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(54) Title: METHODS, MATERIALS AND TECHNIQUES FOR PRECIOUS METAL RECOVERY

(57) Abstract: An aqueous-based leaching solution for precious metal, the leaching solution comprising iodide salt material; and carboxylic acid material, the leaching solution being made by a process including the step of passing a first mixture through an electrochemical cell until a measured oxidation reduction potential (ORP) is at least 540 mV, the first mixture including iodide salt material, carboxylic acid material and water.

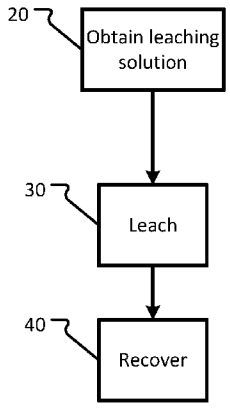

FIG. 1

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METHODS, MATERIALS AND TECHNIQUES FOR PRECIOUS METAL RECOVERY

CROSS-REFERENCE

[0001] This application is being filed on 23 June 2017, as a PCT International patent application, and claims priority to U.S. Provisional Patent Application No. 62/354,393, filed June 24, 2016, U.S. Provisional Patent Application No. 62/421,483, filed November 14, 2016, U.S. Provisional Patent Application No. 62/512,462, filed May 30, 2017, and U.S. Patent Application No. 15/631,252, filed June 23, 2017, the disclosures of which are hereby incorporated by reference herein in their entireties.

FIELD OF DISCLOSURE

[0002] The present disclosure relates to methods, materials and techniques for precious metal recovery. Example applications relate to the preparation of leaching solutions and use of resulting leaching solutions in the recovery of precious metals from substrates, such as gold bearing ores, concentrates, anodic slimes and residues, electronic waste, metallic scrap, and materials previously treated by roasting, bacterial leaching, pressure leaching, or other techniques used to liberate precious metal from its matrix. Many of the materials, methods, and techniques disclosed herein are particularly advantageous for gold recovery.

BACKGROUND

[0003] Precious metal in substrate such as mined ore can be recovered by contacting the substrate with leaching solution. Typically, the leaching solution is an aqueous-based solution. Generally, the leaching solution is contacted with substrate to solubilize the precious metal. Thereafter, valuable components of the solution, such as the solubilized precious metal, are recovered.

[0004] Issues with past approaches relate to: efficiency of leaching recovery; avoidance of undesirable materials such as cyanide materials; and generation of stable solutions. Improvements in at least one, and sometimes more, of these issues are sought.

SUMMARY

[0005] Techniques and materials disclosed herein relate to extracting precious metal from substrate into solution, for example, using leaching solutions. In addition, techniques and materials disclosed herein relate to methods for recovering precious metal from the leaching solutions. Techniques and materials disclosed herein also relate to methods for regenerating components of leaching solutions.

[0006] There is no specific requirement that a material, technique or method relating to a leaching solution include all of the details characterized herein, in order to obtain some benefit according to the present disclosure. Thus, the specific examples characterized are meant to be exemplary applications of the techniques described, and alternatives are possible.

[0007] According to certain techniques, an aqueous-based leaching solution for precious metal includes iodine materials, such as triiodide, iodide material, and/or iodate material, carboxylic acid material, and optionally chlorine and/or bromine material in an amount effective to enhance leaching. Carboxylic acid material includes citric acid, acetic acid, and/or a combination of citric acid and acetic acid. Boric acid can be used independently from, or in combination with, the carboxylic acid material.

[0008] In general, an aqueous-based leaching solution for precious metal includes water-soluble, carboxylic acid in an amount sufficient to enhance leaching and iodide material in an amount effective to enhance leaching. Preferably, the leaching solution has a pH of no greater than 7.

[0009] In various applications, a stable, aqueous-based, precious metal-containing leachate results from leaching precious metal oxidizable with an aqueous-based leach solution. Various leaching methods are contemplated, such as continuous or batch stirred tank agitation, vat leaching, or in situ techniques such as dump and heap leaching.

[0010] Generally, a method of recovering a precious metal from a precious metal-containing pregnant leach solution includes recovering the precious metal by various methods, such as electrowinning, precipitation, cementation, ion exchange, and/or adsorption onto activated carbon, thereby generating a barren solution and passing

current through the barren solution having a triiodide precursor to increase a triiodide content of the barren solution.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 is a schematic flow diagram indicating steps in a process for precious metal recovery.

[0012] FIG. 2 is a schematic flow diagram in accordance with FIG. 1 indicating example steps in a recovery of gold from an ore.

[0013] FIG. 3 is a graph showing experimental results described herein below.

[0014] FIG. 4 is a graph showing experimental results, including data of FIG. 3, described herein below.

[0015] FIG. 5 is a graph showing experimental results described herein below.

[0016] FIG. 6 is a graph showing experimental results described herein below.

[0017] FIG. 7 is a graph showing experimental results described herein below.

[0018] FIG. 8 is a graph showing experimental results described herein below.

DETAILED DESCRIPTION

I. Issues, Materials and Techniques Related to Precious Metals Recovery Generally

A. General

[0019] Precious metal recovery involves separation of the precious metal, such as gold, from ore, mining tails, and/or waste such as electronic waste. The techniques disclosed and contemplated herein include treating substrate with aqueous-based leach solution to produce a "pregnant solution." Herein, the term "pregnant solution" is meant to refer to a leach solution having leached precious metal therein.

[0020] Also described herein are processes used to recover the precious metal from the pregnant solution and processes relating to regeneration of various components of the aqueous based leach solution. The techniques disclosed and contemplated by this disclosure are particularly well-adapted for processes that involve the recovery of gold as the precious metal.

B. Leaching Solutions

[0021] Aqueous-based leaching solutions usable in techniques characterized herein are those that, when in contact with substrate, solubilize at least a portion of precious metal in the substrate by oxidizing the precious metal. Typical leaching solutions characterized herein are effective under a wide pH range, such as between a pH of 3 to 10. Typically, the aqueous-based solutions characterized herein have at or near-neutral pH, for instance, in the range of pH 4-7. Usually, the aqueous-based solutions characterized herein have a pH of at least 4. Preferably, the aqueous-based leaching solutions characterized herein are provided with a pH within the range 5-7, inclusive. As used herein, "inclusive", in this context, means the end points are included within the range.

[0022] Typically, leaching solutions characterized herein preferably are practiced in a manner that avoid the use of soluble, inorganic cyanide materials (such as cyanide salts). Cyanide materials are preferably avoided in the leaching solutions characterized herein because, at least, they are hazardous and subject to stringent environmental regulations.

[0023] Typically, leaching solutions characterized herein include iodate material, iodide material, and one or more weak acids. During typical leaching operations, electrochemical cell(s) are used to maintain the oxidation reduction potential of leaching solutions. Typically, acid is added to a barren solution (the solution resulting from removing precious metal from a leaching solution) to partially regenerate the barren solution before or after using electrochemical cell(s) to fully regenerate the leaching solution for further use. Typically, divided electrochemical cells are used to regenerate the leaching solution.

[0024] It is noted that in mining applications, the leaching solution is sometimes referred to as a lixiviant. Herein, when the term "leaching solution" is used, it is meant to include lixiviant(s).

1. Iodine Material

[0025] The instantly-disclosed aqueous-based leaching solutions include iodine material, which includes iodide material and iodate material. Iodide material

includes compounds capable of forming iodide in an aqueous solution, such as triiodide. Iodide material includes iodide salt, such as KI.

[0026] Preferably, pure elemental iodine is not added to the leaching solution. Rather, without being bound by a particular theory, it is speculated that triiodide material is formed electrochemically. Without being bound by a particular theory, it is speculated that iodide material is useful for complexing and solubility of precious metal.

[0027] The instantly-disclosed aqueous-based leaching solutions also include iodate material. Iodate material includes compounds capable of forming iodate in an aqueous solution. Example iodate material includes iodate salt, such as potassium iodate (KIO_3).

2. Acidic Components

[0028] As indicated above, the leaching solutions disclosed herein include acidic material. The acidity is preferably provided by weak acid material. As used herein, weak acid is intended to mean that the acid does not have any acid group having a pK_a less than 3. Put another way, each pK_a of the weak acid is greater than 3. Weak acid material can facilitate leaching of the target metal. Additionally, without being bound by a particular theory, it is speculated that weak acid material improves the ability of the leaching solution to hold the precious metal in solution. In many instances, the weak acid material is a carboxylic acid. As used herein, weak acid material includes the acid, a salt of the acid, or a combination thereof.

[0029] One example of water-soluble, carboxylic acid material is citric acid. Citric acid is a weak, organic acid. Citric acid has pK_a values of 3.13, 4.76, and 6.4. Another example is acetic acid.

[0030] Without being bound by a particular theory, it is speculated that citric acid improves the ability of the instant leaching solutions to solubilize precious metal. Although citric acid is preferable, acetic acid can be used in place of citric acid.

[0031] In some instances, the leaching solutions can include both citric acid and acetic acid material. Acetic acid material includes glacial acetic acid, dry acetic acid, or equivalents thereof.

[0032] Another example of an acidic component is boric acid. Boric acid is a weak, inorganic acid. Boric acid has pK_a values of 9.24, 12.4 and 13.3. Without being bound by a particular theory, it is speculated that boric acid improves the ability of the instant leaching solutions to solubilize precious metal. Without being bound by a particular theory, it is speculated that boric acid acts as a buffer in the instant leaching solutions. Optionally, borates can be used in place of boric acid. Storage stability is discussed in more detail below.

3. Bromine or Chlorine material

[0033] The instantly-disclosed aqueous-based leaching solutions also optionally include bromine material or chlorine material ("halogen material"). Halogen material is usually added as a sodium salt or a potassium salt. Typical halogen material is chloride salt or bromide salt. Accordingly, example halogen material can include bromide salt material, such as potassium bromide and/or sodium bromide, and chloride salt material, such as potassium chloride and/or sodium chloride.

4. Oxidants

[0034] The leaching solutions disclosed herein preferably include triiodide material and iodide material for dissolution of the precious metal during leaching. Triiodide material is typically generated through oxidation of iodide electrochemically on electrochemical cell anode and/or optionally by addition of a chemical oxidant such as hypochlorite, hydrogen peroxide, persulfate (e.g., potassium monopersulfate, potassium persulfate, sodium persulfate), ozone, or another materials capable of oxidizing iodide to iodine. Alternatively, triiodide material can be generated using iodate material with addition of acid materials (i.e., mixing iodate material with an acid).

[0035] Preferably, triiodide material is generated in-situ through electrochemical approaches from relatively inexpensive, safe and easy to use sources, such as iodide materials and iodate materials. Examples of triiodide material production using a chemical oxidant are provided below. An example pathway using hydrogen peroxide starting material is as follows:

$$H_2O_2 + 2I^- + 2H^+ \rightarrow I_2 + 2H_2O \quad (1)$$

[0036] The reaction in equation (1) is followed by:

$$I_2 + I^- \rightarrow I_3^- \quad (2)$$

[0037] Another example pathway is using persulfate.

$$S_2O_8^{2-} + 2I^- \rightarrow I_2 + 2SO_4^{2-} \quad (3)$$

[0038] The reaction in equation (3) is followed by reaction of iodine with iodide to form triiodide ion:

$$I_2 + I^- \rightarrow I_3^- \quad (4)$$

5. Cyanide Avoidance

[0039] Many precious metal recovery operations use cyanide-based solutions for the leachate. Generally, in contrast, cyanides and cyanide salts are avoided or limited in the instantly-disclosed leaching solutions. Because the instant leaching solutions preferably have no cyanide added, the disclosed solutions avoid the environmental impacts, hazards, and regulations attendant to the use of cyanide.

[0040] Preferably, the leaching solutions disclosed herein have no more than 0.0001 wt% cyanide (e.g. NaCN) added. As used herein, "wt%" means the weight percent of all ingredients, including the solvent, combined to form the leaching solution. Most preferably, the leaching solutions disclosed herein have no cyanide (e.g. NaCN) added. However, the disclosed leaching solutions can acquire some cyanide during the leaching process.

C. Leaching Techniques: Precious Metal Solubility

[0041] Upon contact with substrate containing precious metal, the leaching solution solubilizes the precious metal. Contact time between the leaching solution and the substrate can be selected to achieve desired recovery targets and processing goals. The addition of water-soluble, carboxylic acid to the leaching solution improves the ability of the instant leaching solutions to solubilize precious metal.

D. Leaching Techniques: Storage Stability

[0042] After leaching precious metal from the substrate, the pregnant leach solution can be stored or transported. Days, weeks, or months can pass before the precious metals are extracted from pregnant leach solutions. The instantly-disclosed leaching solutions include additive that improve the storage stability of the precious metal.

