



(51) International Patent Classification:

C22B 1/11 (2006.01) C22B 3/22 (2006.01)
C22B 3/02 (2006.01) C22B 3/44 (2006.01)
C22B 3/08 (2006.01) C22B 11/08 (2006.01)
C22B 3/10 (2006.01)

(21) International Application Number:

PCT/IB2020/051218

(22) International Filing Date:

13 February 2020 (13.02.2020)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/805,194 13 February 2019 (13.02.2019) US

(71) Applicant: FLSMIDTH A/S [DK/DK]; Vigerslev Alle 77,
2500 Valby (DK).

(72) Inventors: EYZAGUIRRE, Carlos; 558 East Camden
Park Lane, Draper, UT 84020 (US). CHAIKO, David
John; 11102 South Cadbury Drive, South Jordan, UT 84095
(US).

(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,
CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO,
DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN,
HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP,
KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME,
MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,
OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,
SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR,
TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ,

(54) Title: PRE-TREATMENT PROCESS FOR THE RECOVERY OF PRECIOUS METALS

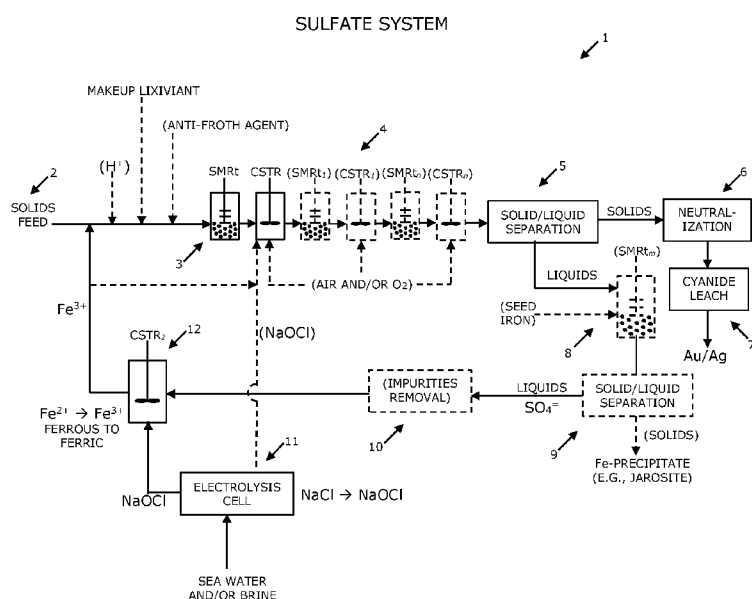


FIG. 1

(57) Abstract: A method (1) for pre-treating whole ore and/or concentrate comprising a precious metal for subsequent precious metal recovery involves processing a solids feed (2) in a pre-treatment stage (3) and then in a sulfide oxidation stage (4). The pre-treatment stage (3) may include a stirred media reactor (SMRt) therein, and the sulfide oxidation stage (4) may have at least one continuous stirred tank reactor (CSTR, CSTR_i, CSTR_n) therein. A solid-liquid separation step (5) downstream of the stages (3, 4) forms a solids fraction and a liquids fraction. A precious metal is recovered from the solids fraction, and the liquids fraction is processed in a ferric regeneration stage (12) to convert iron (II) within the liquids fraction to iron (III). The iron (III) produced via the ferric regeneration stage (12) is then delivered to one or both of the stages (3, 4).



UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *of inventorship (Rule 4.17(iv))*

Published:

- *with international search report (Art. 21(3))*
- *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

PRE-TREATMENT PROCESS FOR THE RECOVERY OF PRECIOUS METALS

Inventors: Carlos Eyzaguirre, David J. Chaiko

5

CROSS-REFERENCE TO RELATED APPLICATIONS

None.

FIELD OF THE INVENTION

10 Embodiments of the invention relate to hydrometallurgical processing of whole ores and/or sulfide concentrates and more particularly, to leaching or dissolving metal sulfides for downstream precious metals recovery.

 Embodiments further relate to improved oxidation techniques and novel methods for producing and using oxidants for metal sulfide oxidation.

15

OBJECTS OF THE INVENTION

 It is an object of some embodiments of the present invention, to reduce the need to provide and operate an oxygen plant in order to provide sufficient conversion of ferrous to ferric during metal sulfide oxidation.

20 It is another object of some embodiments of the present invention, to improve oxidation kinetics by circumventing oxygen solubility limitations for processes involving the atmospheric leaching of metal sulfides.

 It is a further object of some embodiments of the present invention, to provide a manner in which sulfide oxidation may be performed quickly, economically, and efficiently for downstream precious metal recovery.

25

 It is yet another object of some embodiments of the present invention, to provide an effective manner in which to oxidize single and/or double refractory ores for downstream precious metal recovery.

30 It is a further object of some embodiments of the present invention to provide a metal sulfide leaching circuit that can mostly be operated at substantially atmospheric pressure, without limitation.

It is a further object of some embodiments of the present invention to reutilize spent lixiviant solution from a metal sulfide leaching circuit by re-oxidizing liquid fractions recovered from the metal sulfide leaching circuit prior to combining it with fresh feed solids entering the metal sulfide leaching circuit.

