Method For High And Selective Extraction of A Precious Metal

Technical Field

The present invention relates to a composition comprising a strong base, an oxidant and a thiocyanate, wherein the composition has a pH in the range of 12 to 14. The present invention also relates to a method of preparing such a composition, a method of extracting a precious metal using such a composition, and use of the composition to recover a precious metal.

Background Art

The demand for noble metallic gold (Au) has been increasing due to its practical uses in industry for centuries. Gold has excellent chemical resistance, as it does not react in air or water with oxygen or sulphur, ensuing its durability under corrosive conditions which has led to its widespread usage in coinage and jewellery throughout the ages. Gold also has excellent electrical conductivity, allowing for its application as a coating in electrical contacts. Recent technological innovations have also utilized gold in the fields of medicine, nanotechnology, engineering and environmental management.

Similarly, the demand for metallic silver (Ag) from the industries is rapidly increasing due to its use in the manufacture of numerous products. Silver is used extensively in electrical and electronic devices due to its superior electrical and heat conductivity. It also plays a key role in photovoltaic modules in the form of a conductive paste for efficient electricity generation. Owing to its malleability, ductility, high reflectivity and strength, silver is employed in jewellery, silverware, solders and other industry applications. In addition, the photosensitive nature of silver halides allows its use in photography. Silver is also utilised in medicine and consumer products because of its antimicrobial and non-toxic nature.

According to the United Nation (UN), each person will produce an average of 7.6 kg of e-waste in 2021, generating 57.4 million tonnes of e-waste worldwide, in which considerable amount of gold and silver can be potentially recovered. E-waste is an invaluable unconventional resource due to its high metal content, as nearly 40% of e-waste is comprised of metals. To keep up with the increasing demand for gold and silver, it is essential to recover these metals from secondary sources such as gold- and silver-coated printed circuit boards (PCBs) of discarded computers and mobile phones, metallic scraps, and integrated circuits. As electrical and electronic wastes account for the bulk of secondary resources of gold and silver, methods for leaching gold and silver from such waste would need to take into consideration their complex matrix, which includes a mixture of toxic heavy metals such as copper (Cu), zinc (Zn), aluminium (Al), tin (Sn), and lead (Pb), and hazardous organic components including brominated flame retardants and polybrominated biphenyls.

At present, however, the lixiviants used in industry to leach gold and silver comprise of either highly corrosive aqua regia, or highly toxic cyanide-based solutions with a free cyanide concentration (CN^-) of up to 20,000 ppm, which is attributed to their low cost and extended use in history. Leaching of precious metals using aqua regia is slow and may take days. Further, aqua regia is non-selective due to its preferential leaching of toxic base metals such as copper (Cu) and nickel (Ni) that are more reactive than gold or silver in nature. Gold and silver leaching from e-waste using aqua regia is applied only in experimental research, with very few full-scale operations conducted due to the highly oxidative and corrosive effects of aqua regia on the equipment, relatively high operation costs and difficulty in dealing with the downstream waste.

Cyanide-based lixiviants have been employed for leaching of gold ores for centuries, and is currently still used in the leaching of gold in secondary sources due to its high efficiency, simplicity, and relatively low cost. Cyanide-based lixiviants act faster than aqua regia, with leaching of gold achieved usually within a day, and are also more selective towards gold. Free cyanide ions (CN^-) in cyanide-based lixiviants act as complexing agents to form a stable complex with gold at pH values above 10. Cyanide leaching has been estimated to be used in about 90% of gold production from primary ores, and also the primary lixiviant used in e-waste recycling in China.

While cyanide leaching is generally more selective than nitric acid towards precious metals such as gold and silver with minimal reagent loss during the process, reported leaching efficiencies are moderate, achieving, for example, only about 60% extraction of gold from secondary sources such as pulverised waste PCBs using commercial cyanide lixiviant with a recovery of only 500 g gold per ton of PCB waste. Although 88% leaching efficiency of gold has been achieved using commercial cyanide stripping in 2 hours at room temperature, the concentration of gold per mass of PCBs has not been reported. Similarly, reported leaching efficiencies of silver using cyanide-based lixiviants from secondary sources such as pulverised waste PCBs was only about 60%.

However, interest in the use of non/low-cyanide methods for the dissolution of gold and silver arises from concerns regarding the extremely high toxicity of cyanide under high concentrations over an extended period of time. Further, due to the toxicity, there are high costs associated with the treatment of downstream waste. Due to the high toxicity of cyanide, its use has been under tight regulation or even prohibited in many countries, especially at a large scale.

With an increasing demand for gold and silver from the industry, there is a need for effective technologies to extract and recover gold and silver from secondary sources so as to meet the demand. This is also synchronous with the increase in regulations enforced worldwide that mandates the recycling of electronic wastes, which accounts for the bulk of secondary sources of gold and silver.

In view of the limitations of current methods for extraction of gold and/or silver from solid wastes comprising gold and/or silver, there is a need for development of a lixiviant that is non-toxic, user and environmentally friendly, economical, and capable of achieving selective extraction with high efficiencies, to overcome or at least ameliorate, one or more of the disadvantages described above.

Summary

In an aspect, there is provided a composition comprising:

i) a strong base;

ii) an oxidant; and

iii) a thiocyanate,

wherein the composition has a pH in the range of 12 to 14.

Advantageously, the composition as defined above may be selective for a precious metal such as gold and/or silver, may be non-toxic, compatible with downstream recovery processes, inextensible and recyclable. Further advantageously, the composition as defined above may be low in cyanide, containing 20 times as less cyanide as compared to conventional lixiviants, may be low in lead ions, and may facilitate leaching of precious metals under moderate temperatures in an alkaline system having a pH of about 12 to 14.

More advantageously, the composition as defined above may provide a simple, low-cost and comparatively safe means to efficiently leach precious metals such as gold and/or silver selectively from gold- or silver-coated solid waste through hydrometallurgy. Unlike conventional lixiviants, the composition as defined above may be basic (pH 12 to 14), may be free of aqua regia and may be low in cyanide (1,400 ppm to 1,900 ppm) which may further deplete overtime, making it relatively safer to handle without generating a significant amount of toxic waste streams.

Advantageously, thiocyanate may be used in the composition. Thiocyanate may have excellent selectivity for precious metal, low environmental risks and simple subsequent processing. Use of thiocyanate during the leaching process may further facilitate stronger adaptive capacity and higher leaching efficiency than other cyanide-free lixiviants. In addition, thiocyanate may be 1000 times less toxic than cyanide and may be a very strong complexing agent for the precious metal. Further advantageously, reagent loss may be lower when thiocyanate is used.

