about 10%, based on the total amount of chloride ions consumed through digestion, is employed. The reaction mixture after digestion has a pH ranging from 0.5 to 1.0 and is therefore quite acidic.

10 The solution, following acid digestion of a typical magnetic fraction obtained from Mine Jeffrey tailings, presented the following composition: Fe, 3700 mg/l; Co, 17.1 mg/l; Ni, 525 mg/l; Cr, 22.3 mg/l; Mg, 5500 mg/l. These results indicate that about 93 % of the nickel and about 95% of the cobalt initially present in the magnetic fraction is dissolved during the digestion process. The amounts of iron and magnesium solubilized as chlorides are very significant and in fact they represent the main source of hydrochloric acid consumption. The handling of iron and magnesium chloride, is therefore of prime importance, if an efficient acid recycling cycle is to be obtained.

20 The method for the recovery of nickel and cobalt as well as magnesium oxide from serpentine ores, as described by the present invention, involves oxidizing the iron and chromium chlorides into insoluble oxides with the concomitant formation of additional magnesium chloride. In fact all the chlorides formerly associated with iron and chromium, are transformed into magnesium chloride. The magnesium chloride is eventually transformed into magnesium oxide, with the concomitant production of hydrochloric acid gas, which is recycled into the system. In addition to the recovery of nickel and cobalt, magnesium oxide constitutes a useful by-product of commercial value.

30 Further scope and applicability will become apparent from the detailed description given hereinafter. It should be understood however, that this detailed description, while indicating preferred embodiments of the invention, is given by way of illustration only, since various changes and modifications will become apparent to those skilled in the art.

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DESCRIPTION OF THE DRAWINGS

Figure 1 is a diagram illustrating the various steps involved in the production of a solution composed of nickel, cobalt and magnesium chloride devoid of iron and chromium, according to one embodiment of the method of the present invention.

Figure 2 is a block diagram illustrating the various steps of one embodiment of the method according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION10 1. Iron removal

As was previously indicated, acid digestion of the magnetic fraction or concentrate is carried out by using an excess amount of a concentrated hydrochloric acid solution. This generates a reaction mixture having a pH ranging from 0.5 to 1.0 and is therefore quite acidic.

15 The removal of iron and chromium from this acidic solution is readily achieved by pH adjustment, following treatment with chlorine gas. The acidic solution obtained after acid digestion comprises ferrous chloride $[\text{FeCl}_2]$ which is readily oxidized into ferric chloride $[\text{FeCl}_3]$ upon treatment with chlorine gas. The pH of the solution is then adjusted to essentially 3.5, value at which
20 ferric chloride is readily hydrolyzed to provide insoluble ferric oxide $[\text{Fe}_2\text{O}_3]$. A similar behavior is observed with chromium trichloride, which is hydrolyzed into insoluble chromium oxide $[\text{Cr}_2\text{O}_3]$.

The pH adjustment is carried out with the non-magnetized fraction of the serpentinic tailings. This material is a magnesium silicate $(3 \text{ MgO} \cdot 2 \text{ SiO}_2 \cdot 2 \text{ H}_2\text{O})$ comprising a significant amount of brucite $(\text{Mg}(\text{OH})_2)$. It can therefore
25 readily supply the amount of base required to neutralize any initial excess acid, and to neutralize the hydrochloric acid produced during the hydrolysis of ferric chloride and chromium trichloride to ultimately achieve the required pH increase from 0.5–1 to 3.5. In addition to the formation of ferric oxide $[\text{Fe}_2\text{O}_3]$ and
30 chromium oxide $[\text{Cr}_2\text{O}_3]$, additional magnesium chloride $[\text{MgCl}_2]$ is also produced. The use of an excess of the non-magnetized fraction, not only achieves the required pH increase from 0.5-1 to 3.5, it also has the added advantage of acting

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as a filtering aid in the recovery of the solution comprising the nickel, cobalt and magnesium chlorides.