5 It is yet another object of some embodiments of the present invention to provide a manner in which to reutilize spent lixiviant solution in different chemical environments.

It is a further object of some embodiments of the present invention to provide a system and method for using sea water and or brine solutions in metal sulfide leaching pre-treatments for downstream precious metal recovery.

10 These and other objects of the present invention will be apparent from the drawings and description herein. Although every object of the invention is believed to be attained by at least one embodiment of the invention, there is not necessarily any one embodiment of the invention that achieves all of the objects of the invention.

15 BRIEF SUMMARY OF THE INVENTION

A method (1) for pre-treating whole ore and/or concentrate comprising a precious metal for subsequent precious metal recovery is disclosed. The method (1) may comprise processing a solids feed (2) in a pre-treatment stage (3). The pre-treatment stage (3) may comprise a stirred media reactor (SMRt). The stirred media reactor (SMRt) may comprise
20 media, such as grinding media. The media preferably comprises an inert material which is not native to the solids feed (2). The media is also preferably at least ten times larger in size than particles in the solids feed (2). The stirred media reactor (SMRt) is preferably configured for producing a processed slurry from the solids feed (2). The method (1) may further comprise processing the processed slurry in a sulfide oxidation stage (4) to form a twice-processed slurry.
25 The sulfide oxidation stage may comprise at least one continuous stirred tank reactor (CSTR, CSTR₁, CSTR_n), without limitation.

The method (1) may comprise the step of performing a solid-liquid separation step (5) on the twice-processed slurry to form a solids fraction and a liquids fraction. The method (1) may comprise the step of recovering a precious metal from the solids fraction. The method (1)
30 may comprise the step of processing the liquids fraction in a ferric regeneration stage (12) to convert iron (II) within the liquids fraction to iron (III). The method may comprise the step of

delivering the iron (III) produced via the ferric regeneration stage (12) to the pretreatment stage (3) and/or to the sulfide oxidation stage (4), without limitation.

In some embodiments, the sulfide oxidation stage (4) may comprise at least one stirred media reactor ($SMRt_l$, $SMRt_n$). The at least one stirred media reactor ($SMRt_l$, $SMRt_n$) in the sulfide oxidation stage (4) may comprise media, and may be configured for producing the twice-processed slurry. In some embodiments, the media described herein may comprise an inert material which is not native to the solids feed (2). The media described herein may be preferably sized to be diametrically larger than leach particles within the solids feed (2), without limitation. The media described herein may be at least ten times larger in size than the particles in the solids feed (2), without limitation. The media described herein may comprise grinding or tumbling media such as beads or cylinders made from ceramic, polymeric, steel, or tungsten carbide, without limitation. The media described herein may, in some alternative embodiments, comprise silica (e.g., coarse sand), without limitation.

In some embodiments, the step of recovering a precious metal from the solids fraction may comprise neutralizing (6) the solids fraction. The step of recovering a precious metal from the solids fraction may comprise leaching (7) the solids fraction. In some embodiments, the liquids fraction may comprise ferric ion. A concentration of ferric ion in the liquids fraction may be higher after processing the liquids fraction in the ferric regeneration stage (12).

In some embodiments, the liquids fraction may comprise sulfate. In some embodiments, the liquids fraction may comprise chloride (e.g., derived from brine and/or sea water). In some embodiments, prior to being processed in the ferric regeneration stage (12), the liquids fraction may be processed in a second stirred media reactor ($SMRt_m$) (8), for example, in the presence of seed iron. In some embodiments, the method (1) may comprise the step of performing a solid-liquid separation on product processed by the second stirred media reactor ($SMRt_m$) (8). The solid-liquid separation may be performed, for example, using a solid-liquid separation device (9), without limitation.

In some embodiments, processing the liquids fraction in ferric regeneration stage (12) to convert iron (II) within the liquids fraction to iron (III) may comprise processing the liquids fraction by adding oxidants to a continuous stirred tank reactor ($CSTR_2$), adding oxygen to a pressurized oxidation vessel, adding electricity to a direct electrolysis cell, or directly contacting a catalyst with the liquids fraction in a mass-transfer column, without limitation. In some

embodiments, adding oxidants to the continuous stirred tank reactor (CSTR₂) may comprise the steps of producing NaOCl in an electrolysis cell (11) from NaCl derived from brine or sea water and/or of delivering the NaOCl to the continuous stirred tank reactor (CSTR₂), without limitation.

5 A system (1) for pre-treating whole ore and/or concentrate comprising a precious metal for subsequent precious metal recovery is also disclosed. The system (1) may comprise a pre-treatment stage (3) for processing a solids feed (2). The pre-treatment stage (3) may comprise a stirred media reactor (SMRt) having media therein. The media may comprise an inert material which is not native to the solids feed (2). The media may be at least ten times
10 larger in size than particles in the solids feed (2), without limitation. The stirred media reactor (SMRt) may be configured for producing a processed slurry. A sulfide oxidation stage (4) for processing the processed slurry may be provided downstream of the pre-treatment stage (3). The sulfide oxidation stage (4) may comprise at least one continuous stirred tank reactor (CSTR, CSTR_l, CSTR_n) which is configured to produce a twice-processed slurry. A solid-
15 liquid separation device (5) may be provided downstream of the sulfide oxidation stage (4). The solid-liquid separation device (5) may be configured to perform a solid-liquid separation of the twice-processed slurry produced in the sulfide oxidation stage (4). The solid-liquid separation device (5) may be configured to form a solids fraction and a liquids fraction from the twice-processed slurry.