Further advantageously, the composition may be basic. The use of a strong base may allow the leaching process of precious metals to occur in basic conditions. Since the use of thiocyanates in acidic conditions may cause the generation of poisonous hydrogen cyanide (HCN) gas during the liberation of cyanide, the basic pH of the composition as defined above may advantageously prevent the generation of poisonous HCN gas during the extraction process.

In an example, the composition may further comprise an amine compound. The addition of the amine compound may boost the amount of precious metal extractable to 3 to 4 g/L, and may also aid in the retardation of base metals extraction. In a further example, the composition may advantageously comprise a lead ion to prevent unwanted side-reactions such as precious metal passivation.

In another aspect, there is provided a method of preparing the composition as defined above, comprising the step of mixing:

i) a strong base;

ii) an oxidant; and

iii) a thiocyanate,

wherein the composition has a pH in the range of 12 to 14.

Advantageously, the method as defined above may be performed at mild temperatures of ≤ 70°C and within a few hours, meaning that only moderate energy consumption is required. Further advantageously, as the leaching proceeds, the alkalinity of the composition may decrease towards neutral, making the resulting leachate even less corrosive over time, simplifying the post-treatment of the waste.

In another aspect, there is provided a method of extracting a precious metal from a solid mixture comprising the precious metal, the method comprising the step of contacting the composition as defined above with the solid mixture to form a leachate solution.

Advantageously, over 95% of gold or silver may be extracted using the method as defined above, with a minimum saturation concentration of 3 to 4 g/L gold or silver at a temperature 50 to 60°C in less than 4 hours. Extraction may be relatively selective, with gold and/or silver constituting a major 85 to 96% of the metals extracted, therefore reducing the complexity of downstream recovery processes to obtain high purity gold and silver. Further advantageously, extraction of gold or silver may be conducted in a batch-wise manner by the method as defined above, until the composition is saturated.

Further advantageously, the method as defined above may be versatile and may be applied to a wide range of e-wastes including gold- or silver-coated solid wastes such as motherboards, printed circuit boards (PCBs,) connectors, hull cell samples and lead frames.

In another aspect, there is provided the use of the composition as defined above, to recover a precious metal from a solid mixture comprising a plurality of metals comprising the precious metal.

Advantageously, the extracted precious metal may be recovered from the leachate through conventional means such as reduction and precipitation, whereby over 99% precious metal may be precipitated with a purity of 90 to 95%.

Definitions

The following words and terms used herein shall have the meaning indicated:

The word “leaching” for the purposes of this disclosure refers to the process of extracting a substance from a solid mixture into a liquid by dissolution. The word “leachate” should be construed accordingly.

The word “recovery” for the purposes of this disclosure refers to the process of retrieving a dissolved substance from a solution as a solid.

The word “substantially” does not exclude “completely” e.g. a composition which is “substantially free” from Y may be completely free from Y. Where necessary, the word “substantially” may be omitted from the definition of the invention.

Unless specified otherwise, the terms "comprising" and "comprise", and grammatical variants thereof, are intended to represent "open" or "inclusive" language such that they include recited elements but also permit inclusion of additional, unrecited elements.

As used herein, the term "about", in the context of concentrations of components of the formulations, typically means +/- 5% of the stated value, more typically +/- 4% of the stated value, more typically +/- 3% of the stated value, more typically, +/- 2% of the stated value, even more typically +/- 1% of the stated value, and even more typically +/- 0.5% of the stated value.

Throughout this disclosure, certain embodiments may be disclosed in a range format. It should be understood that the description in range format is merely for convenience and brevity and should not be construed as an inflexible limitation on the scope of the disclosed ranges. Accordingly, the description of a range should be considered to have specifically disclosed all the possible sub-ranges as well as individual numerical values within that range. For example, description of a range such as from 1 to 6 should be considered to have specifically disclosed sub-ranges such as from 1 to 3, from 1 to 4, from 1 to 5, from 2 to 4, from 2 to 6, from 3 to 6 etc., as well as individual numbers within that range, for example, 1, 2, 3, 4, 5, and 6. This applies regardless of the breadth of the range.

Certain embodiments may also be described broadly and generically herein. Each of the narrower species and subgeneric groupings falling within the generic disclosure also form part of the disclosure. This includes the generic description of the embodiments with a proviso or negative limitation removing any subject matter from the genus, regardless of whether or not the excised material is specifically recited herein.

Detailed Disclosure of Optional Embodiments

There is provided a composition comprising:

i) a strong base;

ii) an oxidant; and

iii) a thiocyanate,

wherein the composition has a pH in the range of 12 to 14.

The pH may be in the range of about 12 to about 14, about 12 to about 12.5, about 12 to about 13, about 12 to about 13.5, about 12.5 to about 13, about 12.5 to about 13.5, about 12.5 to about 14, about 13 to about 13.5, about 13 to about 14, or about 13.5 to about 14.

The strong base may be a hydroxide of an alkali metal or an alkali earth metal. A strong base may be completely dissociated in an aqueous solution.

The strong base may be an alkali hydroxide. The strong base may be selected from the group consisting of sodium hydroxide, potassium hydroxide, lithium hydroxide, rubidium hydroxide, cesium hydroxide and any mixture thereof.

The composition may comprise the strong base at a concentration in a range of about 2% w/v to about 5% w/v, about 2% w/v to about 3% w/v, about 2% w/v to about 4% w/v, about 3% w/v to about 4% w/v, about 3% w/v to about 5% w/v, or about 4% w/v to about 5% w/v, based on the total volume of the composition.

The composition may comprise the strong base at concentration in a range of 2% w/v to 5% w/v based on the total volume of the composition, giving the composition a pH in the range of 12 to 14.

The oxidant may be selected from the group consisting of a persulfate, a peroxide, a peroxy acid, an oxoacid, an oxyanion, a nitrate compound, a hexavalent chromium compound, permanganates, cerium (IV) compounds, sodium bismuthate, lead dioxide and any mixture thereof.

The oxidant may be selected from the group consisting of sodium persulfate ($Na_2S_2O_8$), potassium persulfate ($K_2S_2O_8$), ammonium persulfate ($(NH_4)_2S_2O_8$), sodium nitrate, potassium nitrate, peroxydisulfuric acid, peroxymonosulfuric acid, hypochlorite, sodium hypochlorite, calcium hypochlorite, chlorite, sodium chlorite, chlorate, sodium chlorate, potassium chlorate, perchlorate, sodium perchlorate, potassium perchlorate, ammonium perchlorate, perchloric acid, chromic acid, dichromic acid, chromium trioxide, pyridinium chlorochromate, chromate compound, dichromate compound, sodium permanganate, potassium permanganate, ceric ammonium nitrate, ceric sulfate, sodium perborate, sodium percarbonate, sodium perphosphonate, sodium persulfate, urea peroxide, sodium bismuthate, lead dioxide and any mixture thereof.

