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(54) Title: METHOD OF RECOVERING SCANDIUM FROM A METAL-BEARING SLURRY

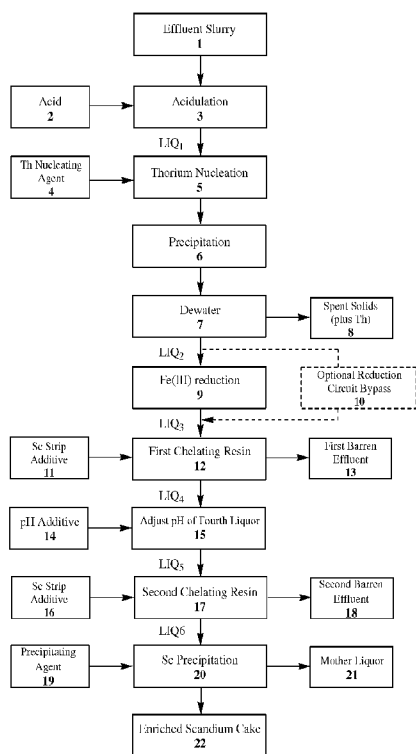


Figure 1

(57) Abstract: Disclosed is a method and apparatus for recovering scandium values in a metal-bearing effluent, e.g., from a fluidized bed chlorination process, without using environmentally persistent organic extractants and solvents. The disclosed process rejects thorium from a pregnant liquor which thereby minimizes later removal efforts. The process comprises acidulating a waste slurry to provide a first liquor comprising dissolved scandium and other metals including thorium. Adjusting the pH of the first liquor causes dissolved thorium values to be nucleated and returned in situ by precipitation. Dewatering the precipitate results in scandium depleted solids and a scandium containing second liquor substantially free from thorium and which is selectively partitioned onto a solid support phase and subsequently stripped from resin in a series of ion exchange steps to yield a scandium liquor from which scandium solids may be isolated. A reduction step helps to minimize potential interferences during chelating resin extractions.

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**TITLE**

Method and Apparatus for Recovering Scandium from a Metal-Bearing Slurry

**CROSS REFERENCE APPLICATIONS**

This application is a PCT application claiming the benefits of provisional application no. 61/718,946 filed October 27, 2012.

**FIELD OF ART**

The disclosed process relates generally to a method for extracting and concentrating scandium values from an aqueous slurry of metal-bearing residues, and more specifically to a process comprising nucleating thorium values from a metal-bearing slurry, returning said thorium values in situ by precipitation to said process and producing a solution that is substantially free from thorium from which scandium salts may be isolated.

**BACKGROUND**

Scandium is commonly grouped as a member of the rare earth elements including yttrium and the lanthanide metals in the Periodic Table of the Elements. It is modestly abundant in the earth's crust with a Clarke value of 25 ppm (Pohl, W.L. *Economic Geology: Principle and Practice*, Wiley-Blackwell, 2011, p 261). With few exceptions, scandium is found as a minor constituent of other economically important metalliferous minerals rather than as an enriched scandium mineral in its own right. High grade scandium ore is quite scarce and is found in only a few locations around the globe. More commonly, scandium and other rare earth elements are found dispersed at low levels in ores that are mined and processed for their primary value in tungsten, tantalum, aluminum, nickel, niobium, zirconium, titanium or uranium. In addition to said primary metals, scandium is often associated with other secondary metals such as iron, manganese, vanadium, and thorium. Waste streams in the form of liquors, slag, slimes, sludge, slurries or solid discharge from the primary metal process may be suitable for processing to recover secondary metal values, such as scandium.

The partitioning and ultimate isolation of purified scandium value from a mineral or a process waste stream containing many metallic constituents will generally rely on differential chemical or physical properties. One technique involves treating a scandium-bearing pulp or slurry with a strong mineral acid to extract said scandium and other metals from the solids and provide for a first stage of separation. Selective affinity of dissolved metal ions for a

solvent or for a coordinating chemical functionality like a halide, sulfate, carbonate, or carboxylate ion, etc., will lead to a partitioning of the metal ion between phases. Dissolved aqueous metal ions may undergo characteristic ligand ion-exchange in solution to produce insoluble salts which may be separated by precipitation and filtration. A solid phase resin bearing a monodentate or bidentate ligand with a high relative affinity for dissolved scandium may be used to scavenge scandium directly from a pregnant liquor.

Another scheme for scandium isolation is liquid-liquid extraction. This approach, exemplified in US Patent No. 5,049,363, may be used to extract metal values from acidified liquors into an organic phase comprised of a neat extractant or an extractant contained in a solvent carrier. Liquid-liquid extraction may require more than one stage to produce an economic recovery of scandium values. Significantly, vigorous contact between organic and aqueous phases may result in the transfer of suspended organic phase into the aqueous phase and subsequently transferred into waste treatment where its accumulation is contrary to environmental regulations. Thus, an extraction process that can avoid organic solvent and synthetic additive inputs will be desirable in the presence of environmental constraints.