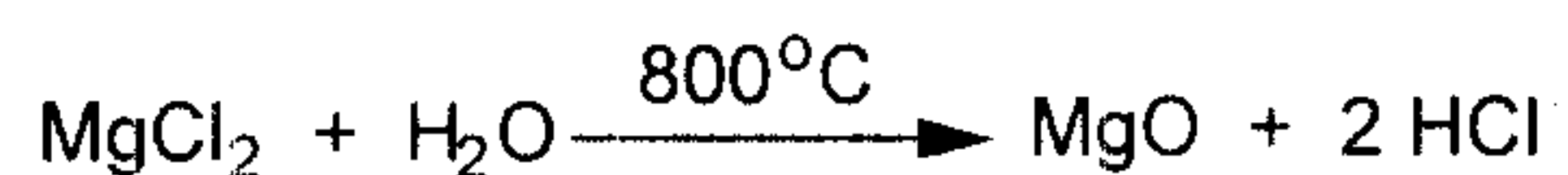
The equations illustrating the different steps involved in the production of a solution of nickel, cobalt and magnesium chlorides, devoid of iron and chromium are illustrated in Scheme 1.

2. Recovery of nickel, cobalt and magnesium oxide

The isolation of nickel (Ni) and cobalt (Co) from the iron and chromium-free solution can be achieved by various techniques such as sulfide precipitation of nickel and cobalt, selective precipitation of nickel and cobalt oxides by pH adjustment, specific ion-exchange resins or electrowinning, techniques well known to those familiar in the art. Since elemental chlorine is needed for the oxidation of ferrous chloride (FeCl_2) to ferric chloride (FeCl_3), the isolation of nickel and cobalt was carried out by electrowinning at low pH (3.5) which produced the chlorine used for the ferrous chloride oxidation.

The electrowinning operation is conducted at high current intensity (such as 20 amp/dm²) and at relatively low pH, allowing for the collection of nickel and cobalt at the cathode without significant hydrogen evolution or magnesium hydroxide formation. The resulting solution, after completion of the electrowinning of nickel and cobalt, is essentially composed of magnesium chloride.

Spray roasting of this solution results in the transformation of magnesium chloride into magnesium oxide, with the concomitant formation of hydrochloric acid gas which is recycled into the system to be used in the acid digestion step. This closed circuit approach has the advantage of reducing the acid consumption to operational losses, but requires an energy investment for spray roasting.



In an open circuit approach, the magnesium chloride solution is treated with either sodium carbonate (Na_2CO_3) or with calcium hydroxide ($\text{Ca}(\text{OH})_2$) in a displacement reaction, resulting in the formation of $\text{Mg}(\text{OH})_2$ which can be readily dehydrated to form MgO.

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The nickel/cobalt cathode can be submitted to standard purification procedures, without interference from common metals, particularly magnesium. A standard procedure will call on the use of Cyanex 272™ for the selective extraction of cobalt while in the presence of nickel, with recycling of the reagents. In this fashion pure nickel and cobalt are obtained.

EXAMPLE 1

A 375 g sample of tailings obtained from Mine Jeffrey Inc. was ground to a size of essentially 200 mesh, suspended in water (20% solids) at room temperature, and submitted to magnetic separation. The so-obtained magnetic fraction was suspended in water and submitted to magnetic separation. The resulting magnetic fraction (33.37 g after drying at 120°C), had the following composition: Fe, 22.3%; Co, 0.06%; Ni, 1.7%; Cr, 0.35%; Mg, 17.1%.

The magnetic fraction was suspended in a solution composed of 66 g of concentrated HCl (36.5%) and 10 g of water. The resulting mass was heated at 100°C for 90 minutes after which it was cooled and filtered. The solid residue obtained after filtration was rinsed twice with water, and the combined filtrate diluted to one liter. The concentrated solution was quite acidic (pH = 0.9) and had the following composition: Fe, 3700 mg/l; Co, 17.1 mg/l; Ni, 525 mg/l; Cr, 22.5 mg/l; Mg, 5500 mg/l.

The solution was subsequently treated with an excess amount of chlorine gas at 25°C, in order to oxidize ferrous chloride (FeCl_2) to ferric chloride (FeCl_3). Thirty grams of the non-magnetic fraction, co-produced with the magnetic fraction, were then added in order to raise the pH of the solution and to convert ferric chloride and chromium chloride to their corresponding oxides. The addition was carried out in small portions over a one-hour period, while stirring vigorously. It was noted that when a pH of approximately 3.5 was reached, precipitate formation could be observed. The precipitate was essentially composed of Fe_2O_3 and Cr_2O_3 with excess non-magnetic tailings. The reaction mixture was filtered, the residue rinsed with water, and the volume of the filtrate reduced to approximately 500 ml. The iron content of the solution was negligible with measured values below 5 ppm.

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The solution was submitted to electrowinning (1.9 V / 20 amp/dm²) in a cell comprising a fritted glass diaphragm (anode: graphite, cathode: copper).