The oxidant may be a persulfate. The oxidant may be selected from the group consisting of sodium persulfate ($Na_2S_2O_8$), potassium persulfate ($K_2S_2O_8$), ammonium persulfate ($(NH_4)_2S_2O_8$), and any mixture thereof.

Persulfates may be one of the cheapest oxidants that have the highest oxidation potential of all peroxygen compounds. This may make them strong oxidants, especially at elevated temperatures in an alkaline system. Persulfates therefore may facilitate oxidation reactions in an efficient manner in the lixiviant as defined above.

The composition may comprise the oxidant at a concentration in a range of about 2% w/v to 8 % w/v, about 2% w/v to about 4% w/v, 2% w/v to about 6% w/v, 4% w/v to about 6% w/v, 4% w/v to about 8% w/v or about 6% w/v to about 8% w/v, based on the total volume of the composition.

The thiocyanate may be any compound comprising the anion $[SCN]^-$. The thiocyanate may be an inorganic thiocyanate, an organic thiocyanate or a mixture thereof.

The thiocyanate may function as a cyanide-associated complexing agent. The thiocyanate may complex to a precious metal.

The precious metal may be a metal selected from group 10 or 11 of the Periodic Table of Elements. The precious metal may be selected from the group consisting of palladium, platinum, silver, gold and any mixture thereof. The precious metal may be silver, gold or silver and gold. The precious metal may be gold.

The thiocyanate may be selected from the group consisting of potassium thiocyanate (KSCN), sodium thiocyanate (NaSCN), phenyl thiocyanate, guanidinium thiocyanate and any mixture thereof.

The composition may comprise the thiocyanate at a concentration in a range of about 0.5% w/v to 2 % w/v, about 0.5% w/v to about 1% w/v, about 0.5% w/v to about 1.5% w/v, about 1% w/v to about 1.5% w/v, about 1% w/v to about 2% w/v, or about 1.5% w/v to about 2% w/v, based on the total volume of the composition.

The amount of thiocyanate in the composition may result in the release of about 1,400 mg/L (ppm) to about 1,900 mg/L (ppm) free cyanide in solution. The amount of free cyanide may decrease overtime as the cyanide is used up in the extraction of the precious metal.

The composition may further comprise a compound comprising a benzoic acid functional group. The compound comprising a benzoic acid functional group may function as a non-cyanide-associated complexing agent that may complex to the precious metal as defined above. The benzoic acid group of the compound comprising the benzoic acid may complex to the precious metal as defined above.

The compound comprising a benzoic acid functional group may be selected from the group consisting of phthalic acid, nitrobenzoic acid, 4-nitrobenzoic acid, salicylic acid, anthranilic acid, hydroxybenzoic acid, halobenzoic acid, toluic acid and any mixture thereof.

The compound comprising a benzoic acid functional group may be present at a concentration in the range of about 0.5% w/v to about 2% w/v, about 0.5% w/v to about 1% w/v, about 0.5% w/v to about 1.5% w/v, about 1% w/v to about 1.5% w/v, about 1% w/v to about 2% w/v, or about 1.5% w/v to about 2% w/v, based on the total volume of the composition.

The composition may further comprise an amine compound.

The amine group of the amine compound may be a primary, secondary or tertiary amine. The amine compound may comprise 1, 2, 3, 4, 5 or 6 amine groups.

The amine compound may further comprise an alcohol group. The amine compound may comprise 1, 2, 3, 4, 5 or 6 alcohol groups

The amine compound may be selected from the group consisting of ethanolamine, hexamethylenetetramine, ethylenediamine, N-(2-hydroxyethyl) ethylenediamine, N,N-Dimethylethylenediamine, ethylenediaminetetraacetic acid (EDTA), 5,5-dimethylhydantoin, ammonia, EDTA, nicotinic acid, 1,10-phenanthroline, 4,6-dimethylpyrimidine, 4,7-phenanthroline, benzo[*c*]cinnoline, 4-(2-pyridyl)pyrimidine and any mixture thereof.

The amine compound may be selected from the group consisting of ethanolamine, hexamethylenetetramine, ethylenediamine, N-(2-hydroxyethyl) ethylenediamine, N,N-dimethylethylenediamine, and any mixture thereof.

Amine compounds, being derivatives of ammonia which has been demonstrated to achieve high and selective extraction of precious metals, may be preferred to ammonia as they are easier to handle and generally have lower consumption than volatile ammonia. The amine compound may form a stable complex with the precious metal, and therefore enhance the extraction of the precious metal, while reducing the oxidation and extraction of base metals.

A base metal may be a common metal that tends to be more abundant and less costly, such as copper (Cu), zinc (Zn), nickel (Ni), aluminium (Al), tin (Sn), lead (Pb) and any mixture thereof. Base metals may generally be plated at the bottom layer of electronic components underneath precious metals such as silver (Ag), (Au), and/or (Pd).

The amine compound may be present at a concentration in the range of about 0.05% w/v to about 1% w/v, about 0.05% w/v to about 0.1% w/v, about 0.05% w/v to about 0.2% w/v, about 0.05% w/v to about 0.5% w/v, about 0.1% w/v to about 0.2% w/v, about 0.1% w/v to about 0.5% w/v, about 0.1% w/v to about 1% w/v, about 0.2% w/v to about 0.5% w/v, about 0.2% w/v to about 1% w/v or about 0.5% w/v to about 1% w/v, based on the total volume of the composition.

The composition may further comprise a lead ion. The lead ion may be present in the form of a lead (II) salt. The lead ion may function as a surfactant inhibitor to prevent the surface of the precious metal from undergoing undesirable reactions such precious metal-passivation during the extraction process. The lead salt may be at least partially soluble in water.

The lead ion may be present in the form of a lead salt selected from the group consisting of lead(II) nitrate, lead(II) carbonate, lead(II) oxide, lead(II) acetate, lead(II) methanesulfonate, lead(II) citrate, and any mixture thereof.

The lead ion or the lead ion in the form of a lead salt may be present at a concentration in the range of about 0.02% w/v to about 0.05% w/v, about 0.02% w/v to about 0.03% w/v, about 0.02% w/v to about 0.04% w/v, about 0.03% w/v to about 0.04% w/v, about 0.03% w/v to about 0.05% w/v, or about 0.04% w/v to about 0.05% w/v, based on the total volume of the composition.