As stated above, thorium is often present in ores containing scandium. Because thorium will readily accompany scandium through a purification scheme, it is therefore desirable to reject thorium from a scandium process stream in the early stages in order to avoid its concentration. Thorium may be partitioned away from scandium using ion selective resins (US Patent No. 4,765,909) or by liquid-liquid extraction (US Patent No. 2,990,244).

An input slurry stream may also contain significant levels of iron as mentioned above. The oxidation state of said iron is nominally Fe(II) but Fe(III) may be present. Because Fe(III) interferes with chelating resin extraction performance, it is desirable to reduce Fe(III) to the Fe(II) state in solution. This may be conducted by contacting the solution to any of a variety of reducing agents including the elemental forms of magnesium, calcium, iron, tin, or zinc. Following the reduction of Fe(III) the resulting solution is filtered of solids.

The disclosed process provides for a method to economically recover available scandium from metal-bearing residues such as those originating from a bed effluent of a fluidized bed chlorination process comprising titanium-bearing ores. Unlike prior techniques, the disclosed process avoids the use of hydrocarbon solvents and hydrophobic extractants. In addition, the disclosed process allows for the rejection of metals such as thorium from a

scandium solution in an early phase of the process in order to avoid the subsequent concentration thereof. The disclosed process also minimizes potential interferences with chelating resin extractions.

### **SUMMARY OF THE DISCLOSURE**

The disclosed process provides for a method of recovering scandium values in a metal-bearing effluent. The disclosed process rejects thorium from a pregnant liquor which thereby minimizes later removal efforts. A reduction step can be implemented to minimize potential interferences during chelating resin extractions.

The disclosed method provides for the recovery of available scandium from a metal-bearing stream without having to use hydrocarbon solvents and hydrophobic extractants.

The disclosed process provides a method of substantially rejecting thorium from a scandium-bearing solution in an early phase of the process in order to avoid a subsequent concentration of thorium.

The disclosed process provides a method of adjusting a pH of an acidulated metal-bearing slurry to cause a nucleation of thorium solids to occur.

The disclosed process provides a method of producing a liquor from a metal-bearing stream that is substantially free of thorium which may be used as an input stream for a scandium isolation phase.

The disclosed process provides a method of producing a liquor from a metal-bearing stream that is substantially free of Fe(III) which may be used as an input stream for a scandium isolation phase.

The disclosed process provides for a method of using a conventional scandium isolation process to receive a stream substantially free of thorium for scandium concentration purposes.

The disclosed process provides for a method of using a conventional scandium isolation process to receive a stream substantially free of Fe(III) for scandium concentration purposes.

The disclosed process provides for a method of recovering scandium values from a titanium carbothermal chlorination waste stream.

Disclosed is an apparatus which substantially rejects thorium from a scandium-bearing solution in an early phase of the process in order to avoid a subsequent concentration

of thorium.

Disclosed is an apparatus which adjusts a pH of an acidulated metal-bearing slurry to cause a nucleation of thorium solids to occur.

These and other advantages of the disclosed method and apparatus will appear from the following description and/or appended claims, reference being made to the accompanying figures that form a part of this specification wherein like reference characters designate corresponding parts in the several views.

### **BRIEF DESCRIPTION OF THE FIGURES**

**FIG. 1** depicts a general flow diagram for a process capable of recovering scandium values from an effluent slurry.

**FIG. 2** shows the transition in solubility of thorium and scandium in a pH range of interest.

**FIG. 3** shows a general comparison of metal concentrations at a beginning and an end of the disclosed process.

Before explaining the disclosed embodiments in detail, it is to be understood that the method and apparatus are not limited in application to the details of the particular arrangements shown, since the method and apparatus are capable of other embodiments. Also, the terminology used herein is for the purpose of description and not of limitation.

### **DESCRIPTION OF THE DISCLOSED EMBODIMENT**

The following description is provided to enable any person skilled in the art to make and use the disclosed process. Various modifications, however, will remain readily apparent to those skilled in the art, since the generic principles of the present process have been defined herein specifically to provide for a method and apparatus for recovering scandium values from a metal-bearing slurry.

**FIG. 1** depicts a process for recovering scandium values from a fluidized bed effluent. Although a fluidized bed effluent was used, it will be evident that the disclosed process may be used to recover scandium values from other metal-bearing slurries.

The process from which the bed effluent originates comprises the carbothermal chlorination of ilmenite and optionally other titanium containing ores. Solid residues from the chlorination process are disengaged from the titanium tetrachloride stream and combined with water to produce an acidic slurry **1** containing scandium values found in the solution

phase, in the suspended solids, and in the sediment. Overall scandium levels in the slurry are low with a nominal concentration of about 25 ppm spread across the solid and solution phases. Acidic slurry **1** serves as the input stream for the disclosed process. It is contemplated that the disclosed process may comprise unit operations conducted as a continuous process, batch process, semi-batch process, or a combination thereof.