20 The system (1) may further comprise means for recovering a precious metal from the solids fraction of the solid-liquid separation device (5). For example, the means may comprise a neutralization stage (6) and/or a leaching stage (7) for leaching the solids fraction and recovering a precious metal therefrom, without limitation. The system (1) may comprise a ferric regeneration stage (12) downstream of the solid-liquid separation device (5). The ferric
25 regeneration stage (12) may comprise means for converting iron (II) within the liquids fraction of the solid-liquid separation device (5) to iron (III). The system (1) may also comprise means for delivering the iron (III) produced via the ferric regeneration stage (12) to the pretreatment stage (3) and/or to the sulfide oxidation stage (4), without limitation.

30 In some embodiments, the sulfide oxidation stage (4) may comprise at least one stirred media reactor (SMRt_l, SMRt_n) comprising media. The at least one stirred media reactor (SMRt_l, SMRt_n) in the sulfide oxidation stage (4) may be configured for producing the twice-

processed slurry via the sulfide oxidation stage (4). The media within the at least one stirred media reactor (SMR_{t_l} , SMR_{t_n}) of the sulfide oxidation stage (4) may comprise an inert material which is not native to the solids feed (2), and/or which is at least ten times larger in size than the particles in the solids feed (2), without limitation. In some embodiments, the liquids fraction from the solid-liquid separation device (5) may comprise ferric ion. A concentration of the ferric ion in the liquids fraction may be higher after processing the liquids fraction in the ferric regeneration stage (12), without limitation.

In some embodiments, the liquids fraction may comprise sulfate, without limitation. In some embodiments, the liquids fraction may comprise chloride derived from brine and/or sea water, without limitation. In some embodiments, the system (1) may comprise a second stirred media reactor (SMR_{t_m}) (8) which is provided upstream of the ferric regeneration stage (12). The liquids fraction of the solid-liquid separation device (5) may be processed in the second stirred media reactor (SMR_{t_m}) (8), for example, in the presence of seed iron, without limitation.

In some embodiments, the system (1) may comprise a solid-liquid separation device (9) for performing a solid-liquid separation on product processed by the second stirred media reactor (SMR_{t_m}) (8). In some embodiments, the ferric regeneration stage (12) may be configured to convert iron (II) within the liquids fraction to iron (III). The ferric regeneration stage (12) may comprise a continuous stirred tank reactor ($CSTR_2$) receiving an oxidant, a pressurized oxidation vessel receiving oxygen, a direct electrolysis cell powered by electricity, or a mass-transfer column for directly contacting a catalyst with the liquids fraction therein, without limitation. In some embodiments, the oxidant received by the continuous stirred tank reactor ($CSTR_2$) may comprise NaOCl produced in an electrolysis cell (11) from NaCl derived from brine or sea water, without limitation.

Further disclosed, is a method of supplying an oxidant to a metal sulfide oxidation stage of a metal sulfide leaching circuit. Embodiments of the method may comprise the step of processing sodium chloride (NaCl) in an electrolysis cell to form sodium hypochloride (NaOCl), without limitation. The electrolysis cell may be located upstream from the metal sulfide oxidation stage, without limitation. The sodium hypochloride (NaOCl) may be provided to a continuous stirred tank reactor ($CSTR_2$) which may contain iron (II). The continuous stirred tank reactor ($CSTR_2$) may be located upstream from the metal sulfide oxidation stage, without limitation. Embodiments of the method may comprise the step of processing sodium

hypochloride with iron (II) in the stirred tank reactor (CSTR₂) to convert the iron (II) to iron (III). The iron (III) may be provided to the metal sulfide oxidation stage and used as an oxidant in the metal sulfide oxidation stage, without limitation. While the sodium hypochloride (NaOCl) may serve as a reagent for converting iron (II) to iron (III), it should be understood that
5 in addition to, or in lieu of the sodium hypochloride, other strong oxidants may be provided to the stirred tank reactor (CSTR₂) including, but not limited to, H₂O₂, SO₂/O₂, a combination thereof, or the like, without limitation.

According to some non-limiting embodiments, a solids feed comprising leach particles may be provided to the metal sulfide oxidation stage. The solids feed may comprise metal
10 sulfide whole ore, and/or it may comprise metal sulfide concentrate, without limitation. The leach particles in the solids feed may comprise a metal sulfide selected from the group consisting of: pyrite, sphalerite, galena, chalcopyrite, marcasite, arsenopyrite, covellite, chalcocite, enargite, tetrahedrite, tennentite, and a combination thereof, without limitation. Leach particles in the solids feed preferably comprise a precious metal which can be extracted
15 through downstream cyanidation. For example, precious metals such as gold (Au) and/or silver (Ag) may be recovered by a cyanide leach step, without limitation.