Advantageously, the amount of lead ion in the composition may be low compared to conventionally known lixiviants.

The composition may be substantially free of iron (Fe) ions. The iron ion may be Fe^{2+} or Fe^{3+}. The composition may not comprise any iron ions. The iron ion may be in the form of an iron salt. The iron salt may be ferrous sulfate.

The composition may further comprise water.

The total %w/v of the composition of the strong base, the oxidant, the thiocyanate, water, optionally the compound comprising a benzoic acid functional group, optionally the amine compound and optionally the lead ion, may be 100% w/v.

There is provided a composition comprising:

i) 2% w/v to 5% w/v of a strong base;

ii) 2% w/v to 8% w/v of an oxidant;

iii) 0.5% w/v to 2% w/v of a thiocyanate; and

iv) 85% w/v to 95.5% w/v of water,

wherein the composition has a pH in the range of 12 to 14, and the total %w/v of the composition is 100% w/v.

There is provided a composition consisting essentially of:

i) 2% w/v to 5% w/v of a strong base;

ii) 2% w/v to 8% w/v of an oxidant;

iii) 0.5% w/v to 2% w/v of a thiocyanate; and

iv) 85% w/v to 95.5% w/v of water,

wherein the composition has a pH in the range of 12 to 14, and the total %w/v of the composition is 100% w/v.

There is provided a composition comprising:

i) 2% w/v to 5% w/v of a strong base;

ii) 2% w/v to 8% w/v of an oxidant;

iii) 0.5% w/v to 2% w/v of a thiocyanate;

iv) 0.5% w/v to 2% w/v of a compound comprising a benzoic acid functional group;

v) 0.05% w/v to 1%w/v of an amine compound;

vi) 0.02% w/v to 0.05% w/v of a lead ion; and

vii) 81.95% w/v to 94.93% w/v of water,

wherein the composition has a pH in the range of 12 to 14, and the total %w/v of the composition is 100% w/v.

There is provided a composition consisting essentially of:

i) 2% w/v to 5% w/v of a strong base;

ii) 2% w/v to 8% w/v of an oxidant;

iii) 0.5% w/v to 2% w/v of a thiocyanate;

iv) 0.5% w/v to 2% w/v of a compound comprising a benzoic acid functional group;

v) 0.05% w/v to 1%w/v of an amine compound;

vi) 0.02% w/v to 0.05% w/v of a lead ion; and

vii) 81.95% w/v to 94.93% w/v of water,

wherein the composition has a pH in the range of 12 to 14, and the total %w/v of the composition is 100% w/v.

The combination of the specific concentrations of the strong base, oxidant and thiocyanate may be essential for high yield and selective extraction of the precious metal, as the deprivation or use of any one of these components at a different concentration may adversely affect the performance of the composition.

The composition may be a lixiviant (extraction or leaching medium) for extracting a precious metal from a solid mixture comprising the precious metal. The composition may be a lixiviant for extracting a precious metal from a solid mixture comprising the precious metal.

There is also provided a method of preparing the composition as defined above, comprising the step of mixing:

i) a strong base;

ii) an oxidant; and

iii) a thiocyanate,

wherein the composition has a pH in the range of about 12 to 14.

The method may further comprise the step of adding a compound comprising a benzoic acid functional group to the composition.

The method may further comprise the step of adding an amine compound to the composition.

The method may further comprise the step of adding a lead ion to the composition.

There is also provided a method of extracting a precious metal from a solid mixture comprising a plurality of metals comprising the precious metal, the method comprising the step of contacting the composition as defined above with the solid mixture to form a leachate solution.

The contacting step may be performed at a temperature in the range of about 40°C to about 70°C, about 40 °C to about 50 °C, about 40 °C to about 60 °C, about 50°C to about 60°C, about 50 °C to about 70 °C or about 60 °C to about 70 °C.

The temperature of the method may be relatively low in comparison to conventionally known methods. The temperature of the method may be a crucial consideration relating to energy consumption, workplace safety, and equipment consideration. Therefore, the method as defined above may advantageously facilitate lower energy consumption and higher safety of the method.

The contacting step may be performed for a duration of less than 1 hour, less than 45 minutes, less than 30 minutes, less than 15 minutes, or less than 1 minute. The contacting step may be performed for a duration in the range of about 1 minute to about 1 hour, about 1 minute to about 15 minutes, about 1 minute to about 30 minutes, about 1 minute to about 45 minutes, about 15 minutes to about 30 minutes, about 15 minutes to about 45 minutes, about 15 minutes to about 1 hour, about 30 minutes to about 45 minutes, about 30 minutes to about 1 hour or about 45 minutes to about 1 hour.

The contacting step may be performed until the leachate solution is saturated. Upon saturation, the pH of the leachate may have a pH in the range of about 8 to 10.

The method may be applied to extract a precious metal from the surface of the solid mixture, as well as a precious metal embedded or integrated in the solid mixture.

The plurality of metals may be selected from the group consisting of silver, palladium, aluminium, gold, platinum, copper, iron, nickel, lead, tin, zinc and any mixture thereof.

The solid mixture may further comprise a base metal as defined above.

The solid mixture may further comprise silica, silicates or an organic compound.

The silica or silicates may be in the form of a rock.

The solid mixture may be an ore comprising a precious metal.

The solid mixture may further comprise an organic compound. The organic compound may be a polymer. The polymer may be selected from the group consisting of epoxide resin, acrylates,

polyamides, poly(ethersulfone) (PES), polyetherimide (PEI), poly(phenylene sulfide) (PPS), polyethylene terephthalates and any mixture thereof. The organic compound may be a brominated flame retardant or a polybrominated polyphenyl.

The solid mixture may be electronic waste or industrial waste. The electronic waste may be selected from the group consisting of TV board scrap, PC board scrap, central processing units (CPU), mobile phone scrap, portable audio scrap, DVD player scrap, calculator scrap, PC mainboard scrap, printed circuit board (PCB) scrap, solar panel wafer, connectors, hull cell samples and lead frames and any mixture thereof. The industrial waste may be photographic films.

The solid mixture may be selected from the group consisting of a precious metal-coated electronic wastes such as printed circuit boards (PCBs), connectors, hull cell samples and lead frames.

The method may further comprise the step of pre-treating the solid mixture before contacting with the composition as defined above.

The pre-treatment step may comprise the step of rinsing the solid mixture with an organic solvent and/or a strong acid before contacting with the composition.