Following this treatment, the solution was devoid of nickel and cobalt (values less than 5 ppm). The copper cathode was dissolved in nitric acid and the solution analyzed for its nickel and cobalt content. More than 95% of the nickel and cobalt initially present in the solution subjected to electrowinning, was deposited on the copper cathode.

Following the removal of nickel and cobalt, the solution is essentially composed of magnesium chloride. It was circulated in a Vycor tube while being heated at 800°C in a Lindberg furnace. A solid deposit of MgO was obtained with the concomitant evolution of hydrochloric gas.

Although the present invention has been described herein above by way of preferred embodiments thereof, it can be modified, without departing from the spirit and nature of the subject invention as defined in the appended claims.

CLAIMS

1. A method for recovering nickel, cobalt and magnesium oxide from serpentine ores containing nickel, cobalt, iron, chromium and magnesium comprising the steps of:

- a) grinding said serpentine ores to yield granules;
- b) magnetically enriching said granules to produce a magnetic concentrate;
- c) digesting said magnetic concentrate to produce a reaction mixture comprising water soluble metal chlorides and an insoluble residue;
- d) filtering said reaction mixture to provide a filtered solution of said water soluble metal chlorides;
- e) precipitating and filtering ferric oxide and chromium oxide from said filtered solution providing a second filtered solution;
- f) selectively recovering nickel, cobalt and magnesium oxide from said second filtered solution with concomitant formation of gaseous hydrochloric acid, said hydrochloric acid being recycled to said acid digesting step.

2. A method as defined in claim 1, wherein said enriching comprises preparing a slurry of said granules and exposing said slurry to a magnet thereby producing said magnetic concentrate and a non-magnetic fraction.

3. A method as defined in claim 1 or 2, wherein said digesting comprises dissolving said magnetic concentrate in a concentrated hydrochloric acid solution to provide said reaction mixture including said water soluble metal chlorides and said insoluble residue.

4. A method as defined in claim 1 or 3, wherein said filtering removes said insoluble residue from said reaction mixture to provide said filtered solution of water soluble metal chlorides, and wherein said water soluble chlorides contain FeCl_2 , NiCl_2 , CrCl_3 , CoCl_2 and MgCl_2 .

5. A method as defined in claim 1 or 4, wherein said filtered solution is treated with chlorine gas, providing an oxidized solution composed of FeCl_3 , NiCl_2 , CrCl_3 , CoCl_2 and MgCl_2 .

6. A method as defined in claim 1 or 5, wherein said oxidized solution is treated with said non-magnetic fraction of claim 2, precipitating ferric oxide and chromium oxide and whereby a second reaction mixture comprising water soluble metal chlorides is provided wherein said water soluble metal chlorides contain NiCl_2 , CoCl_2 and MgCl_2 .

7. A method as defined in claim 1 or 6, wherein filtering said second reaction mixture provides a second filtered solution of soluble metal chlorides composed of NiCl_2 , CoCl_2 and MgCl_2 .

8. A method as defined in claim 1 or 2, wherein said digesting comprises dissolving said magnetic concentrate in excess of a concentrated hydrochloric acid solution to provide said reaction mixture including said water soluble metal chlorides and said insoluble residue and wherein said reaction mixture has a pH ranging from about 0.5 to about 1.0.

9. A method as defined in claim 1 or 8, said reaction mixture including excess hydrochloric acid, wherein said filtering removes said insoluble residue from said reaction mixture to provide said filtered solution of water soluble metal chlorides, whereby said filtered solution contains excess hydrochloric acid and has a pH ranging from about 0.5 to about 1.0 and wherein said water soluble chlorides contain FeCl_2 , NiCl_2 , CrCl_3 , CoCl_2 and MgCl_2 .

10. A method as defined in claim 1 or 9, wherein said filtered solution is treated with chlorine gas, providing an oxidized solution composed of FeCl_3 , NiCl_2 , CrCl_3 , CoCl_2 and MgCl_2 and wherein said oxidized solution has a pH ranging from about 0.5 to about 1.0.

11. A method as defined in claim 1 or 10, wherein said oxidized solution is treated with said non-magnetic fraction of claim 2 to produce a second reaction mixture having a pH ranging from about 3.0 to about 4.0, said treatment precipitating said ferric oxide and said chromium oxide and whereby said second reaction mixture comprises water soluble metal chlorides wherein said water soluble metal chlorides contain NiCl_2 , CoCl_2 and MgCl_2 .