In some embodiments, the sodium chloride (NaCl) used to generate sodium hypochloride via electrolysis may be derived from sea water, brine, or a combination thereof, without limitation. In some embodiments, the sodium hypochloride (and/or other strong
20 oxidant(s) mentioned above) may optionally be provided directly or indirectly to the metal sulfide oxidation stage, without limitation. In some embodiments, at least 10% of the metal sulfide may be oxidized in the leach circuit within an hour, without limitation. In some non-limiting embodiments, an anti-frothing agent may be provided to the metal sulfide oxidation stage. In some purely exemplary non-limiting embodiments, the anti-frothing agent may, for
25 instance, comprise ligninsulfonate, without limitation. Other anti-frothing agents and particle surface treatments are envisaged.

A leach circuit for processing a solids feed is also disclosed. The solids feed preferably comprises a metal sulfide whole ore comprising a precious metal and/or a metal sulfide concentrate comprising a precious metal, without limitation. The leach circuit may
30 comprise a feed inlet for receiving the solids feed. The leach circuit may comprise an inlet for receiving liquid comprising sea water and/or brine, without limitation. A stirred media reactor

(SMRt) may be provided to the leach circuit; for example, as part of a pre-treatment stage, without limitation. The stirred media reactor (SMRt) may comprise media such as media comprising an inert material which is not native to the solids feed. The stirred media reactor may receive the liquid comprising sea water and/or brine and may receive the solids feed and process the same in the presence of the media. The media is preferably sized to be diametrically larger than leach particles within the solids feed, without limitation. The stirred media reactor (SMRt) may be configured to produce processed slurry from the liquid comprising sea water and/or brine and the solids feed, without limitation.

A continuous stirred tank reactor (CSTR) may receive processed slurry from the stirred media reactor (SMRt) and oxidize it to produce twice-processed slurry. The continuous stirred tank reactor (CSTR) may form a portion of a sulfide oxidation stage; or, it may form the entire sulfide oxidation stage. One or more stirred media reactors (SMRt₁, SMRt_n) may be provided to the sulfide oxidation stage without limitation. Multiple continuous stirred tank reactors (CSTR₁, CSTR_n) may be provided to the sulfide oxidation stage, without limitation.

A solid/liquid separator may receive the twice-processed slurry from the sulfide oxidation stage and may separate it into a solids stream and a liquids stream. The solids stream may be sent to a neutralization circuit followed by a cyanide leach circuit configured for extracting one or more precious metals therefrom. The liquids stream may be sent to a ferric regeneration circuit comprised of a second continuous stirred tank reactor (CSTR₂) or a pressure oxidation (POx) device, without limitation.

For example, the leach circuit may comprise a second continuous stirred tank reactor (CSTR₂) or a pressure oxidation (POx) device configured for receiving liquids separated by the solid/liquid separator. The second continuous stirred tank reactor (CSTR₂) may be configured to convert iron (II) to iron (III), without limitation. Similarly, the pressure oxidation (POx) device may be configured to convert iron (II) to iron (III), without limitation. In some non-limiting embodiments, the stirred media reactor (SMRt) of the pre-treatment stage may receive the iron (III) from the ferric regeneration circuit. For example, iron (III) from the second continuous stirred tank reactor (CSTR₂) or pressure oxidation (POx) device may be conveyed to the stirred media reactor (SMRt), without limitation.

The leach circuit may, in some embodiments, comprise an optional second stirred media reactor (SMRt_m) downstream of the sulfide oxidation stage. The optional second stirred

media reactor (SMR_{tm}) may be configured for receiving liquids from the solid/liquid separator. The optional second stirred media reactor (SMR_{tm}) may be configured for receiving seed material, such as a material comprising iron, without limitation. In some instances, iron-containing seed material provided to the optional second stirred media reactor (SMR_{tm}) may comprise pyrite, goethite, magnetite, jarosite, basic iron sulfate, or a combination thereof, without limitation). The second stirred media reactor (SMR_{tm}) may be operatively configured for precipitating a material comprising iron (i.e., an Fe-precipitate) from liquids received from the solid/liquid separator. Like the stirred media reactor (SMR_t), the second stirred media reactor (SMR_{tm}) may comprise media therein; and the media may comprise an inert material which is not native to the solids feed, without limitation.

According to some non-limiting embodiments, a leach circuit may comprise an electrolysis cell configured for receiving liquid. The liquid received by the electrolysis cell preferably comprises sea water and/or brine, without limitation. The electrolysis cell is also preferably configured for converting sodium chloride (NaCl) in the liquid to sodium hypochloride (NaOCl), without limitation. The sodium hypochloride (NaOCl) may be delivered to and/or received by the second stirred tank reactor (CSTR₂), without limitation. In some embodiments, the stirred media reactor (SMR_t) may receive sodium hypochloride (NaOCl) from the electrolysis cell. For example, in some embodiments, sodium hypochloride may be provided directly or indirectly to the stirred media reactor (SMR_t), as indicated by a dotted line in FIGS. 1-3, without limitation.