The organic solvent may be selected from the group consisting of methanol, ethanol, propanol, acetone, chloroform, dichloromethane, dimethylsulfoxide, dimethylformamide, toluene, tetrahydrofuran, acetone, acetonitrile and any mixture thereof.

The strong acid may be selected from the group consisting of hydrochloric acid, nitric acid, sulfuric acid, hydrobromic acid, hydroiodic acid, perchloric acid, chloric acid and any mixture thereof.

Where the solid mixture comprises an organic compound, the pre-treating step may comprise the step of separating the solid mixture into the organic compounds and the plurality of metals to form a solid metal mixture.

The pre-treating step may comprise a size-reduction step, wherein the solid mixture or the solid metal mixture may be crushed or cut.

Those skilled in the art will recognise that the solid mixture or the solid metal mixture may be ground to particle or a particular average size though various well know crushers or grinders, such as hammer mills, ball mills, ring mills and shredders or a combination of two or more such implements. By way of example, the grinding step ay include a cutting stage followed by a two-step grinding and crushing stage. The particle size may be reduced to be in the mm to cm range. The particle size may be reduced to less than 10 cm, less than 5 cm, less than 2 cm, less than 1 cm, or less than 1 mm. The particle size may be reduced to an average of about 1 mm to about 10 cm, about 1 mm to about 2 mm, about 1 mm to about 5 mm, about 1 mm to about 1 cm, about 1 mm to about 2 cm, about 1 mm to about 5 cm, about 2 mm to about 5 mm, about 2 mm to about 1 cm, about 2 mm to about 2 cm, about 2 mm to about 5 cm, about 2 mm to about 10 cm, about 5 mm to about 1 cm, about 5 mm to about 2 cm, about 5 mm to about 5 cm, about 5 mm to about

10 cm, about 1 cm to about 2 cm, about 1 cm to about 5 cm, about 1 cm to about 10 cm, about 2 cm to about 5 cm, about 2cm to about 10 cm, or about 5 cm to about 10 cm.

The size reduction step may follow the separation step.

The pre-treating step may comprise a priming step, wherein the optionally crushed or cut solid mixture or the solid metal mixture may be contacted with a strong acid. The strong acid may be sulfuric acid.

The priming step may follow the size reduction step.

The pre-treating step may comprise a washing step, wherein the optionally crushed, cut or primed solid mixture or the solid metal mixture may be rinsed with water.

The washing step may follow the priming step.

The contacting step may be repeated on the same solid mixture multiple times. That is, the solid mixture may be contacted with a first batch of the composition as defined above to form the first leachate solution, and the same solid mixture may be contacted with a second batch of the composition as defined above after being contacted with the first bath of the composition to form the second leachate solution. The second batch of the composition may not have previously been contacted with any solid mixtures. Similarly, the same solid mixture may be contacted with a third batch of the composition as defined above after being contacted with the second batch of the composition to form the third leachate solution. The third batch of the composition may not have previously been contacted with any solid mixtures.

The first leachate solution and second leachate solution may be combined. The third leachate solution may be combined with the first leachate solution and the second leachate solution.

The method may further comprise the step of contacting the leachate solution with a reductant to precipitate the precious metal. The precious metal may be precipitated as a solid in elemental form, as an oxide of the precious metal or as a mixture thereof.

If the solid is precipitated as an oxide of the precious metal or as a mixture of the precious metal in elemental form and an oxide of the precious metal, the solid may be further purified to obtain the precious metal in elemental form.

The reductant may be H_2, hydrazine, sodium borohydride ($NaBH_4$), lithium aluminium hydride ($LiAlH_4$), sodium acetate, citrate salts and any mixture thereof. The citrate salt may be selected from the group consisting of ammonium ferric citrate, sodium citrate, trisodium citrate, potassium citrate, zinc citrate, magnesium citrate and any mixture thereof.

The contacting step to precipitate the precious metal may be performed at a temperature in the range of about 60 °C to about 80 °C, about 60 °C to about 70 °C or about 70 °C to about 80 °C.

The contacting step to precipitate the precious metal may be performed on the combined leachate solution, if the step of contacting the composition with the solid mixture is repeated on the same solid mixture multiple times.

It would be known to a person skilled in the art that the pH, temperature of the contacting step, the duration of the contacting step and the shape and/or volume of the lixiviant may be adjusted to improve the performance of the lixiviant depending on the type of the composition of the solid mixture.

There is also provided the use of the composition as defined above, to recover a precious metal from a solid mixture comprising a plurality of metals comprising the precious metal.

Brief Description of Drawings

The accompanying drawings illustrate a disclosed embodiment and serves to explain the principles of the disclosed embodiment. It is to be understood, however, that the drawings are designed for purposes of illustration only, and not as a definition of the limits of the invention.

Fig. 1

[Fig. 1] shows a photographic image of gold recovered as brownish pellets using the inventive lixiviant.

Fig. 2

[Fig. 2] shows photographic images of gold-coated e-waste used with the inventive lixiviants. Fig. 2A is a motherboard and Fig. 2B is a printed circuit board (PCB).

Fig. 3

[Fig. 3] shows photographic images of gold-coated e-waste before and after exposure to the inventive lixiviants. Fig. 3A shows samples of gold-coated Random Access Memory (RAM), Fig. 3B shows samples of gold-coated pins, Fig. 3C shows samples of gold-coated Central Processing Units (CPUs) and Fig. 3D shows a sample of a gold-coated motherboard.

Fig. 4

[Fig. 4] shows a graph depicting the extraction performance of the inventive lixiviants for gold and silver over time.

Examples

Non-limiting examples of the invention will be further described in greater detail by reference to specific Examples, which should not be construed as in any way limiting the scope of the invention.

Methods And Materials

Potassium hydroxide (99.5%), potassium persulfate (95%) and guanidine thiocyanate (≥98%) were purchased from Shanghai Macklin Biochemical Co., Ltd (Shanghai, China). Lead(II) oxide (≥99%) and ethanolamine (≥98%) were purchased from Sigma-Aldrich (St. Louis, Missouri, USA). Potassium thiocyanate (AR) and 4-nitrobenzoic acid (AR) are purchased from Sinopharm Chemical Reagent Co., Ltd. (Shanghai, China). Glycine (99%) was purchased from Alfa Aesar (Heysham, Lancashire, UK).

Inductively Coupled Plasma - Optical Emission Spectroscopy (ICP-OES) was performed using Thermo Scientific cCAP6300. The elements wavelengths used were 242.795 nm for gold, 328.068 nm for silver, 324.754 nm for copper, 309.271 nm for aluminium, 221.647 nm for nickel, 340.458 nm for palladium, 189.989 nm for tin, and 213.856 nm for zinc. Three calibration standards (5 ppm, 10 ppm and 15 ppm) were prepared for each element. ICP-OES was used to quantify the concentration of dissolved elements (in mg/L).