12. A method as defined in claim 1 or 11, wherein filtering said second reaction mixture provides a second filtered solution of soluble metal chlorides composed of NiCl_2 , CoCl_2 and MgCl_2 said second filtered solution having a pH ranging from about 3.0 to about 4.0.

13. A method as defined in claim 7 or 12, wherein nickel and cobalt are selectively recovered from said second filtered solution of soluble metal chlorides by a process selected from the group consisting of sulfide precipitation, oxide precipitation, specific ion exchange resins and electrowinning providing a third solution containing MgCl_2 .

14. A method as defined in claim 13, wherein said third solution containing MgCl_2 is spray roasted to transform MgCl_2 in to MgO and wherein gaseous hydrochloric acid is produced which is recycled to said digesting process and wherein MgO is produced.

15. A method as defined in claim 13, wherein said nickel and cobalt are selectively recovered by electrowinning and wherein chlorine gas is produced which is recycled to said oxidizing step.

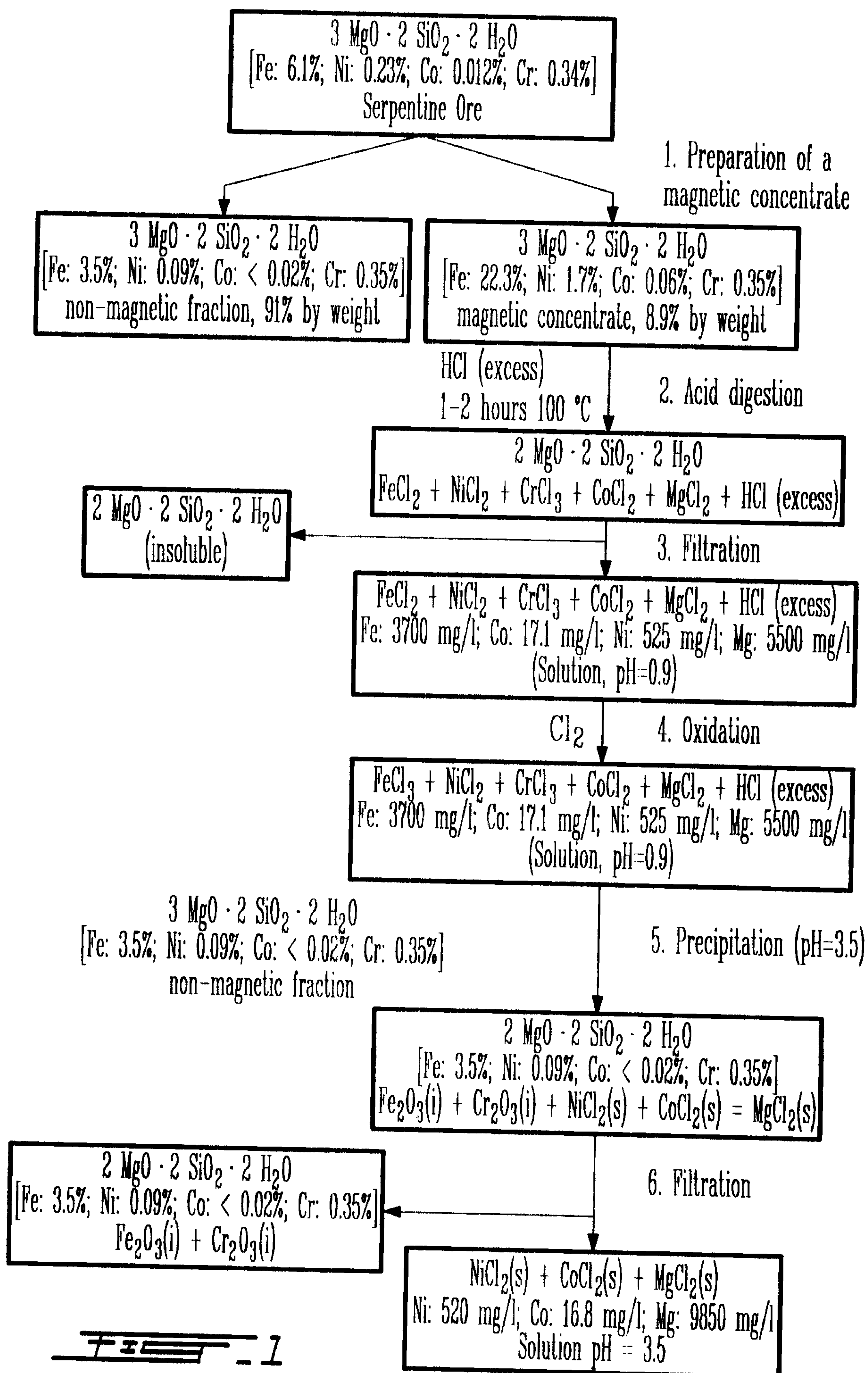
16. A method as defined in claim 6 or 11, wherein treatment with said non-magnetic fraction results in the hydrolysis of ferric chloride and chromium chloride to said ferric oxide and said chromium oxide respectively and wherein chloride ions formerly associated with iron and chromium are transferred to magnesium producing additional MgCl_2 , said magnesium being provided by said non-magnetic fraction.