Scandium is prepared for isolation from the input slurry by acidification of said slurry with an acid **2** which may comprise hydrochloric acid, hydrofluoric acid, sulfuric acid, sulfurous acid, or a combination thereof. Acidulation **3** allows scandium from suspended solids and sediment to be released into the solution phase thereby forming a first liquor **LIQ<sub>1</sub>**. It is contemplated that acidulation of the slurry may be performed within a range of temperatures from about 15 °C to about 85 °C and for a residence time of about thirty (30) seconds to about three (3) hours. Acid concentration comprises a range corresponding to a pH of about 0.00 to about 1.70.

The acidity of the slurry is then adjusted to a pH of about 1.7 to about 2.1 with a nucleating agent **4** and the resulting slurry is allowed to age at a temperature range of about 0 °C to about 50 °C and for up to about one hour. It is contemplated that nucleating agent **4** may comprise an alkali metal hydroxide or an alkaline earth metal hydroxide, however other agents may be used. For example, one having ordinary skill in the art may determine that ammonium hydroxide or an alkali metal carbonate could be suitable. Surprisingly, the thorium in the solution phase nucleates **5** and deposits with the sediment **6** during this interval. Consequently, the concentration of thorium carried forward in solution decreases. **FIG. 2** shows the transition in solubility of thorium and scandium in the pH range of interest (about 0.0 to about 3.1). For example, at a pH of about 2.5, the percentage of scandium in solution is about 38% while the percentage of thorium in solution is about 0%. First liquor **LIQ<sub>1</sub>** is dewatered **7** whereby a second liquor **LIQ<sub>2</sub>** (about 0 °C to about 50 °C) is carried forward. Spent solids from the dewatering step are directed from the process stream to solid waste **8**.

Second liquor **LIQ<sub>2</sub>** is contacted with a reducing substance to reduce interfering cation Fe(III) to Fe(II). Contact of second liquor **LIQ<sub>2</sub>** with a reducing element or ion produces a third liquor **LIQ<sub>3</sub>**. Reduction **9** minimizes unproductive Fe(III) complexation with the ion

exchange resin used in subsequent stages of the disclosed process. Third liquor **LIQ<sub>3</sub>** which comprises a diminished level of interfering Fe(III) ions is carried forward to an ion exchange resin bed (not shown) in which a stripping of scandium takes place. As illustrated, it is contemplated that some or all of second liquor **LIQ<sub>2</sub>** may optionally be sent through a reduction bypass circuit **10** whereby the bypass liquor may be introduced directly to the ion exchange resin bed (not shown). The reducing substances used herein comprise non-interfering metals which upon oxidation by Fe(III) may be rejected from the process stream. Such non-interfering metals may comprise iron, tin, zinc, calcium or magnesium. Third liquor **LIQ<sub>3</sub>** and/or the bypass liquor may optionally be adjusted with a strong mineral acid to ensure a pH range of about 1.70 to about 2.10 prior to contact with the chelating cation exchange resin.

During the scandium stripping step, third liquor **LIQ<sub>3</sub>** is contacted with an ion exchange resin **12** in the resin bed (not shown) at such a rate so as to avoid losses by channeling or inadequate equilibration and in a temperature range of about 0 °C to about 50 °C. When this contact occurs, the scandium values are adsorbed on resin **12**. An effluent **13** that is substantially free of scandium values is directed to waste or for use as process water. In one embodiment, resin **12** comprises a chelating iminodiacetic acid such as commercially available Amberlite 748i. One having skill in the art will recognize however that other suitable resins such as those in bidentate or tridentate form may be chosen.

After a volume of influent corresponding to approximately 0.7 mol of scandium per liter of resin has passed through the resin bed (not shown), the influent is switched to a stripping solution **11** comprising a strong mineral acid or salt or a chelating carboxylic acid. Stripping solution **11** is used to strip scandium and other metals from resin **12** thereby producing a fourth liquor **LIQ<sub>4</sub>** enriched in scandium (pregnant influent liquor). It is contemplated that stripping solution **11** can comprise hydrochloric acid, hydrofluoric acid, sulfuric acid, sulfurous acid, nitric acid or a combination of said acids at a strength of about 3.0 to about 9.0 moles of acid equivalent per liter. An aqueous chelating acid solution comprising citric acid, tartaric acid, lactic acid, malic acid, diglycolic acid, o-phthalic acid, salicylic acid or a combination of a chelating acid and a mineral acid may be used.

A pH additive **14** such as alkali metal hydroxide is used to adjust the pH of fourth



liquor **LIQ<sub>4</sub>** to a pH range of about 1.80 to about 2.10 whereby a fifth liquor **LIQ<sub>5</sub>** is formed. Fifth liquor **LIQ<sub>5</sub>** is passed through a resin bed comprised of chelating ion exchange resin **17** such as Amberlite 748i at a temperature range of about 0 °C to about 35 °C. The scandium values are adsorbed on resin **17** while barren effluent **18** is directed to waste or for use as process water.