[0043] In preferred processes, the precious metal stays in solution during a storage period without requiring cyanide materials, termed "storage stable." Herein, "storage stable" in this context means that the pregnant solution can stand for at least an hour without agitation and without the precious metal falling out of the pregnant solution. Pregnant leaching solutions disclosed herein are preferably storage stable for days. Often, pregnant leaching solutions disclosed herein are storage stable for weeks. In some instances, pregnant leaching solutions disclosed herein are storage stable for months.

[0044] The pregnant leaching solutions disclosed herein are storage stable under typical conditions, such as ambient temperature and pressure. Without being bound by a particular theory, it is speculated that carboxylic acid material and/or boric acid enhances the stability of the pregnant leach solution, such that the pregnant leach solution can be stored for weeks, months, or longer.

E. Preferred Avoidance of Components in the Leaching Solution

[0045] Although strong acids can be used, the instantly-disclosed leaching solutions preferably avoid the use of strong acids. For instance, harsh acids are generally avoided. As an example, sulfuric acid (having pK_a values of -3 and 1.99) is preferably avoided. That said, strong acids such as sulfuric acids and hydrochloric acids can be used in addition to the weak acids discussed above.

II. Example Processing

A. General Process

[0046] FIG. 1 is an example embodiment of method 10 of recovering precious metal using leaching solution. The method 10 includes obtaining leaching solution (operation 20), leaching (operation 30), and recovering (operation 40). FIG. 2 shows a more detailed method 100 for recovering precious metal using leaching solutions and is discussed below.

[0047] The example method 10 begins by obtaining leaching solution (operation 20). The leaching solution can be pre-made and obtained from a third party or prepared on-site. Generating the leaching solution includes preparing an aqueous based solution and raising the oxidation-reduction potential (ORP) of the solution. As part of preparing the aqueous-based solution, one or more additives are added. Each additive is present in an amount sufficient to oxidize, solubilize, and/or stabilize the precious metal. Usable additives and methods of preparing the leaching solution are discussed below in more detail.

[0048] After the leaching solution is obtained (operation 20), substrate containing precious metal is contacted with the leaching solution (operation 30). Leaching (operation 30) strips precious metal from the substrate and forms complexes such that the precious metal is in solution, creating a pregnant solution. When the precious metal is in solution, then the solid substrates can be separated from the pregnant solution. Removing solids from the pregnant solution creates a clear solution that improves the efficacy of precious metal recovery steps.

[0049] Next, precious metal is recovered from the solution (operation 40). Recovering precious metal (operation 40) can include one or more operations. Precious metal recovery operations can include methods such as electrowinning, precipitation, cementation or loading onto activated carbon, and/or ion exchange resins, or any combination thereof.

[0050] Recovery (operation 40) can also include recovering one or more additives by an electrolysis step and/or reactivating the leaching solution. The leaching solution is then reused for subsequent leaching.

B. Example Process for Producing Leaching Solution and Recovering Precious Metal

[0051] FIG. 2 is an example embodiment of method 100 for generating and using aqueous-based leaching solution. The method 100 shown includes mixing in tank (operation 102), passing solution through electrochemical (EC) cell (operation 104), receiving ore (operation 108), reducing ore size (operation 110), mixing reduced-in-size ore with leachate (operation 112), leaching (operation 114), removing solids (operation 116), recovering gold (operation 118), secondary gold recovery (operation 120), and leach solution recycle (operation 122). Other embodiments can include more or fewer operations.

[0052] The embodiment of method 100 begins by obtaining the leaching solution (operation 20). As shown in FIG. 2, the leaching solution is obtained by generating the solution on-site. Specifically, obtaining the leaching solution (operation 20) includes combining ingredients in an aqueous solution in a tank (operation 102) and then passing the solution through an electrochemical cell (operation 104). When in solution, or after current is passed through the solution, the ingredients produce one or more oxidants.

[0053] Generally, iodide material, and carboxylic acid material are combined with water and then agitated or mixed during operation 102. Optionally, iodate material is also included. For example, potassium iodide, potassium iodate, and citric acid are combined with water in a stirred tank during operation 102. Other additives, such as those discussed within this disclosure (e.g., bromide salt), can also be added to the aqueous mixture.

[0054] The tank's contents can be agitated or stirred using a baffle, stirrer, or other apparatus designed to promote mixing of tank contents. The amount of ingredients and the tank size can be scaled to accommodate desired precious metal recovery requirements. Specific examples of ingredients and their relative amounts are provided below in the Example section.

[0055] After the ingredients are mixed, the solution is directed to an electrified cell (operation 104). For instance, the solution prepared during operation 104 is passed through an electrochemical cell. The electrochemical cell can be divided or

undivided. Additionally, more than one electrochemical cell can be used, where the cells are arranged in series and/or in parallel. Typical commercially-available electrochemical cells can be used during operation 104.

[0056] While passing solution through an electrochemical cell for a given period of time (operation 104), the ORP of the solution is monitored. Preferably, the solution is electrified until the ORP is raised to at least 540 mV SHE (standard hydrogen electrode). More preferably, the solution is electrified until the ORP is raised to at least 570 mV SHE. The resulting mixture can be used as leaching solution and stored in a separate tank until it is used in operation 112, discussed below.

[0057] Method 100 also includes receiving ore (operation 108) containing precious metal. The ore is obtained from one or more mining operations that can be local or remote. The ore in the embodiment of method 100 includes gold, although the method 100 can be used to recover other types of precious metal.

[0058] Although the received ore can be crushed, in some embodiments, the ore is further reduced in size (operation 110). Reducing the ore size can include passing the mined ore through a mill and/or a crushing circuit. An example mill is described in U.S. Patent Application Serial Number 15/063,725, titled "MILL."

[0059] When the ore is reduced in size and the leaching solution is prepared, both are combined (operation 112). Mixing the reduced-in-size ore with the leaching solution (operation 112) is preferably a batch process, although mixing is optionally performed as a continuous process.

[0060] Then the leaching solution and ore undergo leaching (operation 114). Preferably, leaching (operation 114) is conducted as a tank leach. More preferably, leaching (operation 114) is conducted as an agitated tank leach. In other embodiments, vat leaching, heap leaching, and/or in-situ leaching can be used in addition to, or in place of, tank leaching. Tank leaching (operation 114) proceeds at ambient temperature and atmospheric pressure for a predetermined period of time. In various implementations, leach time can vary from a few minutes to over 24 hours, depending upon the materials involved in the process.

[0061] During tank leaching (operation 114), gold from the ore goes into solution, resulting in pregnant leach solution. The pregnant leach solution also includes ore solids and the substrate, that are preferably removed before the gold recovery operation(s). During tank leaching (operation 114), some of the slurry is continuously passed through the electrochemical cell of operation 104 to maintain a desired ORP (loop 106).

[0062] After leaching, the solids are removed (operation 116) through one or more operations, resulting in a pregnant leach solution. For example, removing solids (operation 116) preferably includes filtering or clarification, followed by filtering the underflow. Solids removed during operation 116 can also be subjected to a wash to recover any entrained pregnant leach solution. Other solids removal operations can include fewer or more processes.

[0063] When most or all of the solids above a predetermined size are removed from the pregnant solution, gold is recovered (operation 118). Preferably, all solids are removed from the pregnant solution before gold recovery (operation 118). In some instances, the pregnant solution is stored and/or transported to a different location before gold recovery. Gold recovery (operation 118) can include electroplating/electrowinning, precipitation, cementation, ion-exchange, and/or adsorption onto activated carbon, to extract the gold out of solution. The gold recovery operation (118) is preferably performed as a continuous process. However, gold recovery (operation 118) is optionally conducted as a batch process.

[0064] In some instances, electroplating (operation 118) cannot remove all the gold from solution. Thus, the embodiment of method 100 optionally includes one or more secondary gold recovery operations (120). Secondary gold recovery operations (120) take advantage of other properties of the precious metal to remove precious metal from solution.

[0065] In cases where other metals (e.g., copper, nickel, iron, etc.) are present in the leach solution, a preferable approach is to precipitate the metals by adjusting the pH to above 12.5, preferably above pH 12.8, to precipitate the gold and target materials. The solid precipitate can then be subjected to solid-liquid separation to remove the gold and metal-bearing solid precipitate.

[0066] Secondary gold recovery (operation 120) preferably includes passing the solution through one or more resin columns having ion exchange resin. An example ion exchange resin is anionic resin beads. Secondary gold recovery (operation 120) optionally includes, in place of or in addition to, passing the solution over activated carbon. Other secondary gold recovery operations are possible.

[0067] The barren solution from the gold recovery (operation 118) and secondary gold recovery (operation 120) are next subjected to leach solution recycle (operation 122). Leach solution recycle (operation 122) includes passing the solution through one or more electrochemical cells. That is, one or more cells having cathode(s) and anode(s). Leach solution recycle (operation 122) can also include adding or replenishing one or more of the additives added during operation 102 to bring each additive's concentration to a desired concentration amount.

[0068] The ORP of the solution can be monitored and used in determining the residence time of the solution or the flow rate of the solution through the electrochemical cell(s). Without being bound by a particular theory, passing the solution through the electrochemical cells is believed to reactivate/regenerate iodine, as well as other oxidants, in the solution.

[0069] In situations where gold is precipitated at a high pH, leach solution recycle (operation 122) can additionally include readjusting the pH of the leach solution. Lowering the pH is preferably performed before passing the leach solution through the electrochemical cell. Additionally, lowering the pH can raise the ORP back up to near target levels before the solution is regenerated in the (preferably divided) electrochemical cell.

[0070] The solution with the regenerated contents is then re-used and mixed with the reduced-in-size ore (operation 112).

III. Typical materials and preferred amounts

[0071] The leaching solution is typically prepared by mixing carboxylic acid material and iodide material with water. Iodate material can also be included in the mixture. Typically, both iodate material and iodide material are added as sodium or potassium salts (e.g., potassium iodide and sodium iodate). Preferably, water

soluble, carboxylic acid includes citric acid. Optionally, acetic acid is used as water-soluble, carboxylic acid. Alternatively, water soluble carboxylic acid includes both citric acid and acetic acid. Boric acid can be included in addition to, or instead of, citric acid and/or acetic acid.

[0072] Iodide material concentration in the aqueous solution is typically at least 1 g/L. Usually, iodide material concentration is not greater than 100 g/L. Preferably, iodide material concentration is 5-40 g/L inclusive.

[0073] The resulting solution is then subjected to electrical current from one or more electrodes for a period of time. Typically, the electrodes are included as part of a commercially-available electrochemical cell. Generally, a variety of electrode materials can be used with the methods and materials disclosed herein. Example electrodes include stainless steel electrodes, combination stainless steel and titanium electrodes, and carbon electrodes.

[0074] Voltages applied to the electrodes can vary depending upon the nature and design of a given electrochemical cell. Typically, a voltage of at least 1 V is applied. Typically, voltage applied does not exceed 30 V. In some implementations, leaching solution passes through an electrochemical cell. In other implementations, electrodes are introduced to a tank including the leaching solution. In those implementations, voltage is applied, typically, for 1-60 minutes, inclusive. Other durations are contemplated.

[0075] Typically, water soluble, carboxylic acid concentration is at least 1 g/L. Preferably, water soluble, carboxylic acid concentration is 1-50 g/L inclusive. In some instances, water soluble, carboxylic acid concentration is 10-35 g/L inclusive. In other instances, water soluble, carboxylic acid concentration is 5-20 g/L inclusive. Optionally, water soluble, carboxylic acid concentration is 15-30 g/L inclusive.

[0076] Boric acid is optionally added to the solution with the complexing agent. Typically, when present, boric acid concentration is at least 0.1 g/L but no more than 20 g/L. Preferably, when present, boric acid concentration is 0.5-3.5 g/L inclusive. In some instances, boric acid concentration is 1.5-8.0 g/L inclusive. Optionally, boric acid concentration is 2.0-5.0 g/L inclusive. Optionally, boric acid is 5.0-15 g/L inclusive.

[0077] Preferably, the leaching solutions disclosed herein have no cyanide (e.g. NaCN) added.

IV. Experimental Examples

[0078] FIGs. 3-8 show results of laboratory analyses of different leachate solutions and various substrates. The following examples are illustrative and other embodiments are within the scope of the present disclosure.

A. Test Set 1

[0079] FIGS. 3-4 illustrate results of laboratory analyses of fourteen different leachate solutions, labeled 3a-3n, contacted with froth flotation gold concentrate from a mine located in British Columbia, Canada. FIG. 3 is a bar chart showing gold parts per million in solution after 1 hour of leaching. FIG. 4 is a plot showing the ppm of gold in solution for the fourteen leachate solutions in FIG. 3 over a period of time greater than 1 hour, with measurements recorded every 60 minutes. The results are presented in Table 1 below. Leachate solutions 3l, 3n, and 3m are discussed below in Examples 1, 2 and 3, respectively.