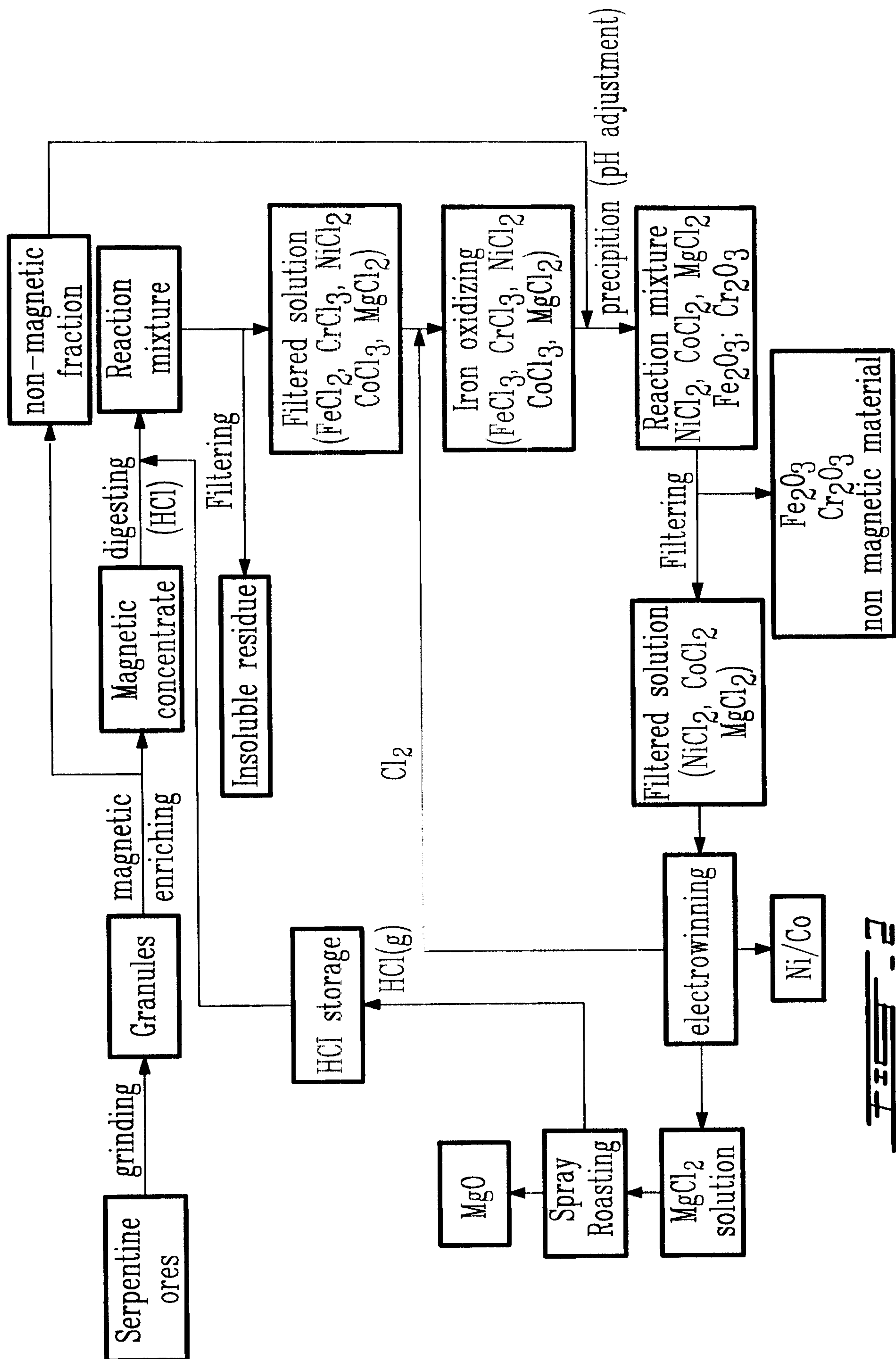
17. A method as defined in claim 18, wherein spray roasting is carried out at about 800 °C.