In some embodiments, a sulfate and/or chloride removal system may be optionally provided to the leach circuit. The sulfate and/or chloride removal system may receive liquids from the solid/liquid separator and process them before conveying the same to said second stirred tank reactor (CSTR₂) or pressure oxidation (POx) device, without limitation.

In some embodiments, the stirred media reactor (SMR_t) may receive solids which are rich in iron (III). The solids rich in iron (III) may be sourced from thickener underflow, wherein the thickener providing the underflow is downstream of a pressure oxidation (POx) device. The pressure oxidation (POx) device may be fed with a solids feed, such as a solids feed comprising a metal sulfide whole ore and/or a concentrate – each comprising a precious metal. In some embodiments, the precious metal may comprise gold (Au) and/or silver (Ag), without limitation.

In some embodiments, an anti-frothing agent may be provided to the pre-treatment stage of a leach circuit, without limitation. For example, a stirred media reactor (SMRt) preceding a continuous stirred tank reactor (CSTR) may receive an anti-frothing agent, without limitation. The anti-frothing agent may, in some non-limiting embodiments, comprise ligninsulfonate, without limitation. Other anti-frothing agents and particle surface treatments are envisaged.

Further details may be appreciated from the below detailed description, appended drawings, and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

To complement the description which is being made, and for the purpose of aiding to better understand the features of the invention, a set of drawings illustrating various systems and methods according to certain embodiments has been added to the present specification as an integral part thereof, in which the following has been depicted with an illustrative and non-limiting character. It should be understood that like reference numbers used in the drawings (if any are used) may identify like components. In the drawings:

FIG. 1 suggests a flowsheet according to some non-limiting exemplary embodiments.
FIG. 2 suggests a flowsheet according to some non-limiting exemplary embodiments.
FIG. 3 suggests a flowsheet according to some non-limiting exemplary embodiments.
FIG. 4 suggests a flowsheet according to some non-limiting exemplary embodiments.
FIG. 5 suggests a flowsheet according to some non-limiting exemplary embodiments.
FIG. 6 suggests a flowsheet according to some non-limiting exemplary embodiments.
FIG. 7 suggests a flowsheet according to some non-limiting exemplary embodiments.
FIG. 8 suggests a flowsheet according to some non-limiting exemplary embodiments.
FIGS. 9 & 10 suggest a method according to some non-limiting exemplary embodiments.

FIG. 11 is a schematic diagram, wherein regimes A and B illustrate the pH change accompanying sulfide oxidation using soluble FeCl_3 and a solid-state oxidant such as Fe_2O_3 , FeOOH , or a combination thereof, without limitation.

In the following, the invention will be described in more detail with reference to drawings in conjunction with exemplary embodiments.

DETAILED DESCRIPTION OF THE INVENTION

The following description of the non-limiting embodiments shown in the drawings is merely exemplary in nature and is in no way intended to limit the inventive embodiments disclosed herein, their applications, or their uses. Disclosed herein, are embodiments of a system and method for leaching a metal sulfide and subsequently recovering one or more precious metals therefrom.

Turning now to FIG. 1, some embodiments may involve a system and method for recovering precious metals via a sulfate system 1. A solids feed 2 may be provided and introduced to a stirred media reactor (SMRt) as part of a pre-treatment stage 3 within a leach circuit. The solids feed 2 may comprise a metal sulfide whole ore, and/or a metal sulfide concentrate, without limitation. Leach particles within the solids feed preferably comprise a precious metal such as gold (Au) and/or silver (Ag), without limitation. Makeup lixiviant may be combined with the solids feed and processed in the stirred media reactor (SMRt), without limitation. An acid (H^+) may also be optionally-combined with the solids feed and processed in the stirred media reactor (SMRt), for example, in order to adjust pH, without limitation. In some embodiments, the acid (H^+) may be provided in the form of sulfuric acid, without limitation. An anti-froth agent may be optionally-combined with the solids feed and processed in the stirred media reactor (SMRt), without limitation.

The stirred media reactor (SMRt) of the pre-treatment stage 3 comprises media (e.g. grinding media). The grinding media is preferably inert, and non-native to the solids feed, without limitation. It is preferred that the media in the stirred media reactor (SMRt) is sized so as to be diametrically larger than leach particles in the solids feed (e.g., at least 10 times greater, without limitation).

Once the solids feed 2 has been pre-processed in the stirred media reactor (SMRt), it is moved downstream to a sulfide oxidation stage 4 comprising a continuous stirred tank reactor (CSTR). The continuous stirred tank reactor (CSTR) differs from the stirred media reactor (SMRt) in that it does not comprise media, that it is larger than the stirred media reactor volumetrically, and that it operates at a lower power density than the stirred tank reactor. Air and/or oxygen may be provided to the continuous stirred tank reactor (CSTR), without limitation. In some embodiments, the sulfide oxidation stage 4 of the system and method 1 may comprise more than one continuous stirred tank reactor (CSTR, CSTR₁, CSTR_n), without

limitation. In some embodiments, one or more additional stirred media reactors (SMR_{t_l} , SMR_{t_n}) may be interspersed between successive continuous stirred tank reactors, in an inter-stage fashion, within a sulfide oxidation stage 4, without limitation. FIG. 1 exemplifies this wherein features incorporating the use of dotted lines represent optional features. Air and/or oxygen may be optionally-provided to any continuous stirred tank reactor ($CSTR$, $CSTR_{l_l}$, $CSTR_{l_n}$) used in the sulfide oxidation stage, without limitation. Air and/or oxygen may be optionally-provided to any stirred media reactor (SMR_t , SMR_{t_l} , SMR_{t_n}) used in the sulfide oxidation stage, without limitation.