Energy Dispersive X-Ray Fluorescence (XRF) was performed using Shimadzu's EDX-720, using aluminium plate (A750) for energy calibration. XRF was used to quantify the elemental metal composition in percentage.

Voltammetric analysis was performed to quantify free cyanide concentration (in mg/L) in accordance with the 4500 CN F method as indicated in the Standard Methods For The Examination Of Water and Wastewater (23rd Edition, 2017) published by the American Public Health Association (APHA).

Metal Extraction

Discarded motherboards and printed circuit boards (PCBs) were obtained from manufacturers of electrical components and recyclers of electronic waste. Before leaching, the waste materials were rinsed with 10% sulphuric acid (H_2SO_4) to remove any oxide layers which may interfere with the extraction, then washed with deionized water and air-dried.

Mixtures of the e-waste samples were immersed in batches (i.e. 50 g e-waste in lab-scale) into the leaching bath at 50°C to 60°C and removed once the precious metal was observed to be leached (no effervescence). This was repeated until the solution was saturated and could no longer leach new batch of samples immersed. Immersion duration for each batch of samples ranged from 1 to 30 minutes dependent on sample type, as the leaching bath became increasingly concentrated and dissolution rate slowed down. After rinsing and drying, all the leached samples were subjected to a second leaching using the same formulation and under the same conditions as the first leach to ensure complete dissolution of precious metal from the samples. This was to obtain the amount of residual precious metal that remained after the first leach for determination of total amount of precious metal present which was subsequently used to calculate the extraction/recovery rates. The concentration of metal ions in all leachates were analysed by Inductively Coupled Plasma - Optical Emission Spectrometry (ICP-OES). The purity of solid

samples after reducing the saturated leaching bath to obtain pure precious metal were analysed by X-Ray Fluorescence (XRF).

Extraction Efficiency

The extraction efficiency of the formulation is determined via Equation 1.

Equation 1. Determination of extraction rate

$$\textbf{\textit{Extraction rate}}\ (\%) = \frac{Mass\ of\ Au\ extracted\ in\ 1st\ leach}{Total\ Mass\ of\ Au\ extracted\ in\ 1st + 2nd\ leach}$$

$$= \frac{Au\ Concentration\ \left({}^{g}/_{L}\right) \times Volume\ (L)\ in\ 1st\ leach}{\left(Au\ Concentration\ \left({}^{g}/_{L}\right) \times Volume\ (L)\ in\ 1st\ leach\right) + \left(Au\ Concentration\ \left({}^{g}/_{L}\right) \times Volume\ (L)\ in\ 2nd\ leach\right)}$$

Metal Recovery

About 300g of hydrazine was first added to 5 L of saturated lixiviant (concentration: 60 g/L or 2 mol/L of hydrazine) at 70 ºC to reduce the gold. After agitating for 20 minutes, a mixture of 100 g of sodium borohydride ($NaBH_4$) and 100 g sodium acetate were slowly added to further reduce the gold (concentration: 20 g/L or 0.5 mol/L of $NaBH_4$ and 20 g/L or 0.25 mol/L sodium acetate), which was agitated for another hour. Over time, brownish-gold particles (Fig. 1) precipitate from the solution, which were then filtered and dried.

Example 1: Lixiviant

Essentially, the low-cyanide lixiviant developed for the extraction of gold and/or silver from gold- and/or silver-coated solid wastes as disclosed herein, is an alkaline aqueous system (pH 13 to 14) comprising:

i) 2.0 to 8.0 % w/v of potassium persulfate ($K_2S_2O_8$) functioning as the main oxidizing agent for the leaching of gold and/or silver;

ii) 2.0 to 5.0 % w/v of potassium hydroxide (KOH) that provides the alkaline medium for the dissolution of the reagents;

iii) 0.5 to 2.0% w/v of potassium thiocyanate (KSCN) and guanidinium thiocyanate, functioning as a cyanide-associated complexing agent;

iv) 0.5 to 2.0% w/v of nitrobenzoic acid, functioning as a non-cyanide-associated complexing agent;

v) 0.05 to 1.0% w/v of amine additives to boost the gold and/or silver extraction and/or reduce leaching of base metals; and

vi) 0.03% w/v of lead(II) oxide as a surfactant inhibitor to prevent metal surfaces from undergoing undesirable reactions (i.e. gold- or silver-passivation) during the extraction process.

The lixiviant was prepared using 5% w/v (i.e. 50 g/L) of a stock solution consisting of potassium hydroxide, 12.5 g/L 4-nitrobenzoic acid, 0.3 g/L lead(II) oxide, 5 to 10 g/L guanidinium thiocyanate, 0 to 5 g/L potassium thiocyanate, 3 to 4 g/L amine additives, and finally 60 g/L potassium persulfate. The remainder of the lixiviant was made up of deionised water.

Example 2: Gold Leaching

The present invented lixiviant was applied to the extraction of gold coatings on discarded motherboards and printed circuit boards (PCBs) (Fig. 2) obtained from manufacturers of electrical components and recyclers of electronics waste. The major base metals in these materials were Cu, Ni, Zn and Sn. Trace amount of Pd (<0.5%) was also detected.

The amount of gold leached from e-waste depends on the composition of the e-waste sample. It was found that the amount of gold leached was lower for samples with more Cu or those with gold plated directly above Cu such as in PCBs, as Cu is readily leached into the bath once exposed. This resulted in a high proportion of base metal content in the leachate, lowering the proportion of gold leached. On the other hand, the amount of gold leached was higher for samples with less Cu, and other base metals such as Ni and Sn did not affect the performance of the bath significantly.

Table 2 summarizes the result of gold leached (> 3 g/L gold at saturation) for e-waste samples in small scale (i.e. 100 mL of lixiviant) containing less Cu, by varying the concentration of the primary reagents in the leaching bath.

Bath 1 showed the highest concentration of 3.925 g/L gold leached at saturation, which comprised of 60 g/L of oxidant, 15 g/L of cyanide-associated complexing agents, 12.5 g/L of non-cyanide-associated complexing agents, and 1 to 2 g/L of performance enhancing additives. Voltametric analysis of free cyanide in freshly prepared Bath 1 recorded a concentration in the range of 1,800 to 1,900 ppm, which is more than 10 times less than the amount of cyanide used in industry. At saturation, there may be no detectable cyanide in the baths, likely indicating their complete complexation with metal ions.