After a volume of influent corresponding to approximately 0.7 mol of scandium per liter of resin has passed through the resin bed (not shown), the influent is switched to a stripping solution **16** comprising a strong mineral acid. One or more bed volumes of stripping solution **16** may be used to strip resin **17** of scandium and other metals thereby producing a sixth liquor **LIQ<sub>6</sub>** enriched in scandium. Again, it is contemplated that stripping solution **16** can comprise hydrochloric acid, hydrofluoric acid, sulfuric acid, sulfurous acid, nitric acid or a combination of said acids at a strength of about 3.0 to about 9.0 moles of acid equivalent per liter.

Sixth liquor **LIQ<sub>6</sub>** is treated with an additive **19** to cause the dissolved scandium to precipitate **20**. Additives **19** comprise ammonium carbonate, ammonium hydroxide or oxalic acid. It is contemplated that monocarboxylic acid, dicarboxylic acid or tricarboxylic acid, non-metallic hydroxides, non-metallic carbonates, or non-metallic organic carboxylates could also be used. The precipitate is dewatered to produce a compact cake of scandium enriched solids **22**. The remaining solution or mother liquor **21** will be returned to the disclosed process.

As disclosed herein, the scandium stripping step comprises contacting one or more resultant liquors with an ion exchange resin in a resin bed. One having ordinary skill in the chemical arts will recognize that other scandium isolation processes could be utilized and still fall with the spirit and scope of the disclosure. For example, depending of the constituents of a particular metal-bearing stream, it could be determined that liquid to liquid extraction would be a suitable choice.

**FIG. 3** shows a comparison of metal concentrations at the beginning and end of the disclosed process. The solid line represents the metal values detected in the input slurry. The dotted line represents the metal values detected in the second resin strip solution (sixth liquor **LIQ<sub>6</sub>**).

### EXAMPLE 1

A 513.6 g sample of titanium dioxide sump slurry was treated with 18 mL of 12 M hydrochloric acid. This pH adjustment, from 2.18 to 0.13, causes the lixiviation of scandium. To induce thorium nucleation the pH was adjusted using 30 mL of 6 M sodium hydroxide to a pH of 1.66. The slurry was filtered and 34.3 g of residue was isolated. The residue was analyzed and found to contain 4.16 mg of scandium, and 19.04 mg of thorium. 504.1 g of filtrate was isolated and determined to contain 10.31 mg of scandium and 4.31 mg of thorium by ICPMS. In this way 71.25 % of the scandium moved forward post filtration and 81.57 % of the thorium was rejected to the residue. The filtrate contained 947.8 mg of Fe, 162.7 mg of Mn, 26.40 mg of V, and 94.78 mg of Al, per mg of Sc.

The filtrate, containing a majority  $\text{Fe}^{3+}$ , underwent a reduction using 20.167 g of iron powder. The slurry was agitated for approximately 15 seconds before any residual iron powder was recovered via magnetic separation affording the reduction liquor. Unreduced ferric iron was not detectable with potassium thiocyanate as an indicator.

The reduction liquor was passed through 13 mL of Amberlite-748i ion exchange resin. The column was pre conditioned using 200 mL of 6 M hydrochloric acid followed by 100 mL of pH 2.04 hydrochloric acid solution. Through the resin bed was passed 38.78 bed volumes of ferrous filtrate at a flow rate of 0.37 bed volume/min or 4.85 mL/min. The effluent solution was collected and analyzed. The effluent solution contained 2.44 mg of scandium, a 16.88 % Sc loss. The column was washed with 4.85 bed volumes of pH 2.04 hydrochloric acid solution resulting in a 1.37 % Sc loss. The wash and effluent contained 99.9 % Fe, 99.9 % Mn, 89.17 % V and 99.0 % of the respective influent metal mass.

The resin was quantitatively stripped using 22.9 g of 3 M hydrochloric acid. To prepare the strip liquor for a second pass through the resin bed the pH was adjusted to 1.94 using 4.5 mL of 6 M sodium hydroxide and 0.3 mL of 3 M hydrochloric acid. For the second pass through the resin bed 28.35 g of influent resulted in 27.233 g of effluent containing 0.00 % of the initial scandium. The column was washed with 43.85 g of pH 2.04 hydrochloric acid solution. 0.74 % of the initial scandium was lost in the wash solution. The second resin bed effluent contained 100.00 % Fe, 99.99 % Mn, 47.19 % V, and 99.54 % Al by comparison to the influent metal mass. The column was stripped and regenerated using 25.05 g of 3 M hydrochloric acid. The final solution was analyzed and found to contain 7.56 mg of scandium

for a final scandium recovery of 52.65 %.