Processed slurry leaving the sulfide oxidation stage 4 may be delivered to a solid/liquid separation step 5. The solid/liquid separation step 5 may comprise a solid/liquid separator; such as a thickener/clarifier, filter, centrifuge, classifier, screen, or other solid/liquid separator to separate liquids from solids, without limitation. In some embodiments, a plurality of solid/liquid separators may be employed, without limitation. A solids fraction of the slurry processed by the sulfide oxidation stage 4 may move to a neutralization step 6 before being subjected to a cyanide leach 7 where precious metals (e.g., gold (Au) and/or silver (Ag)) can be recovered therefrom. Liquids from the solid/liquid separation step 5 may be moved to a ferric regeneration step 12 after the solid/liquid separation step. In some embodiments, such as the one shown in FIG. 1, the ferric regeneration step 12 may comprise a second continuous stirred tank reactor ($CSTR_2$), without limitation. The second continuous stirred tank reactor ($CSTR_2$) may operate above atmospheric pressure, without limitation.

Prior to being received in the second continuous stirred tank reactor ($CSTR_2$) of the ferric regeneration step 12, liquids from the solid/liquid separation step 5 may be processed via an optional iron removal step 8. The iron removal step 8 may be configured to remove iron from the liquids from the solid/liquid separation step 5. In some embodiments, the iron removal step 8 may comprise a second stirred media reactor (SMR_{t_m}), as shown, without limitation. The second stirred media reactor (SMR_{t_m}) may be seeded with a material comprising iron (e.g., pyrite, goethite, jarosite, or a combination thereof), without limitation. An optional second solid/liquid separation step 9 may be employed downstream of the second stirred media reactor (SMR_{t_m}), for example, to remove iron precipitates and/or other solids comprising iron from the liquids fraction of the solid/liquid separation step 5. In some embodiments, sulfates contained

in the liquids from the solid/liquid separation step 5 may be processed in an optional impurity removal step 10.

An electrolysis cell 11 may receive a liquid comprising sea water and/or brine. The electrolysis cell 11 may be used to convert sodium chloride (NaCl) in the liquid to sodium hypochloride (NaOCl), without limitation. Sodium hypochloride (NaOCl) produced via the electrolysis cell 11, and liquids from the solid/liquid separation step 5 may feed the ferric regeneration circuit 12 (e.g., may be sent to the second continuous stirred tank reactor (CSTR₂), without limitation. Iron (III) may be generated from iron (II) in the ferric regeneration circuit 12. The iron (III) produced via ferric regeneration 12 may be introduced to and/or combined with the solids feed 2 for processing in the stirred media reactor (SMRt) of the pre-treatment stage 3, without limitation. Optionally, while not shown, sodium hypochloride (NaOCl) produced using the electrolysis cell 11 may be delivered directly or indirectly to the stirred media reactor (SMRt) of the pre-treatment stage 3, and used as an oxidant, without limitation. Optionally, as indicated with dashed lines, sodium hypochloride (NaOCl) produced using the electrolysis cell 11 may be delivered directly or indirectly to the continuous stirred tank reactor (CSTR) of the sulfide oxidation stage 4, and used as an oxidant, without limitation. It should be understood that while not shown, in some embodiments, other strong oxidants such as a mixture of sulfur dioxide and oxygen (SO₂/O₂) and/or hydrogen peroxide (H₂O₂) may be employed and provided to the second continuous stirred tank reactor (CSTR₂) of the ferric regeneration step 12, without limitation. It should be understood that while not shown, in some embodiments, oxidants such as air, enriched air, pure oxygen (O₂), a mixture of sulfur dioxide and oxygen (SO₂/O₂), and/or hydrogen peroxide (H₂O₂) may be employed to the stirred media reactor (SMRt) of the pre-treatment stage 3 and/or to the continuous stirred tank reactor, without limitation.

Turning now to FIG. 2, some embodiments may involve a system and method for metal sulfide leaching via a ferric chloride system 1 followed by downstream precious metal recovery. The system and method 1 may differ from the embodiment shown in FIG. 1, in that liquid containing sea water and/or brine may be present within stages 3 and 4, and/or acid in the form of hydrochloric acid (HCl) may be added to the system 1 rather than sulfuric acid.

Turning now to FIG. 3, some embodiments may involve a system and method 1 with solutions containing sulfate and chlorides.