Table 2. Summary of small scale gold extraction result from saturation leaching baths at 50 °C to 60°C

Bath	Primary Reagent Concentration (g/L)				Free CN^- (ppm)	Metal Concentration at Saturation (g/L)			Extraction Rate
	Ox	CA_{CN}	CA_{NCN}	Ad		Au	Pd	BM	
1	60	15	12.5	1 to 2	1800 to 1900	3.925 (89.0%)	0.012 (0.27%)	0.473 (10.7%)	ND
2	60	15	12.5	2 to 3	1800 to 1900	3.80 (90.9%)	0.02 (0.48%)	0.361 (8.6%)	ND
3	60	10	12.5	1 to 2	1500 to 1600	3.24 (89.6%)	0.003 (0.08%)	0.374 (10.3%)	95.1%
4	60	10	17.5	1 to 2	1700 to 1800	3.404 (85.5%)	0 (0%)	0.577 (14.5%)	ND
5	60	10	12.5	6 to 7	1700 to 1800	3.083 (96.2%)	0.0012 (0.03%)	0.123 (3.84%)	ND

Note: (a) Ox = oxidant, CA_{CN} = cyanide-associated complexing agents, CA_{NCN} = non-cyanide-associated complexing agents, Ad = performance enhancement additives, (b) BM = base metals, including Cu, Ni, Zn, Sn, Al etc, (c) ND = not determined

Using Bath 1 as the benchmark, a slightly higher amount of performance enhancing additives was tested in Bath 2 in an attempt to increase the amount of leachable gold. Although the gold extraction efficiency was increased from 89.0% to 90.9%, the actual amount of gold leached at saturation decreased by 3.2% from 3.925 g/L to 3.80 g/L. The amount of cyanide was reduced for Bath 3, 4 and 5 by altering the cyanide-associated complexing agents to 10 g/L. Although the free cyanide concentration decreased slightly in Bath 3, 4 and 5 as compared to Bath 1, the actual amount of gold leached at saturation did not improve. This may indicate the effectiveness of cyanide-associated complexing agents. The extraction rate for gold was calculated to be 95.1% in Bath 3. Interestingly, Bath 5 afforded the highest gold extraction efficiency of 96.2% using an elevated amount of performance enhancing additives. In addition, the proportion of gold in the leachate ranged from 85% to 96% at saturation, indicating that the extraction was relatively selective towards gold.

Example 3: Effect of Amine Additive

Using the same base lixiviant of Example 2, the effect of different amine-based performance enhancing additives on the performance of the gold leaching effects was examined and was summarised in Table 3. Among these additives, ethanolamine afforded the highest amount of gold at saturation with ≥3.80 g/L, while hexamethylenetetramine afforded the highest percentage gold of 93.2% in the leachate. However, hexamethylenetetramine is flammable, while ethanolamine is less hazardous in nature as compared to the other additives. Hence, ethanolamine was considered to be the optimal choice of amine-based additives.

Table 3. Extraction performance of various amine performance-enhancing additives in saturated leaching tests under the same base lixiviants[(a)]

Amine Additive	**Concentration (% w/v)**	**% Au in Leachate**	**% Base Metals[(b)] in Leachate**	**Au at saturation (g/L)**
Ethanolamine	0.1	89.0	10.7	3.93
Ethanolamine	0.2	90.9	8.6	3.80
Hexamethylenetetramine	0.1	93.2	6.6	3.33
N-(2-hydroxyethyl) ethylenediamine	0.1	85.7	14.2	3.33
Hexamethylenediamine	0.1	85.1	14.9	3.54

Note: (a) base lixiviants constitutes 5% w/v KOH, 0.03% w/v PbO, 1.25% w/v 4-nitrobenzoic acid, 6% w/v $K_2S_2O_8$, 0.5% w/v KSCN, 1% w/v $C_2H_6N_4S$, and 0.02% w/v glycine to the lixiviant; (b) Base metals include Cu, Ni, Zn, Sn and Al.

Example 4: Recovery of Gold Metal

After developing the lixiviant of Examples 2 and 3, the use of the lixiviant was tested in cooperation with two companies, using the e-waste provided by the respective companies at a capacity of up to 5 L. The e-waste was mechanically broken down into smaller sizes and divided into small batches of about 200 g to 1000 g. Each batch was placed separately into inert net baskets made of polytetrafluoroethylene (PTFE) having a pore size between 3 mm to 10 mm, to fit into a 5-L capacity beaker with a magnetic stirrer, so that the e-waste was fully immersed in the lixiviant.

Fig. 3 shows some of the gold-coated e-waste before and after the leaching tests. The leaching process was conducted via batch immersion, in which the duration, mass, and types of samples were recorded. Upon saturation, the amount of gold and base metals in the leachate was characterized, followed by recovery of gold by reduction using conventional reduction methods.

Table 4 tabulates the results of the two trial runs for the two companies. An example of the gold recovery calculation for Company A Trial 2 is summarized in Table 5.

Table 4 Gold lixiviant test bedding result of two e-waste recycling companies based in Singapore

	Company A		Company B	
	Trial 1	Trial 2	Trial 1	Trial 2
Amount/Types of E-waste	3.5 kg (3 types)	14 kg (8 types)	6 kg (1 type)	4.14 kg (3 types)
Au Saturation content	3.48 g/L	2.82 g/L[#]	1.63 g/L [^]	3.4 g/L
%Au in saturation bath	94.4%	82% [#]	76%[^]	87.7%
Au extraction rate	95.3%	91.2%	97%	93.5%
%Au in Au solid	92.3%	95.8%	97.3%	98.6%
Time spent in leaching	1 hour	5 hours	2 hours	2 hours

Note: (#) = Leaching process is slow but lixiviant is not completely saturated; (^) = Samples are insufficient

Table 5. Result of recovery of gold from leachate for Company A Trial 2

Volume of leachate used	2.35 L
Concentration of Au at saturation (1st leach)	2.82 g/L

Theoretical mass of gold present	2.35 L x 2.82 g/L = 5.64 g
Concentration of residual Au (2nd leach)	0.54 g/L
Extraction efficiency	5.64/(5.64 +0.54) = 91.2%
Mass of metallic gold recovered	5.6 g
Purity of metallic gold recovered	95.8 %
Actual mass of gold recovered	95.8 % x 5.6 g = 5.36 g
Gold percentage recovery	(5.36/5.64) = 95.0 %
Overall recovery	91.2% x 95.0 = 86.6 %

From Table 4, it can be seen that the gold saturation was at up to 3.5 g/L with 94.4% gold in the saturation bath, with an extraction rate of up to 95.0%, and duration of leaching as short as 2 hours. By using a combination of hydrazine and sodium borohydride to reduce gold, the gold percentage recovery was 95.0% as presented in Table 5 with a purity of ≥ 95% based on X-Ray Fluorescence (XRF) analysis. These result were imperative in the validation of the inventive lixiviant under small-scale experimentation as shown in Table 2.