Over the course of this processing the liquor containing the scandium has been concentrated by a factor of 20.5, and the purity by comparison to other metals has increased from 0.1028% Sc to 8.64% Sc, or 84.02 times purity increase.

The disclosed process can be used in conjunction with a scandium isolation phase capable of stripping a scandium value from a metal-bearing stream. The disclosed process comprises a method of providing a stream substantially free of thorium, and optionally Fe(III), for input into a scandium isolation phase which can comprise ion exchange and/or liquid-liquid extraction methodologies. The disclosed process comprises the steps of:

- a) Treating a slurry comprising metal-bearing solids with a strong mineral acid thereby producing a first liquor;
- b) Maintaining the first liquor at a temperature and for a period of time sufficient to dissolve scandium values from the metal-bearing slurry solids;
- c) Adjusting a pH of the first liquor to cause a nucleation of thorium solids to occur;
- d) Dewatering precipitated solids from the first liquor thereby separating the nucleated thorium solids and producing a second liquor substantially free of thorium; and
- e) Optionally introducing the second liquor directly into a scandium isolation phase as an input stream or treating the second liquor with a reducing agent to reduce Fe(III) to Fe(II) and to thereby produce a third liquor substantially free of Fe(III) to be used as an input stream for a scandium isolation phase.

The disclosed process can also be used in conjunction with a scandium isolation phase capable of stripping a scandium value from a titanium carbothermal chlorination waste stream. The disclosed process comprises a method of providing a stream substantially free of thorium, and optionally Fe(III), for input into a scandium isolation phase which can comprise ion exchange and/or liquid-liquid extraction. The disclosed process comprises the steps of:

- a) Treating an aqueous carbothermal chlorination waste slurry comprising metal-bearing solids with a strong mineral acid thereby producing a first liquor;
- b) Maintaining the first liquor at a temperature and for a period of time sufficient to dissolve scandium values from the metal-bearing slurry solids;
- c) Adjusting a pH of the first liquor to cause a nucleation of thorium solids to occur;
- d) Dewatering precipitated solids from the first liquor thereby separating the

nucleated thorium solids and producing a second liquor substantially free of thorium; and

e) Optionally treating the second liquor with a reducing agent to reduce Fe(III) to Fe(II) whereby a third liquor substantially free of Fe(III) is produced, the third liquor capable of being used as an input stream for a scandium isolation phase, or introducing the second liquor directly into a scandium isolation phase as an input stream.

Also disclosed is process for isolating scandium values from a metal-bearing waste stream, the process comprising the steps of: treating a slurry comprising metal-bearing solids with a strong mineral acid thereby producing a first liquor; maintaining the first liquor at a temperature and for a period of time sufficient to dissolve scandium values from the metal-bearing slurry solids; adjusting a pH of the first liquor to cause a nucleation of thorium solids to occur; dewatering precipitated solids from the first liquor thereby separating the nucleated thorium solids and producing a second liquor substantially free of thorium; treating the second liquor with a reducing agent to reduce Fe(III) to Fe(II) and to thereby produce a third liquor substantially free of Fe(III) to be used as an input stream for a scandium isolation phase; and introducing the third liquor into a scandium isolation process whereby scandium values are stripped therefrom. Optionally, the second liquor can be introduced directly into a scandium isolation phase as an input stream.

In this embodiment, the scandium isolation process of the disclosed method further comprises the steps of: treating the third (or second) liquor with a chelating cation exchange resin in protonated form to strip Sc(III) therefrom and thereby produce a barren effluent substantially free of scandium values; and contacting the cation exchange resin with a stripping agent to release scandium values bound thereto to a fourth liquor. The scandium isolation process further comprises the steps of: adjusting a pH of the fourth liquor to form a fifth liquor; treating the fifth liquor with a second chelating cation exchange resin in protonated form to strip Sc(III) therefrom and thereby produce a barren effluent substantially free of scandium values; and contacting the second cation exchange resin with a stripping agent to release scandium values bound thereto to a sixth liquor. The fourth liquor and/or the sixth liquor may be treated with a precipitation agent to produce scandium-enriched solids which are subsequently dewatered to produce a scandium enriched cake.

Disclosed is an apparatus capable of housing a slurry comprising metal-bearing solids for treatment with a strong mineral acid whereby a first liquor is produced, the apparatus

capable of maintaining the first liquor at a temperature and for a period of time sufficient to dissolve scandium values from the metal-bearing slurry solids and wherein a pH of the first liquor can be adjusted to cause a nucleation of thorium solids to occur; the apparatus capable of separating the nucleated thorium solids whereby a second liquor substantially free of thorium is produced. The disclosed apparatus further being capable of reducing Fe(III) to Fe(II) whereby a liquor substantially free of Fe(III) is produced.