Table 1. Concentration of gold in solution (in parts per million) after leaching for 1-6 hours.

Mixture			*Gold in solution (ppm)*					
Label	**Citric Acid (g/L)**	**Boric Acid (g/L)**	**1 hour**	**2 hours**	**3 hours**	**4 hours**	**5 hours**	**6 hours**
3a	0	0	16	26	30	28	39	
3b	0	2	17	24	32	29	41	
3c	2	7	32	35	41	43	48	50
3d	5	0	35	50	48	52	64	
3e	0	2	35	44	45	49	50	60
3f	5	2	36	47	53	50	64	
3g	2	2	41	39	46	49	52	55
3h	7	2	42	47	56	60	62	64
3i	1.3	0	43	56	60	64	68	72
3j	20	2	43	45	47	49	51	54
3k	7	7	46	50	59	64	66	69
3l	10	0	54	56	60	65	70	73
3m	15	2	56	60	64	68	72	74
3n	10	2	63	74	76	78	80	81

[0080] The following examples are illustrative and other embodiments are within the scope of the present disclosure.

1. Example 1 – Leachate Solution 3l

[0081] An example embodiment of the leaching solution was prepared and the gold recovery analyzed. The leaching solution was prepared by adding 25 g KI and 3 g NaCl to 1 L of tap water in a 2L beaker. The contents were agitated with a magnetic stirrer. Then, a stainless steel cathode and a titanium anode were placed into the solution. The electrodes were electrified at 6 V (0.5 amps) for 15 minutes. Then, 10 g of citric acid, $C_6H_8O_7$, were added and the contents stirred using the magnetic stirrer. The resulting solution was the leaching solution.

[0082] Next, 100 mL of the leaching solution was added to 33.3 g of test material in a 500 mL bottle container. The test material was froth flotation gold concentrate. The 500 mL bottle container was placed on rollers that provide constant agitation.

[0083] Every 60 minutes, the bottle was opened and 1 mL of fluid was drawn out and combined with 6 mL of deionized water in a 16 mL test tube. The test tube was placed into a centrifuge for 2 minutes at 1,000 rpm, which accelerated the settling of the solids.

[0084] Then gold concentration of the clarified solution in the test tube was measured using an atomic absorption spectroscopy machine. Two measurements were recorded. From the measurements obtained, the amount of gold in solution was determined in terms of parts per million (ppm). After 60 minutes, gold was present at 54 ppm.

[0085] A leachate solution with 0 g citric acid (the "standard") had 16 ppm gold after one hour. Thus, the leaching solution of Example 1 recovered 38 ppm more than the standard solution, an improvement of 238%. Without being bound by a particular theory, the data in FIGS. 3-5 appear to suggest that citric acid improves gold recovery/solubility in solution.

2. Example 2 – Leachate Solution 3n

[0086] An example embodiment of the leaching solution was prepared and the gold recovery analyzed. The leaching solution was prepared by adding 25 g KI and 3 g NaCl to 1 L of tap water in a 2L beaker. The contents were agitated with a magnetic stirrer. Then, a stainless steel cathode and a titanium anode were placed into the solution. The electrodes were electrified at 6 V (0.5 amps) for 15 minutes. Then, 10 g of citric acid, $C_6H_8O_7$, and 2 g of boric acid, H_3BO_3, were added and the contents stirred using the magnetic stirrer. The resulting solution was the leaching solution.

[0087] Next, 100 mL of the leaching solution was added to 33.3 g of test material in a 500 mL bottle container. The test material was froth flotation gold concentrate. The 500 mL bottle container was placed on rollers that provide constant agitation.

[0088] Every 60 minutes, the bottle was opened and 1 mL of fluid was drawn out and combined with 6 mL of deionized water in a 16 mL test tube. The test tube was placed into a centrifuge for 2 minutes at 1,000 rpm, which accelerated the settling of the solids.

[0089] Then the gold concentration of the clarified solution in the test tube measured using an atomic absorption spectroscopy machine. Two measurements were recorded. From the measurements obtained, the amount of gold in solution was determined in terms of parts per million (ppm). After 60 minutes, gold was present at 63 ppm.

[0090] Thus, the leaching solution of Example 2 had 47 ppm more gold in solution than the standard solution. This is an improvement of 294% over the standard solution. Without being bound by a particular theory, the addition of boric acid to the leaching solution of Example 1 improved the gold recovery.

3. Example 3 – Leachate Solution 3m

[0091] An example embodiment of the leaching solution was prepared and the gold recovery analyzed. The leaching solution was prepared by adding 25 g KI and 3 g NaCl to 1 L of tap water in a 2L beaker. The contents were agitated with a

magnetic stirrer. Then, a stainless steel cathode and a titanium anode were placed into the solution. The electrodes were electrified at 6 V (0.5 amps) for 15 minutes. Then, 15 g of citric acid, $C_6H_8O_7$, and 2 g of boric acid, H_3BO_3, were added and the contents stirred using the magnetic stirrer. The resulting solution was the leaching solution.

[0092] Next, 100 mL of the leaching solution was added to 33.3 g of test material in a 500 mL bottle container. The test material was froth flotation gold concentrate. The 500 mL bottle container was placed on rollers that provide constant agitation.

[0093] Every 60 minutes, the bottle was opened and 1 mL of fluid was drawn out and combined with 6 mL of deionized water in a 16 mL test tube. The test tube was placed into a centrifuge for 2 minutes at 1,000 rpm, which accelerated the settling of the solids.

[0094] Then the gold concentration of the clarified solution in the test tube was measured using an atomic absorption spectroscopy machine. Two measurements were recorded. From the measurements obtained, the amount of gold in solution was determined in terms of parts per million (ppm). After 60 minutes, gold was present at 56 ppm.

[0095] Thus, the leaching solution of Example 3 had 40 ppm more gold in solution than the standard solution. However, the recovery of the leaching solution of Example 3 was less than Example 2. Without being bound by a particular theory, the addition of 5 g more citric acid to the leaching solution of Example 2 did not improve gold recovery. This is confirmed by the test leaching solution having 20 g citric acid and 2 g boric acid, which had 43 ppm gold after 1 hour, less than each of Examples 1, 2 and 3.

B. Test Set 2

[0096] FIGS. 5-8 are plots showing gold recovered into solution for different leachate solutions expressed as a percentage, with various substrates, over a period of time.

1. Example 1 – Froth Flotation Concentrate

[0097] Various leaching solutions were prepared and the gold recovery from froth flotation concentrate analyzed. The results of gold recovery with various leaching solutions are shown in FIG. 5 and in Table 2 below.

Table 2. Gold recovery percentage for various test leaching solutions over time for froth flotation concentrate sample.

Test	Additive Type	Additive Conc. (g/L)	Gold Recovery (%) after			
			1 hour	3 hours	6 hours	24 hours
IB321	Citric acid	10	43.2	59.0	66.7	78.9
IB322	Acetic acid	20	41.4	58.8	66.5	80.4
IB323	Boric acid	20	33.4	47.9	60.1	77.8
IB281	Boric acid	0.5	38.9	53.4	64.8	75.7
AH103	Citric acid / Iodate	5.0 / 0.5	72.0	75.4	77.9	82.2
AH104	None	0	28.8	40.1	47.6	62.8

[0098] Each leaching solution was prepared by mixing tap water with 40 g/L KI and 1.5 g/L NaCl. All but one test solution had one or more additional additives added to the water/KI/NaCl mixture. For test solution IB321, 10 g/L citric acid was also added. For test solution IB322, 20 g/L acetic acid was also added. For test solution IB323, 20 g/L boric acid was also added. For test solution IB281, 0.5 g/L boric acid was also added. For test solution AH103, 5.0 g/L citric acid and 0.5 g/L iodate were also added. For test solution AH104, no additional additives were added to the KI, NaCl, and water mixture. The contents of each test solution were agitated with a magnetic stirrer.

[0099] After mixing, each solution was passed through an electrochemical cell to generate a leaching solution. Froth flotation concentrate sample was then mixed with the test leaching solution at a pulp density of 25%. In this example, froth flotation concentrate was produced from mined ore from British Columbia, Canada.

[00100] The resulting slurry (combination of froth flotation concentrate and leaching solution) was then continuously leached in an agitated vessel for 24 hours.

Samples of the slurry were obtained and assayed at increments of 1, 3, 6 and 24 hours.

[00101] After 24 hours, the solids were separated from the solution and washed. Solution samples were placed in test tubes. Then the gold concentration in each test tube was measured using an atomic absorption spectroscopy machine. From the measurements obtained, the amount of gold in solution was determined in terms of parts per million (ppm). The recovery of gold was calculated for each sample. Results of the calculated gold recoveries are shown in FIG. 5.

[00102] Without being bound by a particular theory, the results in FIG. 5 show that addition of additive (citric acid, acetic acid, boric acid, and/or iodate) improves the gold recovery of the leaching solution as compared to no additives. The results in FIG. 5 also show that citric acid and acetic acid provide similar gold recoveries over 24 hours. The results in FIG. 5 also show that boric acid performs slightly worse than citric acid and boric acid. The results in FIG. 5 show that the best recoveries were achieved with the addition of citric acid and potassium iodate. Iodate additional also provided faster leach rates.

2. Example 2 – Gravity Concentrate

[00103] Various leaching solutions were prepared and the gold recovery from gravity concentrate analyzed. The results of gold recovery with various leaching solutions are shown in FIG. 6 and in Table 3 below.

Table 3. Gold recovery percentage for various test leaching solutions over time for gravity concentrate sample.

			Gold Recovery (%) after			
Test	Additive Type	Additive Conc. (g/L)	1 hour	3 hours	6 hours	24 hours
IB271	None	0	29.0	46.4	55.3	57.1
IB235	Boric acid	0.5	54.6	80.8	85.1	92.5
IB282	Boric acid / Citric acid	0.5 / 10	10.8	71.8	81.5	97.5
IB283	Citric acid	10	74.1	84.4	88.5	97.6
IB291	Boric acid / Citric acid	20 / 20	65.8	76.0	84.2	98.1

[00104] Each leaching solution was prepared by mixing tap water with 40 g/L KI and 1.5 g/L NaCl. All but one test solution had one or more additional additives added to the mixture. For test solution IB271, no additional additives were added to the KI, NaCl, and water mixture. For test solution IB235, 0.5 g/L boric acid was also added. For test solution IB282, 0.5 g/L boric acid and 10 g/L citric acid were also added. For test solution IB283, 10 g/L citric acid was also added. For test solution IB291, 20 g/L boric acid and 20 g/L citric acid were also added. The contents of each test solution were agitated with a magnetic stirrer.

[00105] After mixing, each solution was passed through an electrochemical cell to generate a leaching solution. Gravity concentrate sample was then mixed with the test leaching solution at a pulp density of 25%. In this example, gravity concentrate was obtained from a centrifugal gravity gold concentrator operating at a mine in Arizona.

[00106] The resulting slurry (combination of gravity concentrate and leaching solution) was then continuously leached in an agitated vessel for 24 hours. Samples of the slurry were obtained and assayed at increments of 1, 3, 6 and 24 hours.

[00107] After 24 hours, the solids were separated from the solution and washed. Solution samples were placed in test tubes. Then the gold concentration in each test tube was measured using an atomic absorption spectroscopy machine. From the measurements obtained, the amount of gold in solution was determined in terms of parts per million (ppm). The recovery of gold was calculated for each sample. Results of the calculated gold recoveries are shown in FIG. 6.

[00108] Without being bound by a particular theory, the results in FIG. 6 show that addition of additive (citric acid or boric acid) improves the gold recovery of the leaching solution as compared to no additives. The results in FIG. 6 also show that gold recovery improved with citric acid as the additive as compared to boric acid. The results in FIG. 6 also show that each solution with citric acid performed relatively similarly with respect to gold recovery.

3. Example 3 – E-Waste

[00109] Various leaching solutions were prepared and the gold recovery from e-waste sample analyzed. The results of gold recovery with various leaching solutions over time are shown in FIG. 7 and in Table 4 below.

Table 4. Gold recovery percentage for various test leaching solutions over time for e-waste sample.