18. A method as defined in claim 3 or 8, wherein said digesting is carried out at a temperature of about 100 °C over a period ranging from about 1 to about 2 hours.

19. A method as defined in any one of claims 1 to 18, wherein said serpentine ores are ground to yield granules ranging from about -12 to about -200 mesh.

20. A method as defined in claim 8, wherein said excess constitutes an excess of about 10%.





$3 \text{ MgO} \cdot 2 \text{ SiO}_2 \cdot 2 \text{ H}_2\text{O}$
 [Fe: 6.1%; Ni: 0.23%; Co: 0.012%; Cr: 0.34%]
 Serpentine Ore

1. Preparation of a magnetic concentrate

$3 \text{ MgO} \cdot 2 \text{ SiO}_2 \cdot 2 \text{ H}_2\text{O}$
 [Fe: 3.5%; Ni: 0.09%; Co: < 0.02%; Cr: 0.35%]
 non-magnetic fraction, 91% by weight

$3 \text{ MgO} \cdot 2 \text{ SiO}_2 \cdot 2 \text{ H}_2\text{O}$
 [Fe: 22.3%; Ni: 1.7%; Co: 0.06%; Cr: 0.35%]
 magnetic concentrate, 8.9% by weight

HCl (excess)
 1-2 hours 100 °C

2. Acid digestion

$2 \text{ MgO} \cdot 2 \text{ SiO}_2 \cdot 2 \text{ H}_2\text{O}$
 $\text{FeCl}_2 + \text{NiCl}_2 + \text{CrCl}_3 + \text{CoCl}_2 + \text{MgCl}_2 + \text{HCl (excess)}$

$2 \text{ MgO} \cdot 2 \text{ SiO}_2 \cdot 2 \text{ H}_2\text{O}$
 (insoluble)

3. Filtration

$\text{FeCl}_2 + \text{NiCl}_2 + \text{CrCl}_3 + \text{CoCl}_2 + \text{MgCl}_2 + \text{HCl (excess)}$
 Fe: 3700 mg/l; Co: 17.1 mg/l; Ni: 525 mg/l; Mg: 5500 mg/l
 (Solution, pH=0.9)

Cl_2

4. Oxidation

$\text{FeCl}_3 + \text{NiCl}_2 + \text{CrCl}_3 + \text{CoCl}_2 + \text{MgCl}_2 + \text{HCl (excess)}$
 Fe: 3700 mg/l; Co: 17.1 mg/l; Ni: 525 mg/l; Mg: 5500 mg/l
 (Solution, pH=0.9)

$3 \text{ MgO} \cdot 2 \text{ SiO}_2 \cdot 2 \text{ H}_2\text{O}$
 [Fe: 3.5%; Ni: 0.09%; Co: < 0.02%; Cr: 0.35%]
 non-magnetic fraction

5. Precipitation (pH=3.5)

$2 \text{ MgO} \cdot 2 \text{ SiO}_2 \cdot 2 \text{ H}_2\text{O}$
 [Fe: 3.5%; Ni: 0.09%; Co: < 0.02%; Cr: 0.35%]
 $\text{Fe}_2\text{O}_3(\text{i}) + \text{Cr}_2\text{O}_3(\text{i}) + \text{NiCl}_2(\text{s}) + \text{CoCl}_2(\text{s}) = \text{MgCl}_2(\text{s})$

$2 \text{ MgO} \cdot 2 \text{ SiO}_2 \cdot 2 \text{ H}_2\text{O}$
 [Fe: 3.5%; Ni: 0.09%; Co: < 0.02%; Cr: 0.35%]
 $\text{Fe}_2\text{O}_3(\text{i}) + \text{Cr}_2\text{O}_3(\text{i})$

6. Filtration

$\text{NiCl}_2(\text{s}) + \text{CoCl}_2(\text{s}) + \text{MgCl}_2(\text{s})$
 Ni: 520 mg/l; Co: 16.8 mg/l; Mg: 9850 mg/l
 Solution pH = 3.5