Although the disclosed method and apparatus have been described with reference to disclosed embodiments, those of skill in the art will recognize certain modifications, permutations, additions and subcombinations thereof. No limitation with respect to the specific embodiments disclosed herein is intended or should be inferred. Other alternate embodiments of the present method and apparatus could be employed by those skilled in the art to achieve the desired function and still fall within the true spirit and scope of the disclosure.

**WHAT IS CLAIMED:**

1. In conjunction with a scandium isolation phase whereby a scandium value is stripped from a metal-bearing stream, a process of providing a stream substantially free of thorium and optionally Fe(III), for input into said scandium isolation phase, said process comprising the steps of:
  - a) Treating a slurry comprising metal-bearing solids with a strong mineral acid thereby producing a first liquor;
  - b) Maintaining said first liquor at a temperature and for a period of time sufficient to dissolve scandium values from said metal-bearing slurry solids;
  - c) Adjusting a pH of said first liquor to cause a nucleation of thorium solids to occur;
  - d) Dewatering precipitated solids from said first liquor thereby separating said nucleated thorium solids and producing a second liquor substantially free of thorium; and
  - e) Optionally introducing the second liquor directly into a scandium isolation phase as an input stream or treating the second liquor with a reducing agent to reduce Fe(III) to Fe(II) and to thereby produce a third liquor substantially free of Fe(III) to be used as an input stream for a scandium isolation phase.
2. The method of claim 1, wherein said scandium isolation phase comprises ion exchange.
3. The method of claim 1, wherein said scandium isolation phase comprises liquid-liquid extraction.
4. The method of claim 1, wherein said slurry comprises a titanium carbothermal chlorination waste stream.
5. In conjunction with a scandium isolation phase whereby a scandium value is stripped from a titanium carbothermal chlorination waste stream, a process of providing a stream substantially free of thorium and Fe(III) for input into said scandium isolation phase, said process comprising the steps of:
  - a) Treating an aqueous carbothermal chlorination waste slurry comprising metal-bearing solids with a strong mineral acid thereby producing a first liquor;
  - b) Maintaining said first liquor at a temperature and for a period of time sufficient to dissolve scandium values from said metal-bearing slurry solids;

- c) Adjusting a pH of said first liquor to cause a nucleation of thorium solids to occur;
  - d) Dewatering precipitated solids from said first liquor thereby separating said nucleated thorium solids and producing a second liquor substantially free of thorium; and
  - e) Optionally treating said second liquor with a reducing agent to reduce Fe(III) to Fe(II) whereby a third liquor substantially free of Fe(III) is produced, said third liquor capable of being used as an input stream for a scandium isolation phase, or introducing said second liquor directly into a scandium isolation phase as an input stream.
6. The method of claim 5, wherein said scandium isolation phase comprises ion exchange.
7. The method of claim 5, wherein said scandium isolation phase comprises liquid-liquid extraction.
8. A process for isolating scandium values from a metal-bearing waste stream, said process comprising the steps of:
- a) Treating a slurry comprising metal-bearing solids with a strong mineral acid thereby producing a first liquor;
  - b) Maintaining said first liquor at a temperature and for a period of time sufficient to dissolve scandium values from said metal-bearing slurry solids;
  - c) Adjusting a pH of said first liquor to cause a nucleation of thorium solids to occur;
  - d) Dewatering precipitated solids from said first liquor thereby separating said nucleated thorium solids and producing a second liquor substantially free of thorium;
  - e) Treating said second liquor with a reducing agent to reduce Fe(III) to Fe(II) and to thereby produce a third liquor substantially free of Fe(III) to be used as an input stream for a scandium isolation phase; and
  - f) Introducing said third liquor into a scandium isolation process whereby scandium values are stripped therefrom.
9. The method of claim 8, wherein said scandium isolation process further comprises the steps of:

- a) Treating said third liquor with a chelating cation exchange resin in protonated form to strip Sc(III) therefrom and thereby produce a barren effluent substantially free of scandium values; and
  - b) Contacting said cation exchange resin with a stripping agent to release scandium values bound thereto to a fourth liquor.
10. The method of claim 9, wherein said scandium isolation process further comprises the steps of:
- a) Adjusting a pH of said fourth liquor to form a fifth liquor;
  - b) Treating said fifth liquor with a second chelating cation exchange resin in protonated form to strip Sc(III) therefrom and thereby produce a barren effluent substantially free of scandium values; and
  - b) Contacting said second cation exchange resin with a stripping agent to release scandium values bound thereto to a sixth liquor.
11. The method of claim 9, wherein said scandium isolation process further comprises the step of treating said fourth liquor with a precipitation agent to produce scandium-enriched solids which are subsequently dewatered to produce a scandium enriched cake.
12. The method of claim 10, wherein said scandium isolation process further comprises the step of treating said sixth liquor with a precipitation agent to produce scandium-enriched solids which are subsequently dewatered to produce a scandium enriched cake.
13. A system comprising:
- an apparatus capable of housing a slurry comprising metal-bearing solids for treatment with a strong mineral acid whereby a first liquor is produced;
  - said apparatus capable of maintaining the first liquor at a temperature and for a period of time sufficient to dissolve scandium values from the metal-bearing slurry solids and wherein a pH of the first liquor can be adjusted to cause a nucleation of thorium solids to occur;
  - said apparatus capable of separating the nucleated thorium solids whereby a second liquor substantially free of thorium is produced.
14. The system of claim 13, wherein said apparatus is capable of reducing Fe(III) to Fe(II) whereby a liquor substantially free of Fe(III) is produced.