Test	Additive Type	Additive Conc. (g/L)	Gold Recovery (%) after 30 Min	60 Min	90 Min	120 Min
J101	None	0	44.3	38.6	28.2	18.4
J102	Iodate / Citric acid	10 / 10	70.6	81.4	82.9	84.9
J103	Citric acid	10	57.2	69.1	75.0	79.7
J104	Boric acid / Citric acid	2 / 10	58.7	72.8	80.5	83.2

[00110] Each leaching solution was prepared by mixing tap water with 60 g/L KI. All but one test solution had one or more additional additives added to the water/KI mixture. For test solution J101, no additional additives were added to the KI and water mixture. For test solution J102, 10 g iodate and 10 g citric acid were also added to the beaker. For test solution J103, 10 g citric acid was also added to the beaker. For test solution J104, 2 g boric acid and 10 g citric acid were also added to the beaker. The contents of each test solution were agitated with a magnetic stirrer.

[00111] After mixing, each solution was passed through an electrochemical cell to generate a leaching solution. E-waste sample was then mixed with the test leaching solution at a pulp density of 25%. In this example, e-waste sample included ground electronic waste (such as circuit boards) passed through a 70 mesh screen.

[00112] The resulting slurry (combination of e-waste material and leaching solution) was then continuously leached in an agitated vessel for 120 minutes. Samples of the slurry were obtained and assayed at increments of 30, 60, 90 and 120 minutes.

[00113] After 120 minutes, the solids were separated from the solution and washed. Solution samples were placed in test tubes. Then the gold concentration in each test tube was measured using an atomic absorption spectroscopy machine. From the

measurements obtained, the amount of gold in solution was determined in terms of parts per million (ppm). The recovery of gold was calculated for each sample. Results of the calculated gold recoveries are shown in FIG. 7.

[00114] Without being bound by a particular theory, the results in FIG. 7 show that not including an additive in the leaching solution was detrimental to the stability of gold in solution. Including additives appears to prevent gold from precipitating out of solution. The results in FIG. 7 also suggest that solutions with boric acid and citric acid had similar gold recoveries, with leaching solutions including citric acid performing only slightly better. The results in FIG. 7 also show that the best gold recovery was achieved with the addition of both citric acid and potassium iodate to the leaching solution.

4. Example 4 – E-Waste Pilot Plant

[00115] A leaching solution was prepared and the gold recovery from e-waste sample analyzed. This example utilized a pilot plant as described in the section below titled "Third Example Hypothetical Process". The results of gold recovery with the leaching solution over time are shown in FIG. 8 and in Table 5 below.

Table 5. Gold recovery percentage for a test leaching solution in a pilot plant over time for e-waste sample.

		Additive Conc.	Gold Recovery (%) after			
Test	Additive Type	(g/l)	30 Min	60 Min	90 Min	120 Min
Pilot	Citric / Iodate	10 / 10	66.4	76.5	81.0	83.4

[00116] The leaching solution was prepared by adding 50 g/L KI, 10 g/L citric acid, and 10 g/L potassium iodate to 100 L of tap water. The contents of the test solution were agitated with a magnetic stirrer.

[00117] After mixing, each solution was passed through an electrochemical cell to generate a leaching solution having an ORP of 590 mV (SHE). E-waste sample was then mixed with the test leaching solution at a pulp density of 14%. In this example,

e-waste sample included ground electronic waste (such as circuit boards) passed through a 100 mesh screen.

[00118] The resulting slurry (combination of gravity concentrate and leaching solution) was then continuously passed through the electrochemical cell to maintain the ORP at or above 590 mV (SHE). The resulting slurry was then continuously leached in an agitated vessel for 120 minutes. Samples of the slurry were obtained and assayed at increments of 30, 60, 90 and 120 minutes.

[00119] After 120 minutes, the solids were separated from the solution and washed. Solution samples were placed in test tubes. Then the gold concentration in each test tube was measured using an atomic absorption spectroscopy machine. From the measurements obtained, the amount of gold in solution was determined in terms of parts per million (ppm). The recovery of gold was calculated for each sample. Results of the calculated gold recoveries are shown in FIG. 8.

[00120] The results in FIG. 8 show the stability and scalability of the process. In contrast to the examples 1-3 discussed above (those referring to FIGS. 5-7), this is the only example where the slurry was continuously passed through the electrochemical cell to maintain the ORP. Thus, this example proved up the lab-scale processes described with reference to examples 1-3 (results shown in FIGS. 5-7).

VI. Example Hypothetical Process Using Materials and Techniques Characterized Herein

[00121] In a hypothetical precious metal recovery operation, gravity concentrate including precious metal is received from a mining operation. The gravity concentrate is processed to reduce the size in a mill, where the concentrate exiting the output of the mill generally has a size not greater than 2000 μm.

[00122] Separately, in an agitated tank, water is combined with potassium iodide, potassium iodate, and citric acid, and agitated. The potassium iodide is added to the tank in an amount of 25 grams per liter. The potassium iodate is added to the tank in an amount of 25 grams per liter. The citric acid is added to the tank in an amount of 10 grams per liter.

[00123] Next, the water-additive mixture is pumped to a process tank including electrodes. An ORP meter is positioned such that it can record measurements of the process tank contents.

[00124] A voltage of 6 V is provided to each electrode in the process tank. When the ORP meter indicates a predetermined level has been reached, the voltage to the electrodes is stopped. The aqueous solution is enhanced and ready for leaching.

[00125] The gravity concentrate from the mill is delivered to an agitated leach tank. Leaching in the agitated leach tank proceeds for a predetermined amount of time, such as, for example, 12 hours.

[00126] The leach solution including solids is then pumped through a filter press to separate the solids from the solution.

[00127] Solution passing through the filter press is sent to an electrowinning cell. The output from the electrowinning cell is pumped through activated carbon.

[00128] Solution passing through the carbon resin is pumped to an electrode-containing cell. The output from the electrode-containing cell is pumped back to the agitated leach tank.

VII. Second Example Hypothetical Process Using Materials and Techniques Characterized Herein

[00129] In a hypothetical precious metal recovery operation, mined ore including precious metal is received from a mining operation. The mined ore is processed to reduce the size in a mill, where the ore exiting the output of the mill generally has a size not greater than 250 μm.

[00130] Separately, in an agitated tank, water is combined with: anywhere between 10 grams per liter to 40 grams per liter potassium iodide, 40 grams per liter sodium iodate, 1.5 grams per liter citric acid monohydrate, 1.5 grams per liter boric acid, and anywhere between 5 mL per liter to 20 mL per liter glacial acetic acid. The combination is then agitated.

[00131] Next, the mixture is pumped to a process tank including electrodes. An ORP meter is positioned such that it can record measurements of the process tank contents.

[00132] The mixture is subjected to electrolysis using a carbon anode and stainless steel cathode until the oxidation reduction potential (ORP) of the mixture is a minimum of 540 mV SHE, more preferably a minimum of 570 mV SHE. Alternatively, platinum or titanium cathodes can be used.

[00133] The ore from the mill is delivered to the process tank. Ore is added to the mixture and agitated to create a slurry of 10% to 25% ore volume by weight. Electrolysis then continues for the required leach cycle duration to maintain the ORP levels.

[00134] After a predetermined amount of time, for example, 12 hours or 24 hours, the leach solution including solids is then pumped through a filter press to separate the solids from the solution.

[00135] Solution passing through the filter press is sent to an electrowinning cell. The output from the electrowinning cell is pumped through activated carbon. Solution passing through the activated carbon is pumped to an electrode-containing cell. The output from the electrode-containing cell is pumped to the back to the agitated leach tank.

VII. Third Example Hypothetical Process Using Materials and Techniques Characterized Herein

[00136] In a hypothetical precious metal recovery operation, flotation concentrate solids including precious metal are received from a mining operation.

[00137] Separately, in a leaching tank, water is combined with potassium iodide, potassium iodate, and citric acid, and agitated. The potassium iodide is added to the tank in an amount of 40 grams per liter. The potassium iodate is added to the tank in an amount of 10 grams per liter. The citric acid is added to the tank in an amount of 5 grams per liter. The resulting contents are termed a “water-additive mixture”.

[00138] An ORP probe is positioned in the leaching tank so that the ORP probe can measure the ORP of the solution.

[00139] Next, the water-additive mixture is pumped through an electrochemical cell and returned back to the tank until the measured ORP of the water-additive mixture

is raised to a value of at least 570 mV (vs SHE). The aqueous solution is enhanced and ready for leaching.

[00140] The concentrate from a mill is delivered to the leach tank to make a slurry with a pulp density of 10-35% by weight. Leaching in the leach tank proceeds for 20 hours. The slurry is continuously pumped through the electrochemical cell to maintain the ORP above 570 mV (SHE).

[00141] After a predetermined amount of time, such as 20 hours, the leach solution (pregnant leach solution or "PLS") including the solids are pumped through a filter. Wash water is pumped through the filter to recover entrained PLS.

[00142] Solution and wash water passing through the filter press is sent to a divided electrochemical cell to recover gold by electrowinning. In addition, or alternatively, gold is recovered by precipitation. The solids are discarded.

VII. Example Theoretical Chemistry during Processes and Techniques Characterized Herein

[00143] Without being bound by a particular theory, it is theorized that the following reactions take place during one or more of the processes and techniques characterized herein. Gold leaching with iodine/iodide takes place via the following reactions:

$$2Au + I^- + I_3^- \rightarrow 2AuI_2^- \quad (5)$$

$$2Au + 3I_3^- \rightarrow 2AuI_4^- + I^- \quad (6)$$

The addition of carboxylic acids and boric acid have been shown to accelerate the leaching rate and stabilize gold in solution.

[00144] The addition of iodate (as, e.g., KIO_3) and an acid to the leaching solution can result in a rapid increase in the ORP level via the following reaction:

$$IO_3^- + 2I^- + 6H^+ \rightarrow I_3^- + 3H_2O \quad (7)$$

[00145] An electrochemical cell is used to maintain or increase the ORP over and above the ORP achieved from reaction (7) above. The reaction on the anode in the electrochemical cell generates a triiodide species required for leaching according to the following reaction:

$$3I^- \rightarrow I_3^- + 2e^- \quad (8)$$

[00146] The reaction at the cathode in the electrochemical cell is:

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \qquad (9)$$

[00147] When iodine and iodide are present in a system, a result is the formation of the triiodide ion. In the systems disclosed herein, any iodine produced will typically lead to the formation of triiodide because there are typically always iodide ions present in the system

$$I_2 + I^- = I_3^- \qquad (10)$$

[00148] If chloride (which can be a source of chlorine to produce hypochlorite electrochemically in the cell) or if hypochlorite is added to the system, the following reactions can also take place to produce iodine:

$$2I^- + Cl_2 \rightarrow + I_2 + 2Cl^- \qquad (11)$$

$$Cl_2 + 2OH^- \rightarrow H_2O + Cl^- + ClO^- \qquad (12)$$

$$ClO^- + 2H^+ + 2I^- \rightarrow I_2 + Cl^- + H_2O \qquad (13)$$

Addition of bromides will have a similar effect as that provided above.

[00149] Gold and other metals in solution can be recovered via the various methods described above. However, in the case of e-waste, one preferred route is to raise the pH with the addition of a hydroxide, such as sodium or potassium hydroxide, to precipitate the metals. A result of hydroxide addition to a solution to raise the pH above 12.5 converts much of the iodine species to iodate, as follows:

$$3I_2 + 6OH^- \rightarrow 5I^- + IO_3^- + 3H_2O \qquad (14)$$

[00150] Once the precipitated gold and metals are removed, the resulting clarified solution is referred to as a "barren solution". The barren solution including the iodide and iodate is then treated for recycle to be used for leaching. One possible way the solution can be treated for recycle is to lower the pH. If the material has been subjected to precipitation, such as when processing e-waste, acid material is added to the barren solution to lower the pH back down below pH 12 to approximately neutral levels. In this approach, triiodide is created as shown in reaction (7) above. A number of different acids, inorganic or organic, can be used in this step (e.g., sulfuric acid, hydrochloric acid, citric acid, boric acid, etc.).

[00151] Then the barren solution is treated through a divided electrochemical cell with the leaching solution (anolyte) passing through the anode side of the cell and a hydroxide solution (catholyte) on the cathode side. The reaction on the anode side is

shown above as reaction (8). Electrochemical cell treatment is conducted until a desired ORP is achieved. Then the regenerated leaching solution is available for leaching again.

[00152] It will be clear that the systems and methods described herein are well adapted to attain the ends and advantages mentioned as well as those inherent therein. Those skilled in the art will recognize that the methods and systems within this specification can be implemented in many manners and as such is not to be limited by the foregoing exemplified embodiments and examples. In this regard, any number of the features of the different embodiments described herein can be combined into one single embodiment and alternate embodiments having fewer than or more than all of the features herein described are possible.

[00153] It will be clear that the systems and methods described herein are well adapted to attain the ends and advantages mentioned as well as those inherent therein. Those skilled in the art will recognize that the methods and systems within this specification can be implemented in many manners and as such is not to be limited by the foregoing exemplified embodiments and examples. While various embodiments have been described for purposes of this disclosure, various changes and modifications can be made which are well within the scope of the present disclosure. Numerous other changes can be made which will readily suggest themselves to those skilled in the art and which are encompassed in the spirit of the disclosure.