Example 5: Lixiviant Extraction of Gold and Silver Metals

To further demonstrate the effectiveness of the lixiviant towards the extraction of precious metals, the lixiviant was tested using a mixture of approximately 1300 mg/L of gold (89% purity) powder and 1100 mg/L silver (93% purity) powder.

The gold powder was obtained by extracting and recovering gold from e-waste in the same manner as shown in Examples 2 and 4, at a capacity of 0.1 L.

The silver powder was obtained using a known method, by extracting silver from the e-waste that was sourced from the same companies of Example 4. Briefly, the e-waste was immersed in a lixiviant comprising 0.4 % w/v of acetic acid (CH_3COOH), 1.1 % w/v monochloroacetic acid ($C_2H_3ClO_2$), 0.1% w/v of peptone, 7.5 v% w/v of hydrogen peroxide (H_2O_2), 0.25% w/v of sodium phenol sulfonate ($C_6H_5NaO_4S$), 0.2% w/v of ethanolamine and of 0.2% w/v 5,5-dimethylhydantoin at 40°C. The extracted silver was recovered by precipitation following contact with 1 M sodium chloride and further reduction to metallic silver in the presence of sodium borohydride ($NaBH_4$).

The same extraction and recovery process as Examples 2 and 4 were applied to the mixture of the gold and silver powder. The results are shown in Table 6 and Fig. 4.

Table 6. Extraction performance of lixiviant for gold and silver over time

Time (min)	Gold		Silver	
	Concentration (mg/L)	Selectivity (%)	Concentration (mg/L)	Selectivity (%)
4	1330	97%	40	3%
15	1384	90%	157	10%
60	1224	73%	464	27%
120	1159	64%	663	36%
240	1176	52%	1072	48%

Both gold and silver could be extracted using the lixiviant within 240 minutes. In the presence of a mixture of gold and silver powders, the lixiviant was evidently selective towards gold in which nearly all the gold was extracted within 4 minutes from the start of the test, as shown in Table 6 and Fig. 4. In contrast, the extraction of silver advanced gradually with time, taking 240 minutes to complete. This demonstrates the ability of the lixiviant to extract both gold and silver.

Industrial Applicability

The composition as defined above may be applied in extraction and recovery of precious metals such as gold and/or silver from electronic and industrial wastes such as motherboards, printed circuit boards, connectors, central processing units (CPUs), in the recycling and waste management industry, in extracting precious metals from spent catalysts (spent catalyst recycling), as well as extraction of precious metals from precious metal-containing ores in the mining industry.

It will be apparent that various other modifications and adaptations of the invention will be apparent to the person skilled in the art after reading the foregoing disclosure without departing from the spirit and scope of the invention and it is intended that all such modifications and adaptations come within the scope of the appended claims.

Claims

1. A composition comprising:

   i) a strong base;

   ii) an oxidant; and

   iii) a thiocyanate,

   wherein the composition has a pH in the range of 12 to 14.

2. The composition according to claim 1, wherein the strong base is present at a concentration in the range of 2% w/v to 5% w/v, based on the total volume of the composition.

3. The composition according to claim 1 or 2, wherein the strong base is selected from the group consisting of potassium hydroxide, sodium hydroxide, lithium hydroxide, rubidium hydroxide, cesium hydroxide and any mixture thereof.

4. The composition according to any one of the preceding claims, wherein the oxidant is present at a concentration in the range of 2% w/v to 8% w/v, based on the total volume of the composition.

5. The composition according to any one of the preceding claims, wherein the oxidant is a persulfate, preferably selected from the group consisting of sodium persulfate ($Na_2S_2O_8$), potassium persulfate ($K_2S_2O_8$), ammonium persulfate ($(NH_4)_2S_2O_8$) and any mixture thereof.

6. The composition according to any one of the preceding claims, wherein the thiocyanate is present at a concentration in the range of 0.5% w/v to 2% w/v, based on the total volume of the composition.

7. The composition according to any one of the preceding claims, wherein the thiocyanate is an inorganic thiocyanate, an organic thiocyanate or a mixture thereof, preferably selected from the group consisting of potassium thiocyanate (KSCN), sodium thiocyanate (NaSCN), phenyl thiocyanate, guanidinium thiocyanate and any mixture thereof.

8. The composition according to any one of the preceding claims, further comprising a compound comprising a benzoic acid functional group.

9. The composition according to claim 8, wherein the compound comprising a benzoic acid functional group is present at a concentration in the range of 0.5% w/v to 2% w/v, based on the total volume of the composition.

10. The composition according to any one of the preceding claims, further comprising an amine compound.

11. The composition according to claim 10, wherein the amine compound is present at a concentration in the range of 0.05% w/v to 1% w/v, based on the total volume of the composition.

12. The composition according to any one of the preceding claims, further comprising a lead ion.

13. The composition according to claim 12, wherein the lead ion is present at a concentration in the range of 0.02% w/v to 0.05% w/v, based on the total volume of the composition.

14. A method of preparing the composition according any one of the preceding claims, comprising the step of mixing:

    i) a strong base;

    ii) an oxidant; and

    iii) a thiocyanate,

    wherein the composition has a pH in the range of 12 to 14.

15. The method according to claim 15, further comprising the step of adding a compound comprising a benzoic acid functional group, an amine compound and/or a lead ion to the composition.

16. A method of extracting a precious metal from a solid mixture comprising the precious metal, the method comprising the step of contacting the composition according to any one of claims 1 to 13 with the solid mixture to form a leachate solution.

17. The method according to claim 16, wherein the solid mixture further comprises a base metal, silica, silicates, an organic compound or any mixture thereof.

18. The method according to claim 16 or 17, wherein the contacting step is performed at a temperature in the range of 40°C to 70°C or for a duration of about 1 to 5 hours.

19. The method according to any one of claims 16 to 18, further comprising a pre-treatment step, wherein the solid mixture is rinsed with an organic solvent and/or a strong acid before contacting with the composition.

20. The method according to any one of claims 16 to 19, further comprising the step of contacting the leachate solution with a reductant to precipitate the precious metal.

21. The use of the composition according to any one of claims 1 to 13, to recover a precious metal from a solid mixture comprising a plurality of metals comprising the precious metal.