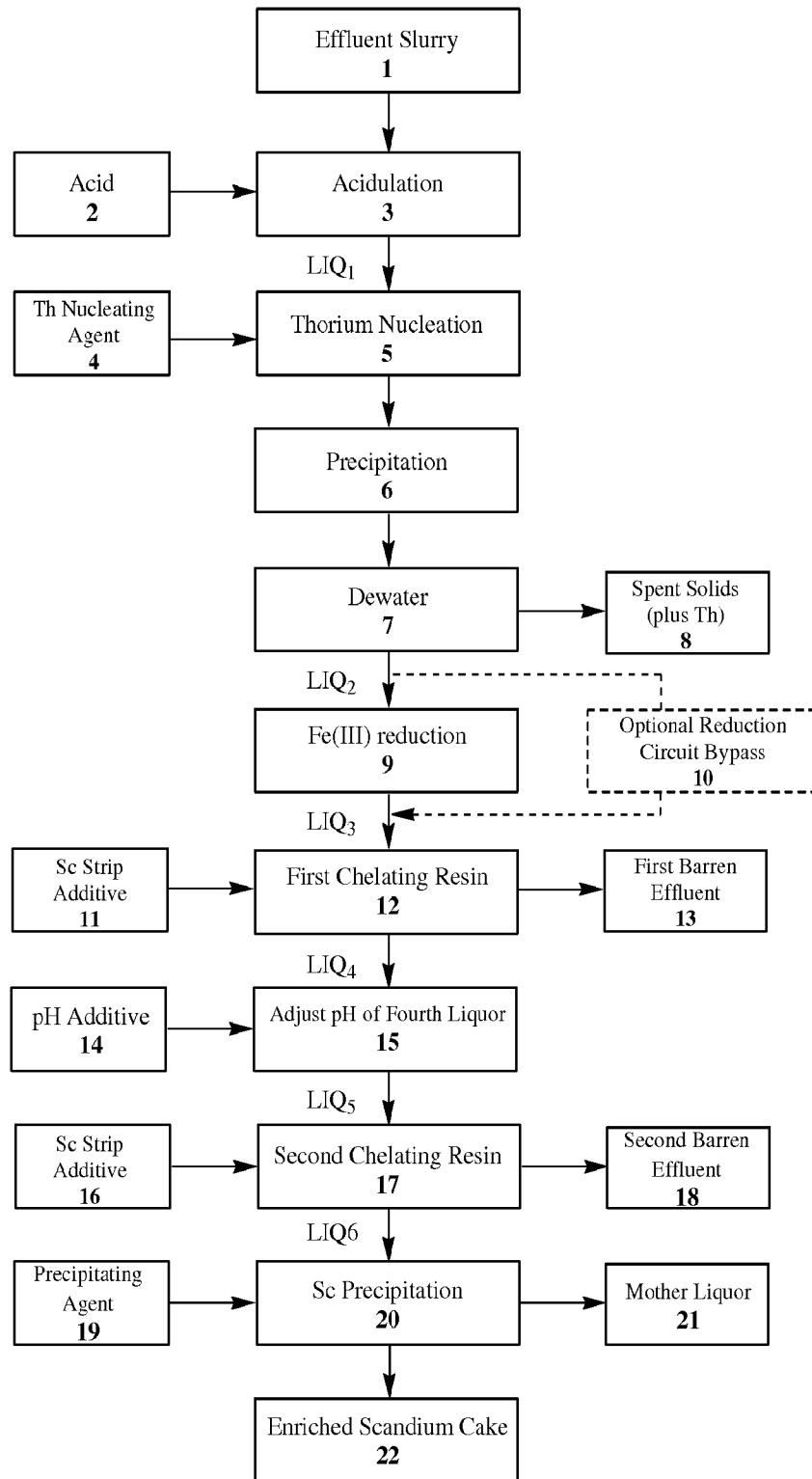


Figure 1

### Th and Sc Separation

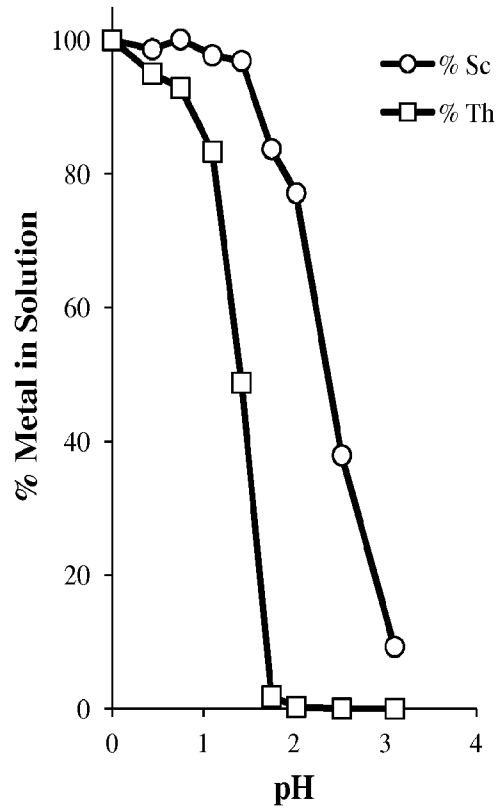


Figure 2

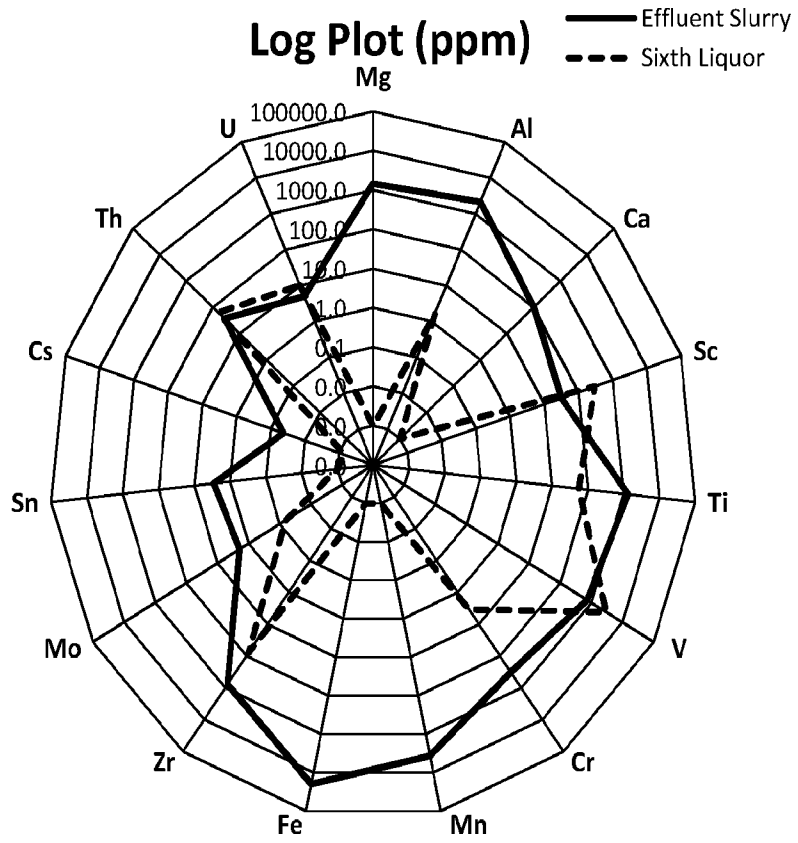


Figure 3

**A. CLASSIFICATION OF SUBJECT MATTER****C22B 59/00(2006.01)i, C22B 3/04(2006.01)i**

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

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

C22B 59/00; C22B 23/00; C22B 7/00; C01F 17/00; B01D 15/04; C22B 3/00; C22B 3/04

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) &amp; keywords: scandium, thorium, acid, pH, and ion exchange

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2000-313928 A (TAIHEIYO KINZOKU K.K.) 14 November 2000 See paragraphs [0012]-[0018]; and claim 1.	1,3-5,7,8,13,14
Y		2,6,9-12
Y	JP 08-232026 A (MITSUBISHI MATERIALS CORP.) 10 September 1996 See paragraphs [0008]-[0010]; and claims 1,5.	2,6,9-12
A	JP 2007-231382 A (MITSUI MINING & SMELTING CO., LTD.) 13 September 2007 See paragraphs [0020]-[0025]; and claims 1,2.	1-14
A	US 4765909 A (ROURKE et al.) 23 August 1988 See column 1, lines 59-68; and claims 1,2.	1-14
A	US 4988487 A (LAI et al.) 29 January 1991 See column 5, line 50 - column 6, line 51; and claim 1.	1-14

 Further documents are listed in the continuation of Box C. See patent family annex.

\* Special categories of cited documents:

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"&amp;" document member of the same patent family


Date of the actual completion of the international search

24 January 2014 (24.01.2014)

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**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2013/066751**

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JP 2007-231382 A	13/09/2007	JP 4730903 B2	20/07/2011
US 4765909 A	23/08/1988	EP 0313647 A1 JP 2681508 B2 WO 88-08323 A1	03/05/1989 26/11/1997 03/11/1988
US 4988487 A	29/01/1991	None	