CLAIMS

What is claimed is:

1. An aqueous-based leaching solution for precious metal, the leaching solution comprising:

iodide salt material; and

carboxylic acid material,

the leaching solution being made by a process including the step of:

passing a first mixture through an electrochemical cell until a measured oxidation reduction potential (ORP) is at least 540 mV, the first mixture including iodide salt material, carboxylic acid material, and water.

2. The aqueous-based leaching solution according to claim 1, further comprising boric acid material.

3. The aqueous-based leaching solution in accord with claim 2, the carboxylic acid additive including at least one of: acetic acid material and citric acid material.

4. The aqueous-based leaching solution according to claim 1, the carboxylic acid additive including at least one of: acetic acid material and citric acid material.

5. The aqueous-based leaching solution according to claim 1, further comprising iodate material.

6. The aqueous-based leaching solution according to claim 5, the iodate material being one of sodium iodate and potassium iodate.

7. The aqueous-based leaching solution according to claim 6, the iodide salt material including potassium iodide; and

the first mixture including iodate material.

8. The aqueous-based leaching solution according to claim 1, further comprising chloride salt material or bromide salt material.

9. The aqueous-based leaching solution according to claim 1, wherein the leaching solution has a pH of at least 3 but no greater than 10.

10. The aqueous-based leaching solution according to claim 9, wherein the leaching solution has a pH of at least 4 but no greater than 7.

11. The aqueous-based leaching solution according to claim 1 including:

iodide salt material at a concentration of at least 5 grams per liter; and

carboxylic acid material at a concentration of at least 1 gram per liter but no greater than 50 grams per liter.

12. The aqueous-based leaching solution according to claim 11, further comprising boric acid material at a concentration of at least 0.1 grams per liter but no greater than 20 grams per liter.

13. A regenerated aqueous-based leaching solution, resulting from:

leaching precious metal-containing substrate with an aqueous-based leaching solution, thereby generating pregnant leach solution;

wherein the aqueous-based leaching solution comprises:

iodide salt material; and

carboxylic acid material; and

removing precious metal from the pregnant leach solution, thereby generating barren leaching solution;

passing the barren leaching solution through an electrochemical cell, thereby generating a regenerated aqueous-based leaching solution.

14. The regenerated aqueous-based leaching solution according to claim 13, further comprising:

monitoring an oxidation reduction potential (ORP) of the barren leaching solution; and

continuing to pass the barren leaching solution through the electrochemical cell until the ORP is at least 540 mV.

15. The regenerated aqueous-based leaching solution according to claim 13, further comprising:

adding supplemental carboxylic acid material to the barren leaching solution.

16. The regenerated aqueous-based leaching solution according to claim 13, wherein the aqueous based leaching solution further comprises:

iodate material;

chloride salt material or bromide salt material;

boric acid material; and

the carboxylic acid material including at least one of: citric acid material and acetic acid material.

17. A method of recovering a precious metal using an aqueous-based leaching solution, the method including the steps of:

obtaining the aqueous-based leaching solution;

contacting substrate including precious metal with the aqueous-based leaching solution, contacting resulting in pregnant leach solution;

recovering precious metal from the pregnant leach solution, thereby generating a barren aqueous-based leaching solution;

passing current through the barren aqueous-based solution to increase an oxidation reduction potential (ORP) of the barren aqueous-based solution, thereby generating a regenerated solution; and

contacting the regenerated solution with substrate including precious metal.

18. The method of claim 17, wherein obtaining the aqueous-based leaching solution includes:

generating the aqueous-based leaching solution by passing leaching solution precursor through an electrochemical cell, the leaching solution precursor including:

iodide salt material;

iodate material; and

carboxylic acid material; and

maintaining the ORP of the aqueous-based leaching solution at or above 540 mV SHE.

19. The method of claim 18, wherein passing current through the barren aqueous-based solution includes passing the barren aqueous-based solution through an electrochemical cell.

20. The method of claim 19, further comprising: prior to passing current through the barren aqueous-based solution, adding supplemental carboxylic acid material to the barren aqueous-based leaching solution,

wherein contacting substrate including precious metal with the aqueous-based leaching solution includes tank leaching; and

wherein, during tank leaching, a portion of the aqueous-based leaching solution is passed through a second electrochemical cell.

21. An aqueous-based leaching solution for precious metal, the leaching solution comprising:

hypochlorite oxidant;

citric acid material in an amount effective to enhance leaching; and

iodide material in an amount effective to enhance leaching.

22. The aqueous-based leaching solution in accord with claim 21, the leaching solution being made by a process including the steps of:

generating an aqueous-based solution including hypochlorite oxidant; and

generating a resulting leaching solution from the aqueous-based solution;

the resulting leaching solution including:

the citric acid material; and
the iodide material.

23. The aqueous-based leaching solution in accord with any one of claims 21 and 22, wherein the leaching solution further comprises boric acid in an amount effective to enhance stability of a resulting pregnant solution when the leaching solution is used to recover precious metal.

24. The aqueous-based leaching solution in accord with any one of claims 21-23 having a pH no greater than 7.

25. The aqueous-based leaching solution in accord with claim 23, wherein the leaching solution has a pH of at least 4.

26. The aqueous-based leaching solution in accord with any one of claims 21-25, wherein the hypochlorite oxidant includes hypochlorite oxidant generated by passing current through an aqueous-based solution including chloride salt.

27. The aqueous-based leaching solution according to any one of claims 21-26 including citric acid material at a concentration of at least 1 gram per liter.

28. The aqueous-based leaching solution according to any one of claims 21-27 including citric acid material at a concentration of at least 5 grams per liter.

29. The aqueous-based leaching solution according to any one of claims 21-28 including citric acid material at a concentration of at least 8 grams per liter.

30. The aqueous-based leaching solution according to any one of claims 21-28 including citric acid material at a concentration of no greater than 15 grams per liter.

31. The aqueous-based leaching solution according to any one of claims 21-30, wherein the iodide material includes I_3.

32. The aqueous-based leaching solution according to any one of claims 21-31, wherein the iodide material includes potassium iodide.

33. The aqueous-based leaching solution according to any one of claims 21-32, including iodide material at a concentration of at least 15 grams per liter.

34. The aqueous-based leaching solution according to any one of claims 21-33, including iodide material at a concentration of at least 20 grams per liter.

35. The aqueous-based leaching solution according to any one of claims 21-34, including iodide material at a concentration of at least 25 grams per liter.

36. An aqueous-based leaching solution for precious metal, the leaching solution comprising:

water-soluble, polyprotic weak acid in an amount sufficient to enhance leaching; and

iodide material in an amount effective to enhance leaching,

wherein the leaching solution has a pH of no greater than 7.

37. The aqueous-based leaching solution according to claim 36 including hypochlorite material.

38. The aqueous-based leaching solution according any one of claims 36 and 37, wherein the water-soluble, polyprotic weak acid includes citric acid material.

39. The aqueous-based leaching solution in accord with any one of claims 36-38, the leaching solution being made by a process including the steps of:

generating an aqueous-based solution including hypochlorite oxidant; and

generating a resulting leaching solution from the aqueous-based solution;

the resulting leaching solution including:

the citric acid material; and

the iodide material.

40. The aqueous-based leaching solution in accord with any one of claims 36-39, wherein the leaching solution further comprises boric acid in an amount effective to enhance stability of a resulting pregnant solution when the leaching solution is used to recover precious metal.

41. The aqueous-based leaching solution in accord with any one of claims 36-40, wherein the leaching solution has a pH of at least 4.

42. The aqueous-based leaching solution in accord with any one of claims 36-41, wherein the hypochlorite oxidant includes hypochlorite oxidant generated by passing current through an aqueous-based solution including chloride salt.

43. The aqueous-based leaching solution according to any one of claims 36-42 including citric acid material at a concentration of at least 1 gram per liter.

44. The aqueous-based leaching solution according to any one of claims 36-43 including citric acid material at a concentration of at least 5 grams per liter.

45. The aqueous-based leaching solution according to any one of claims 36-44 including citric acid material at a concentration of at least 8 grams per liter.

46. The aqueous-based leaching solution according to any one of claims 36-45 including citric acid material at a concentration of no greater than 15 grams per liter.

47. The aqueous-based leaching solution according to any one of claims 36-46, wherein the iodide material includes potassium iodide.

48. The aqueous-based leaching solution according to any one of claims 36-47 including iodide material at a concentration of at least 16 grams per liter.

49. The aqueous-based leaching solution according to any one of claims 36-48 including iodide material at a concentration of at least 20 grams per liter.

50. The aqueous-based leaching solution according to any one of claims 36-49 including iodide material at a concentration of at least 25 grams per liter.

51. The aqueous-based leaching solution according to any one of claims 36-50, wherein generating the aqueous-based solution including hypochlorite oxidant includes passing current through the aqueous-based solution including potassium iodide.

52. The aqueous-based leaching solution according to any one of claims 36-50, wherein the aqueous-based leaching solution includes cyanide present at no more than 0.0001 wt % of all ingredients, including a solvent, combined to form the aqueous-based leaching solution, the solvent being water.

53. A stable, aqueous-based, precious metal-containing leachate, resulting from:

leaching precious metal oxidizable by hypochlorite -containing material with an acidic, aqueous-based leach solution,

wherein the acidic, aqueous-based leach solution comprises:

boric acid;

citric acid; and

hypochlorite material,

wherein each of the boric acid, the citric acid, and the hypochlorite material are present in an amount effective to oxidize and solubilize precious metal upon contact therewith.

54. The leachate according to claim 53, wherein the leach solution holds the precious metal in solution for at least one month at ambient temperature and ambient pressure.

55. The leachate according to claim 54, wherein the acidic, aqueous-based leach solution comprises no more than 0.0001 wt% cyanide, the wt% being of all ingredients, including a solvent, combined to form the acidic, aqueous-based leach solution, the solvent being water.

56. The leachate according any one of claims 54 and 55, wherein the hypochlorite material is generated by a process comprising:

passing current through an aqueous-based solution comprising a chloride salt and an iodide, the chloride salt being present in sufficient amount to generate hypochlorite.

57. The leachate in accord with any one of claims 53-56, wherein precious metal is gold.

58. The leachate in accord with any one of claims 53-57, wherein the leachate further comprises potassium iodide in an amount effective to enhance leaching.

59. The leachate in accord with any one of claims 53-58, wherein leaching the precious metal is for not greater than 2 hours.

60. A method of recovering a precious metal from a precious metal-containing pregnant leach solution, the method including the steps of:

recovering the precious metal by electrodepositing, thereby generating a barren solution; and

passing current through the barren solution having an iodine precursor to increase an iodine content of the barren solution.

61. The method of claim 60, wherein the step of recovering the precious metal comprises electrodepositing in a solution comprising:

boric acid;

citric acid;

hypochlorite material; and

cyanide present at no more than 0.0001 wt% of all ingredients, including a solvent, combined to form the acidic, aqueous-based leach solution the solvent being water,

wherein each of the boric acid, the citric acid, and the hypochlorite material are present in an amount effective to oxidize and solubilize precious metal upon contact therewith.

62. The method of claim 60 or 61, further comprising:

passing the remainder solution through a secondary precious-metal recovery system.

63. The method of claim 62, wherein the secondary precious-metal recovery system comprises an ionic resin.

64. The method of claim 62, wherein the secondary precious metal recovery system comprises an activated carbon system.

65. The method of any of claims 61-64, wherein the hypochlorite material is generated by a process comprising:

passing current through an aqueous-based solution comprising a chloride salt and an iodide, the chloride salt being present in sufficient amount to generate hypochlorite.

66. The method of any of claims 61-65, wherein the solution further comprises potassium iodide in an amount effective to enhance leaching.

67. The aqueous-based leaching solution in accord with any of one of claims 21-35, further comprising acetic acid material in an amount effective to enhance leaching.

68. The aqueous-based leaching solution according to any one of claims 36-52, further comprising acetic acid material in an amount effective to enhance leaching.

69. The leachate according to any one of claims 53-58, further comprising acetic acid material in an amount effective to enhance leaching.

70. The method of any of claims 61-66, wherein the solution further comprises acetic acid material in an amount effective to enhance leaching.

71. The aqueous-based leaching solution in accord with any of one of claims 21-35 and 67, further comprising potassium persulfate material in an amount effective to enhance leaching.

72. The aqueous-based leaching solution according to any one of claims 36-52 and 68, further comprising potassium persulfate material in an amount effective to enhance leaching.