Turning now to FIG. 4, liquids from the solid/liquid separation step 5 may be moved to a ferric regeneration step 12 which may be provided downstream of the solid/liquid separation step 5, as with the embodiment shown in FIG. 1. In the particular embodiment shown in the figure, the ferric regeneration step 12 may comprise a pressure oxidation (POx) device, such as an autoclave or pressurized stirred tank reactor, without limitation. The pressure oxidation device may receive oxygen (O_2), as shown. The pressure oxidation device may optionally receive a catalyst. For example, in some non-limiting embodiments, the catalyst may be selected from the group consisting of: platinum, palladium, gold, cobalt, copper, phosphate, an organic chelating agent, activated carbon, and a combination thereof, without limitation. If activated carbon is utilized as a catalyst in the ferric regeneration step 12, it should be acknowledged that preferred embodiments may employ CENTAUR® brand granular activated carbon sold by Calgon Carbon Corporation – in particular, for the oxidation of ferrous in acid systems where the pH is less than 2, without limitation. While not shown, in some embodiments, the pressure oxidation device used in ferric regeneration step 12 may comprise a direct electrolysis apparatus which is configured to convert ferrous to ferric, without limitation.

Prior to being received by the pressure oxidation device of the ferric regeneration step 12, the liquids from the solid/liquid separation step 5 may be additionally processed by an optional iron removal process 8.

Iron (III) may be generated from iron (II) in the ferric regeneration step 12. The iron (III) produced may be introduced to the stirred media reactor (SMRt) of the pre-treatment stage 3 or otherwise combined with the solids feed 2 for pre-treatment processing, without limitation. The iron (III) produced in ferric regeneration step 12 may optionally be introduced to the continuous stirred tank reactor (CSTR) of the sulfide oxidation stage 4 as indicated by dashed line. It should be understood that while not shown, in some embodiments, other oxidants such as air, enriched air, pure oxygen (O_2), a mixture of sulfur dioxide and oxygen (SO_2/O_2), and/or hydrogen peroxide (H_2O_2) may be employed to the ferric regeneration step 12, without limitation. It should be understood that while not shown, in some embodiments, oxidants such as air, enriched air, pure oxygen (O_2), a mixture of sulfur dioxide and oxygen (SO_2/O_2), and/or hydrogen peroxide (H_2O_2) may be employed to the stirred media reactor (SMRt) of the pre-treatment stage 3 and/or to the continuous stirred tank reactor (CSTR) of the sulfide oxidation stage 4, without limitation.

Turning now to FIG. 5, some

embodiments may involve a system and method 1 that may differ from the embodiment shown in FIG. 4, in that chlorides in the liquid received from the solid/liquid separation step 5 may be processed via an optional impurities removal step 10. Ferric regeneration step 12 would operate similarly as it would for the embodiment shown in FIG. 4.

5 Turning now to FIG. 6, some embodiments may involve a system and method for recovering precious metals after metal sulfide leaching in a chloride and sulfate system 1.

Turning now to FIG. 7, some embodiments may involve a system and method for recovering precious metals wherein a solids feed 2 may be provided to a stirred media reactor (SMRt) as part of a pre-treatment stage 3. The solids feed 2 may comprise a metal sulfide
10 whole ore, and/or a metal sulfide concentrate, without limitation. The solids feed comprises leach particles that preferably comprise a precious metal such as gold (Au) and/or silver (Ag). Liquid comprising sea water and/or brine may be combined with the solids feed 2 and processed in the stirred media reactor (SMRt) to pre-treat the material, without limitation. Acid (H^+) may be optionally combined with the solids feed and processed in the stirred media reactor (SMRt);
15 for example, to adjust pH, without limitation. The acid (H^+) may be provided in the form of sulfuric or hydrochloric acid, without limitation. As shown by dotted lines, acid (H^+) can be optionally provided via the delivery of additional liquids produced from an upstream conventional pressure oxidation process 14, without limitation. One or more anti-froth agents may be optionally-combined with the solids feed 2 and processed in the stirred media reactor
20 (SMRt), without limitation.

The stirred media reactor (SMRt) of the pre-treatment stage 3 comprises media (e.g. grinding media) which is generally inert and non-native to the solids feed, without limitation. It is preferred that media within the stirred media reactor (SMRt) is sized so as to be diametrically larger than leach particles in the solids feed. It is also preferred that the media is sized to
25 discourage its displacement from the stirred media reactor (SMRt).

Once the solids feed is pre-processed by the stirred media reactor (SMRt) (in the presence of the liquid comprising sea water and/or brine), pre-processed slurry is moved downstream from the stirred media reactor (SMRt) to a sulfide oxidation stage 4 comprising at least one continuous stirred tank reactor (CSTR) which does not comprise media. Air and/or
30 oxygen may be provided to the at least one continuous stirred tank reactor (CSTR), in any fashion, without limitation. In some embodiments, the sulfide oxidation stage 4 may comprise

more than one continuous stirred tank reactor (CSTR, CSTR_l, CSTR_n), without limitation. In some embodiments, one or more “additional” stirred media reactors (SMR_t, SMR_{tl}, SMR_{tn}) may be interspersed between successive stirred tank reactors, in an inter-stage fashion within the sulfide oxidation stage 4 (e.g., to provide synergistic oxidizing effects), without limitation. This is suggested in FIG. 4 (exemplified using dotted lines to represent optional features). Air, enriched air, and/or oxygen may be optionally-provided to any one or more of the continuous stirred tank reactors (CSTR, CSTR_l, CSTR_n) or stirred media reactors (SMR_t, SMR_{tl}, SMR_{tn}) within the sulfide oxidation stage 4, in any combination or permutation, without limitation.