73. The leachate according to any one of claims 53-58 and 69, further comprising potassium persulfate material in an amount effective to enhance leaching.

74. The method of any of claims 61-66 and 70, wherein the solution further comprises potassium persulfate material in an amount effective to enhance leaching.

75. An aqueous-based leaching solution for precious metal, the leaching solution comprising:

iodate material in an amount effective to enhance leaching;

carboxylic acid material in an amount effective to enhance leaching; and iodide material in an amount effective to enhance leaching.

76. The aqueous-based leaching solution for precious metal according to claim 75, the leaching solution further comprising chloride salt material.

77. The aqueous-based leaching solution for precious metal according to claim 75, the leaching solution further comprising bromide salt material.

78. The aqueous-based leaching solution for precious metal according to claim 75, the leaching solution further comprising boric acid material.

79. The aqueous-based leaching solution for precious metal according to claim 75, the leaching solution further comprising hypochlorite material.

80. The aqueous-based leaching solution for precious metal according to claim 75, the carboxylic acid material including citric acid.

81. The aqueous-based leaching solution for precious metal according to claim 75, the carboxylic acid material including acetic acid.

82. The aqueous-based leaching solution for precious metal according to claim 75, the iodate material being one of sodium iodate and potassium iodate.

83. The aqueous-based leaching solution for precious metal according to claim 75, the iodide material being one of sodium iodide and potassium iodide.

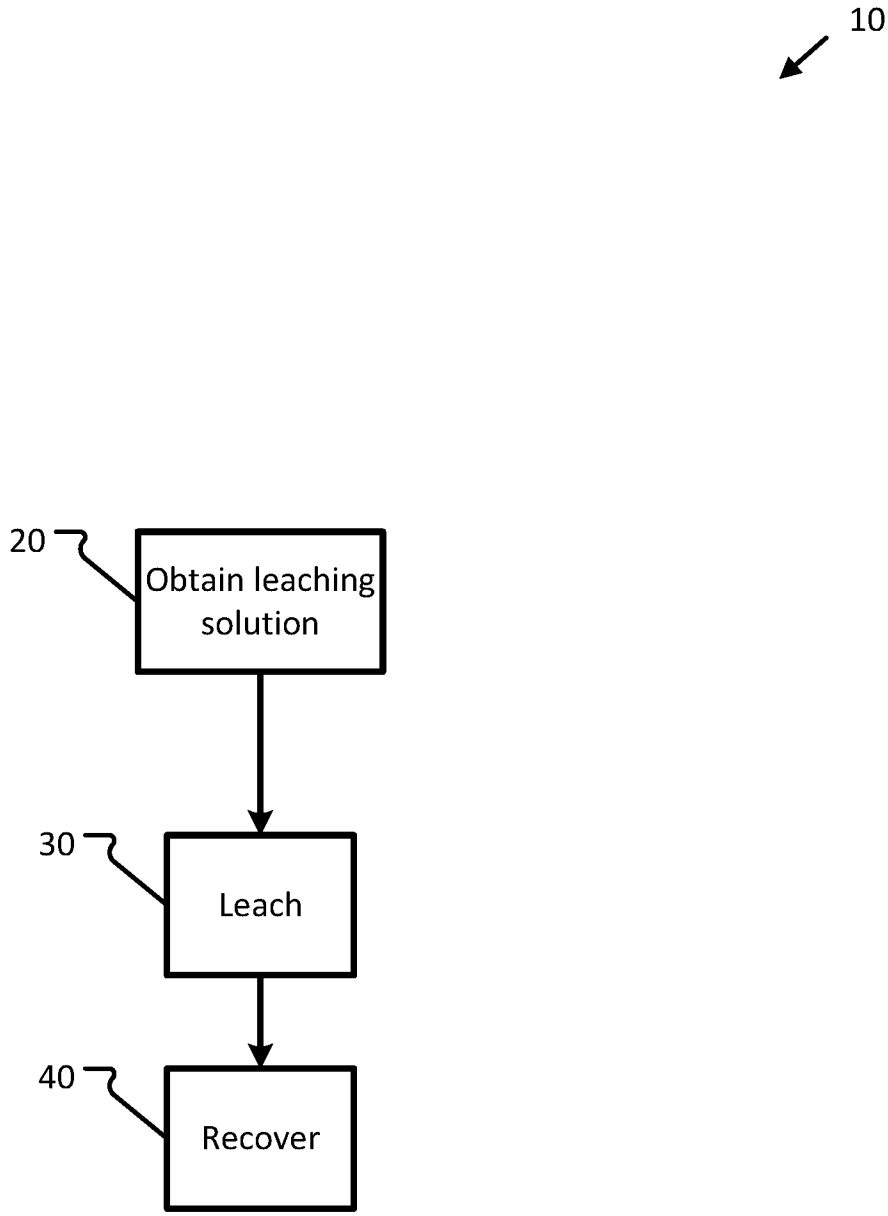

FIG. 1

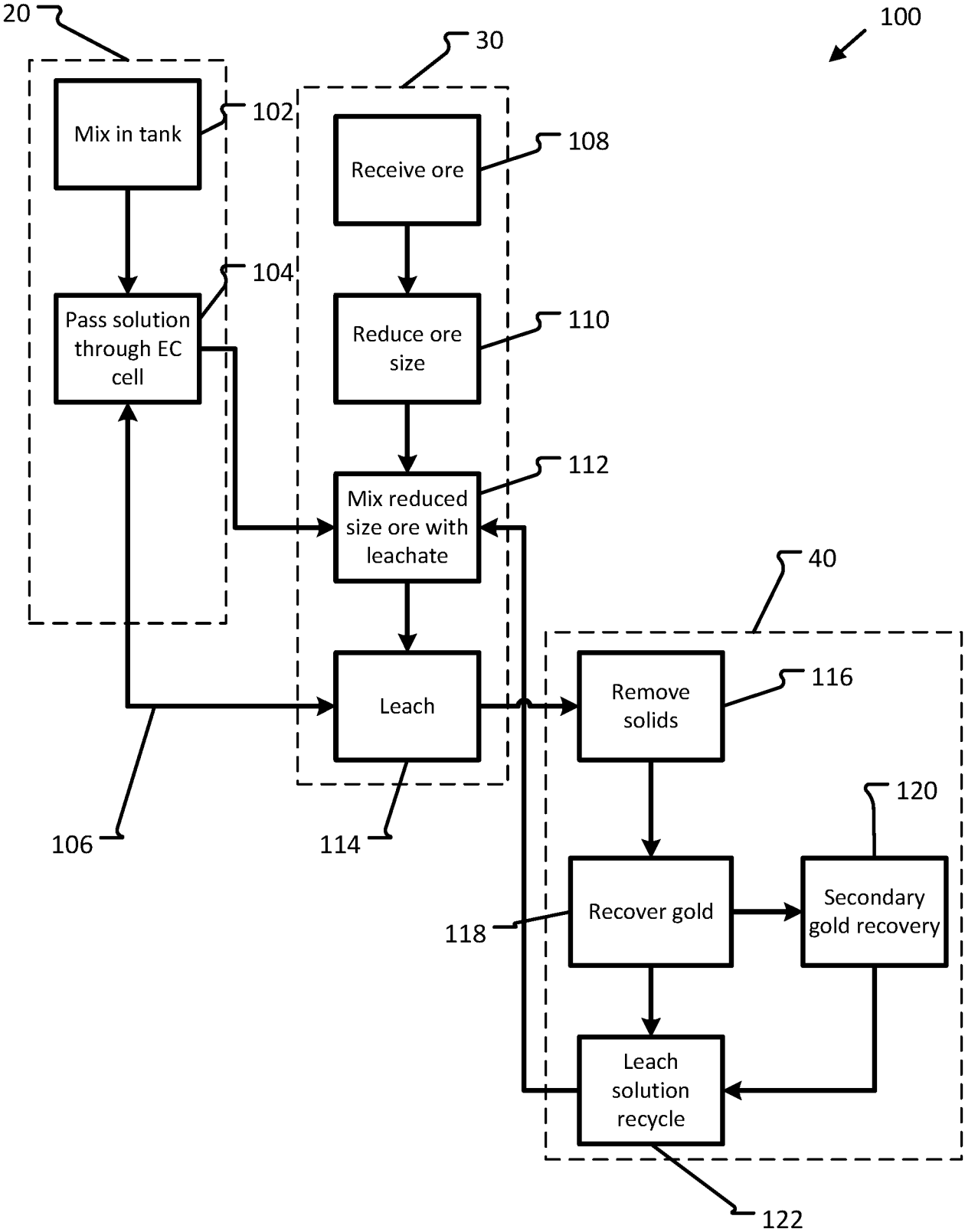
20
100
30
Mix in tank
102
Receive ore
108
104
Pass solution through EC cell
Reduce ore size
110
112
Mix reduced size ore with leachate
40
Leach
Remove solids
116
120
Recover gold
Secondary gold recovery
118
Leach solution recycle
106
114
122

FIG. 2

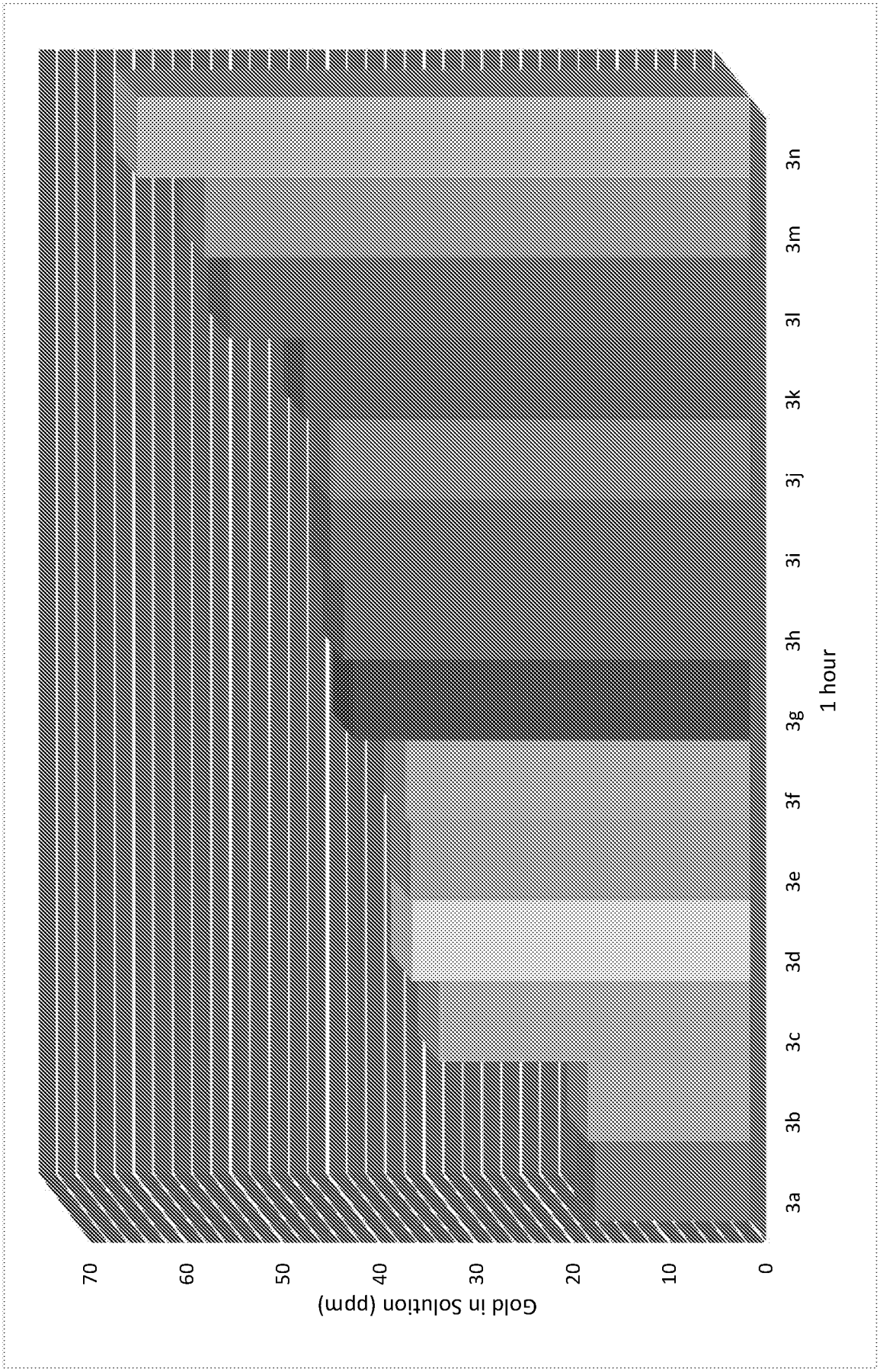
Gold in Solution (ppm)
0
10
20
30
40
50
60
70
3a
3b
3c
3d
3e
3f
3g
3h
3i
3j
3k
3l
3m
3n
1 hour

FIG. 3

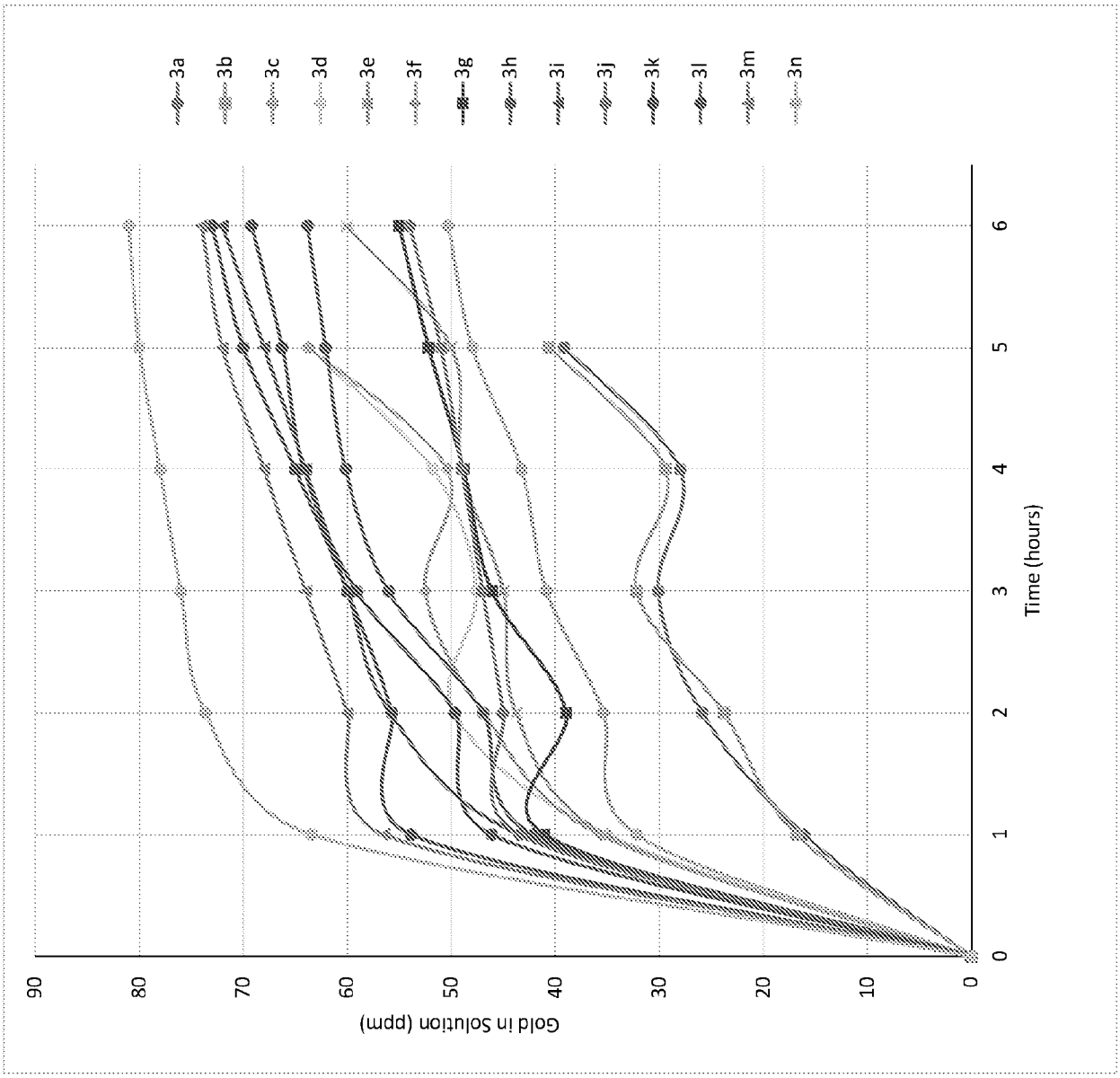
3a
3b
3c
3d
3e
3f
3g
3h
3i
3j
3k
3l
3m
3n
Gold in Solution (ppm)
0
10
20
30
40
50
60
70
80
90
0
1
2
3
4
5
6
Time (hours)

FIG. 4

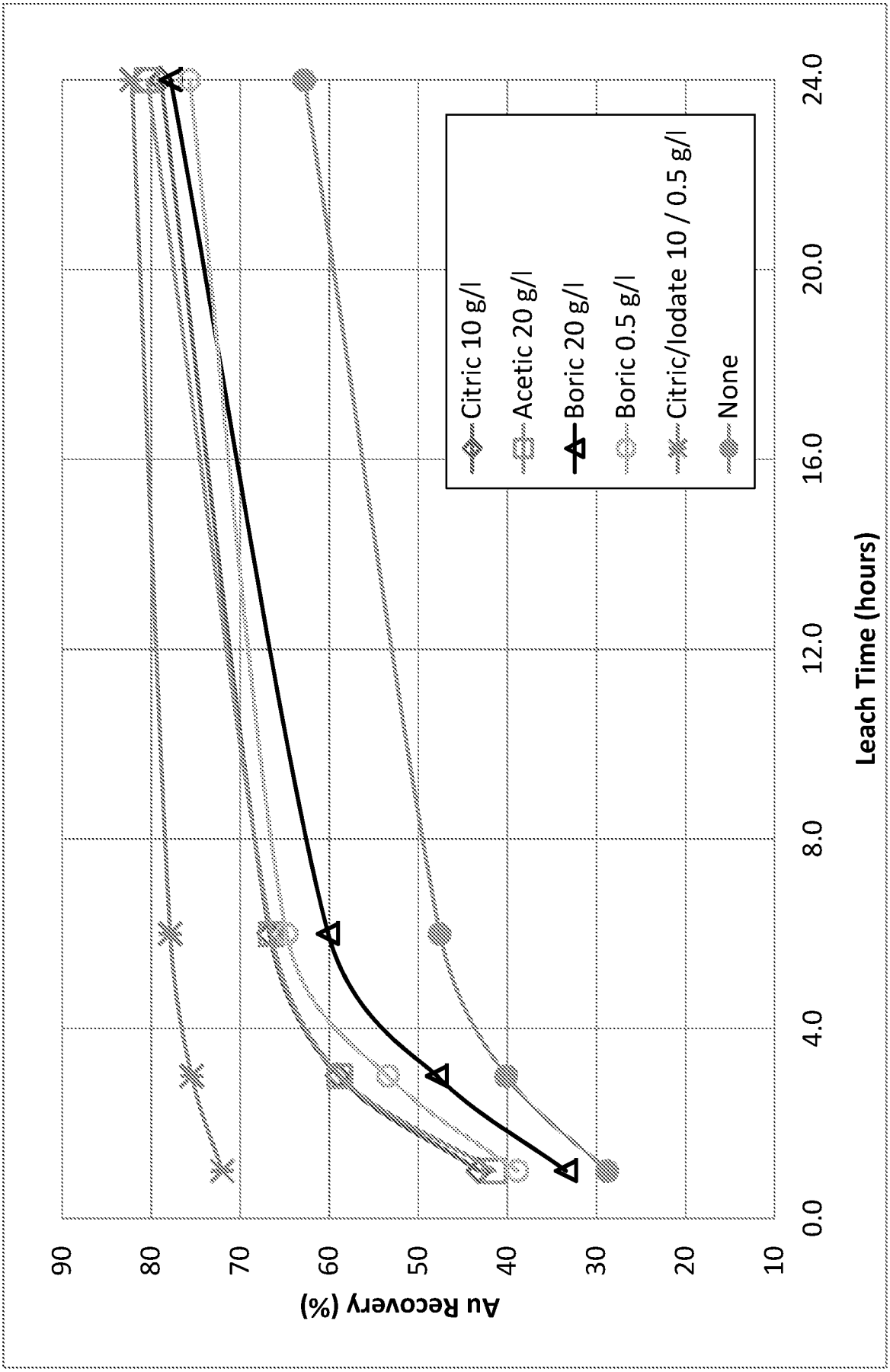
Au Recovery (%)
90
80
70
60
50
40
30
20
10
0.0
4.0
8.0
12.0
16.0
20.0
24.0
Leach Time (hours)
Citric 10 g/l
Acetic 20 g/l
Boric 20 g/l
Boric 0.5 g/l
Citric/Iodate 10 / 0.5 g/l
None

FIG. 5

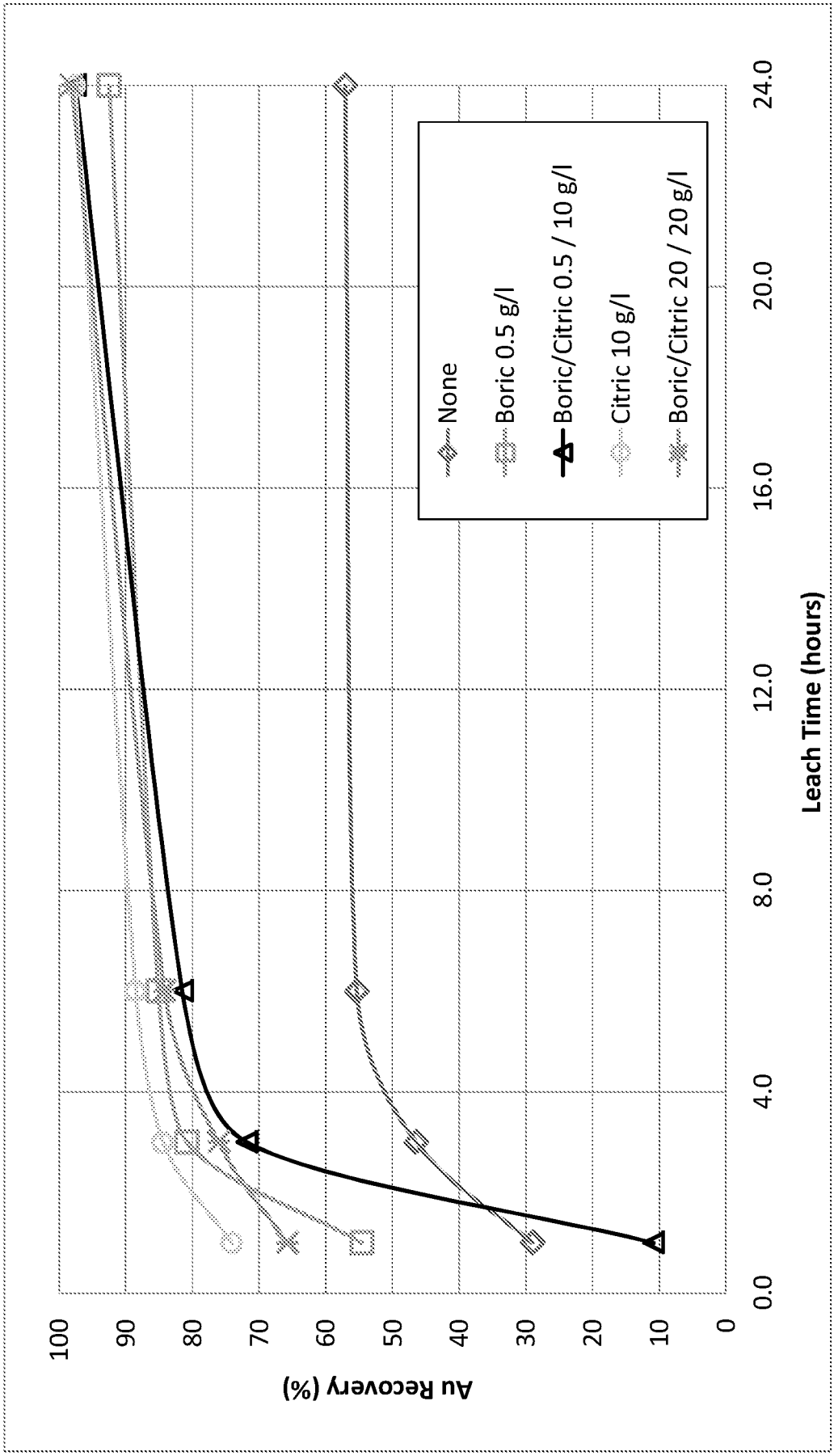
Au Recovery (%)
100
90
80
70
60
50
40
30
20
10
0
0.0
4.0
8.0
12.0
16.0
20.0
24.0
Leach Time (hours)
None
Boric 0.5 g/l
Boric/Citric 0.5 / 10 g/l
Citric 10 g/l
Boric/Citric 20 / 20 g/l

FIG. 6

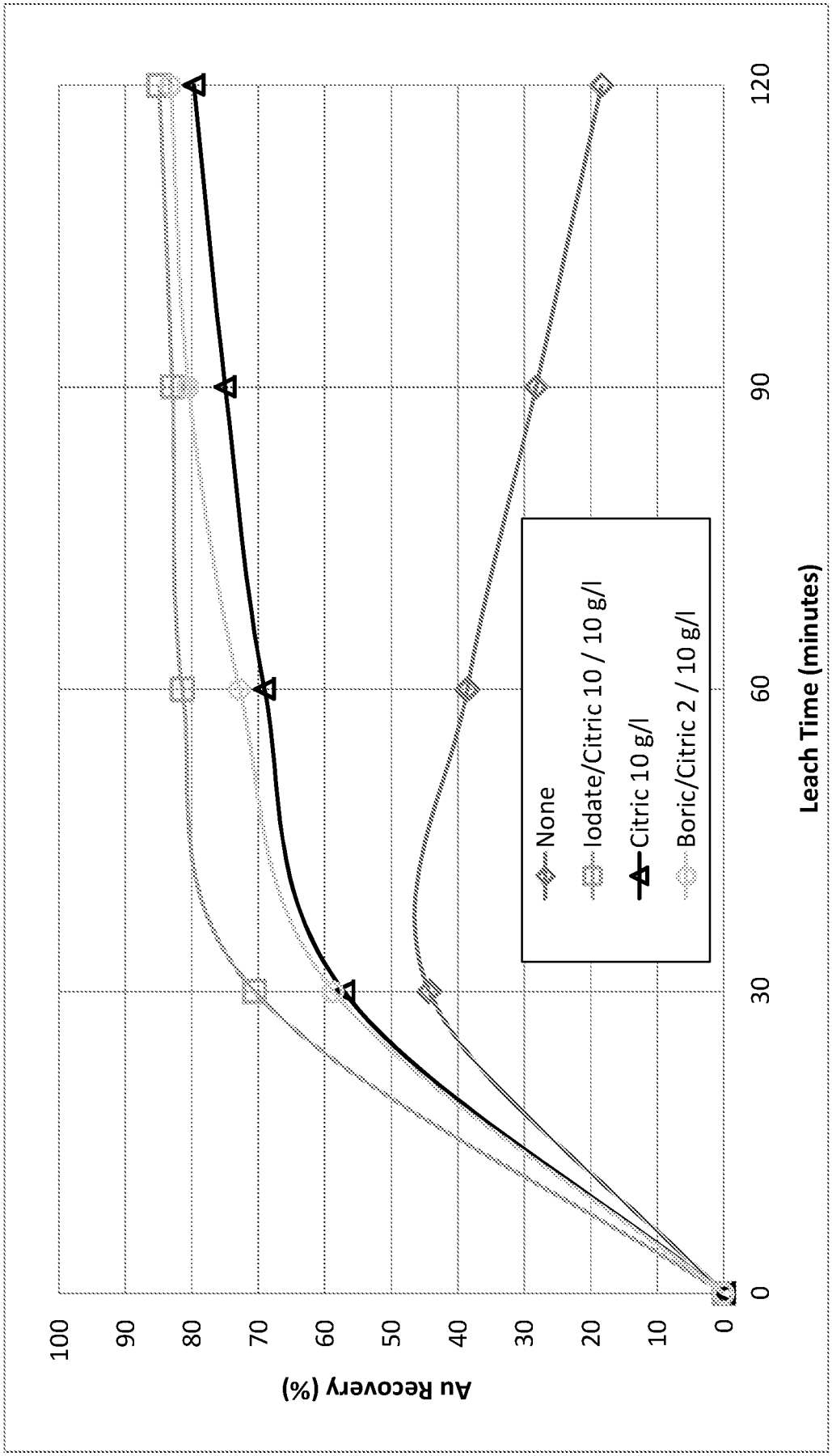
Au Recovery (%)
100
90
80
70
60
50
40
30
20
10
0
0
30
60
90
120
Leach Time (minutes)
None
Iodate/Citric 10 / 10 g/l
Citric 10 g/l
Boric/Citric 2 / 10 g/l

FIG. 7

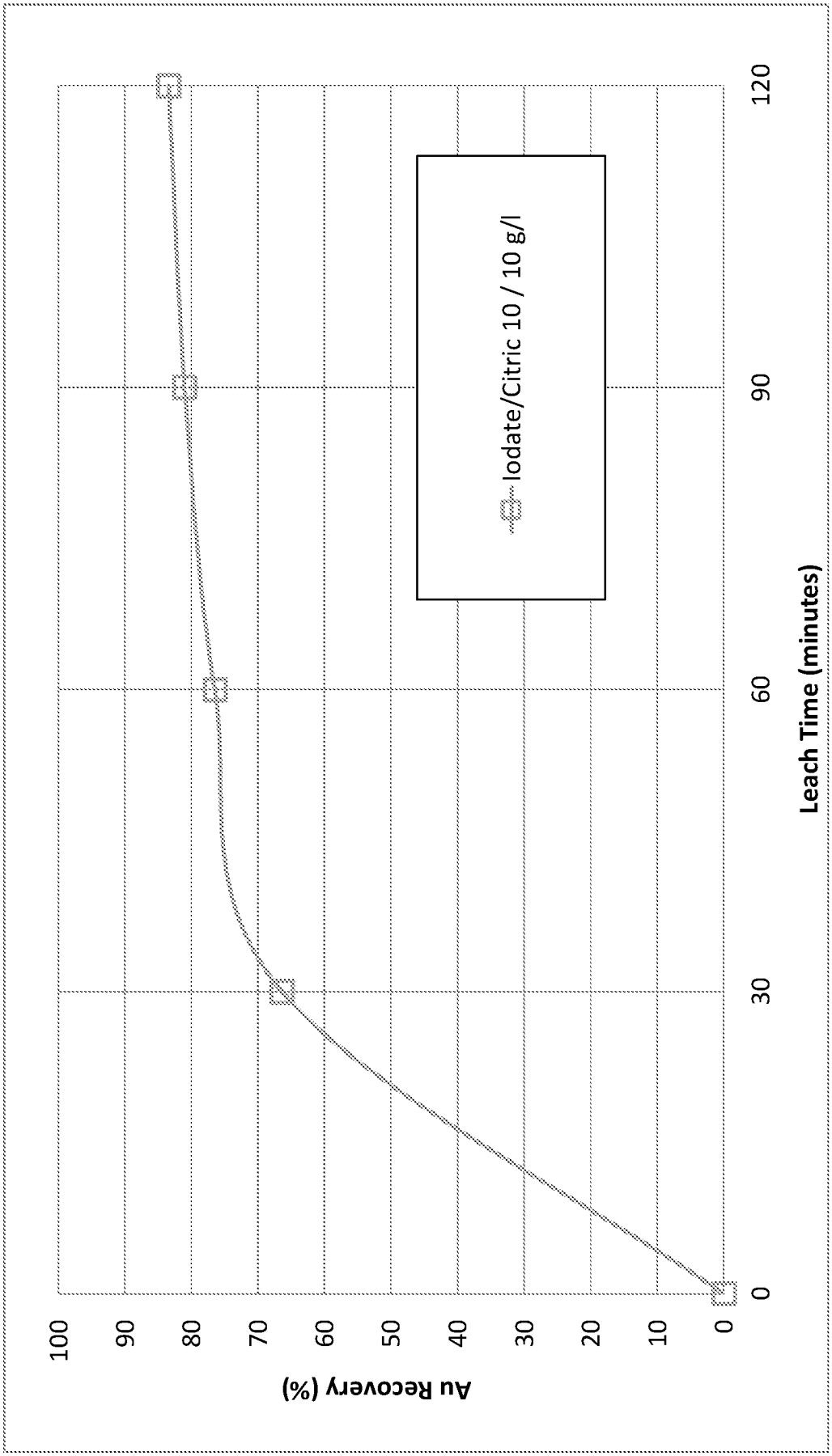
Au Recovery (%)
100
90
80
70
60
50
40
30
20
10
0
0
30
60
90
120
Leach Time (minutes)
Iodate/Citric 10 / 10 g/l

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2017/000958

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***C22B 3/16*** (2006.01) , ***C22B 3/20*** (2006.01) , ***C25B 1/24*** (2006.01) , *C22B 11/00* (2006.01)

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)
IPC: *C22B 11/00* (2006.01), ***C25B 1/24*** (2006.01)

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

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
FAMPAT (Questel), Scopus, Google

Iod+/hydroiod+, carboxylic/citric/acetic/stearic, leach+/dissol+/solub+/extract+, gold/noble/precious/platinum, potential/orp/eh, electro+, cell/tank/vessel

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y	US4734171A (MURPHY) 29 March 1988 (29-03-1988)	13, 15 -- 1-16
Y	AYLMORE, M.G., Alternatives to Cyanide for Leaching Gold Ores - Chapter 27, Gold Ore Processing: Project Development and Operations. Mike Adams, Ed., Elsevier, pp. 447-484, 17 May 2016 (17-05-2016) ** pages 448-449, 454-456 **	1, 4, 9-11, 14, 16
Y	US4859293A (HIRAKO et al.) 22 August 1989 (22-08-1989)	5-8, 16
Y	JP2005154892A (KAWASE YASUHIRO et al.) 16 June 2005 (16-06-2005)	2-3, 12 ,16

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

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier application or patent but published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 14 November 2017 (14-11-2017)	Date of mailing of the international search report 21 November 2017 (21-11-2017)
Name and mailing address of the ISA/CA Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 819-953-2476	Authorized officer Jay Fothergill (819) 639-8455

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN105018725A (ZHOU WENBIN et al.) 04 November 2015 (04-11-2015)	
A	WO2011130622A1 (BROSSEAU et al.) 20 October 2011 (20-10-2011)	

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2017/000958

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of the first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claim Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claim Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claim Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
- See additional sheet -

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claim Nos.:

4. ☑ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim Nos.:

Claims 1-16

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

(from Box III)

An attempt to find inventive concepts for the eight (8) independent claims resulted in the following claim groups:

Group A: claims 1-16 are directed to aqueous-based leaching solutions for precious metals (PM) comprising iodide salt material, a carboxylic acid (e.g. citric acid), wherein the solution is made by passing the solution through an electrochemical cell.

Group B: claims 17-20 are directed to a method of recovering PM using an aqueous-based leaching solution comprising contacting substrate with the solution resulting in pregnant solution, recovering precious metal from pregnant leach solution to generate a barren solution, and passing current through the barren solution to increase an ORP to generate a regenerated solution, and contacting with substrate.

Group C: claims 21-35 are directed to an aqueous-based leaching solution for PM comprising hypochlorite oxidant, citric acid material in an amount effective to enhance leaching, and iodide material in an amount effective to enhance leaching.

Group D: claims 36-52 are directed to an aqueous-based leaching solution for PM comprising water-soluble, polyprotic weak acid and iodide material, each in an amount effective to enhance leaching, wherein the solution has a pH of no greater than 7.

Group E: claims 53-59 are directed to a stable, aqueous-based PM leachate resulting from leaching PM oxidizable by hypochlorite-containing material with an acidic leach solution, wherein the solution comprises boric acid, citric acid, and hypochlorite material, each in amounts effective to oxidize and solubilize PM.

Group F: claim 60-74 are directed to a method of recovering PM from a pregnant solution including the steps of recovering the PM by electrodepositing to generate a barren solution, passing current through the barren solution having an iodine precursor to increase an iodine content.

Group G: claims 75-83 are directed to an aqueous-based leaching solution for PM comprising iodate material, carboxylic acid material, and iodide material, each in an amount effective to enhance leaching.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IB2017/000958

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
US4734171A	29 March 1988 (29-03-1988)	US4734171A	29 March 1988 (29-03-1988)
		US4557759A	10 December 1985 (10-12-1985)
US4859293A	22 August 1989 (22-08-1989)	US4859293A	22 August 1989 (22-08-1989)
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		KR101705417B1	09 February 2017 (09-02-2017)
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		KR101737711B1	18 May 2017 (18-05-2017)
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		SG10201502960YA	29 June 2015 (29-06-2015)
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		TWI558817B	21 November 2016 (21-11-2016)
		TW201634702A	01 October 2016 (01-10-2016)
		TWI568859B	01 February 2017 (01-02-2017)
		TW201634701A	01 October 2016 (01-10-2016)
		TW201634703A	01 October 2016 (01-10-2016)
		US2013276284A1	24 October 2013 (24-10-2013)
		US9215813B2	15 December 2015 (15-12-2015)
		US2016095230A1	31 March 2016 (31-03-2016)
		US2017079146A1	16 March 2017 (16-03-2017)