Processed slurry leaving the sulfide oxidation stage 4 may be delivered to a solid/liquid separation step 5. The solid/liquid separation step 5 may comprise one or more separators (e.g., one or more thickener/clarifiers, filters, centrifuges, classifiers, screens, or other type of solid/liquid separator), in order to separate liquids from the solids, without limitation. A solids fraction of the slurry processed by the sulfide oxidation stage 4 may move to a neutralization step 6 before being subjected to a cyanide leach step 7 where precious metals (e.g., gold (Au) and/or silver (Ag)) may be recovered therefrom.

In some embodiments, the conventional upstream pressure oxidation step 14 may comprise a pressure oxidation device, such as an autoclave, without limitation. The pressure oxidation device may receive oxygen (O₂) as shown. A solids feed 13 may be provided to the pressure oxidation device as shown. The solids feed 13 may comprise metal sulfide whole ore and/or metal sulfide concentrate, without limitation. The whole ore and/or concentrate preferably comprise one or more precious metals (e.g., gold (Au) and/or silver (Ag), without limitation).

After pressure oxidation 14, slurry may pass from the pressure oxidation step 14 to a number of flash tanks, and then to a solid/liquid separation step 15. As shown, the solid/liquid separation step 15 may comprise a thickener/clarifier; however, it may additionally or alternatively comprise one or more thickener/clarifiers, filters, centrifuges, classifiers, screens, or other solid/liquid separators configured to separate liquids from solids, without limitation. Liquids from the solid/liquid separation step 15 may be removed from the flowsheet 1 and/or may be re-combined with the solids feed 2 to maintain water balance in the system/process 1, without limitation. Liquids from the solid/liquid separation step 15 may be removed from the

flowsheet 1 and/or may be re-combined with the solids feed 2; for example, in order to maintain or assist with pH control, without limitation.

As shown in FIG. 7, solids from the solid/liquid separation step 15 may subsequently undergo an optional filtration step 16, without limitation. Iron (III)-rich solids from the solid/liquid separation step 15 may be combined with solids feed 2 and processed in pre-treatment stage 3, and/or sent to a downstream neutralization step 6. In some non-limiting exemplary embodiments, iron (III)-rich solids may be procured from underflow of a thickener/clarifier, without limitation. In the particular embodiment shown in FIG. 7, the iron (III)-rich solids derived from pressure oxidation step 14 may contain hematite formed from complete oxidation of sulfides such as pyrite, without limitation.

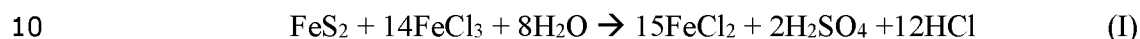
Iron (III) may be generated by the upstream pressure oxidation step 14. The iron (III) produced may be introduced to/combined with the solids feed 2 and processed in the stirred media reactor (SMRt) of the pre-treatment stage 3, without limitation. It should be understood that while not shown, in some embodiments, oxidants such as air, enriched air, pure oxygen (O_2), a mixture of sulfur dioxide and oxygen (SO_2/O_2), and/or hydrogen peroxide (H_2O_2) may be provided to the pressure oxidation device of the pressure oxidation step 14, without limitation. It should also be understood that while not shown, in some embodiments, oxidants such as air, enriched air, pure oxygen (O_2), a mixture of sulfur dioxide and oxygen (SO_2/O_2), and/or hydrogen peroxide (H_2O_2) may be employed to the stirred media reactor (SMRt) of the pre-treatment stage 3 and/or to the continuous stirred tank reactor (CSTR) in sulfide oxidation stage 4, without limitation.

Turning now to FIG. 8, a source of iron 17 or other catalyst may be introduced to a system and method for recovering precious metals 1, without limitation. The source of iron 17 may comprise natural iron ore, goethite, hematite, basic iron sulfate, iron hydroxide, or a combination thereof, without limitation. Turning now to FIGS. 9 and 10, a method for recovering precious metals is schematically depicted. It is envisaged that for some embodiments, steps may be performed out of chronological order, or in another order than what is depicted, without limitation. Steps may be combined in any combination/permutation, without limitation. Some embodiments of the method may comprise fewer steps than what is shown in FIGS. 9 and 10. Optional steps may be performed or not performed for certain

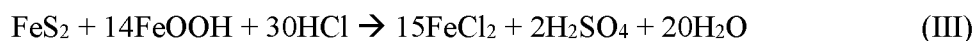
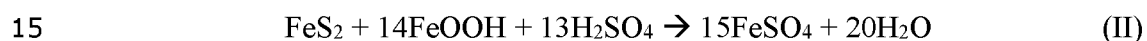
embodiments of the inventive method. Optional steps are expressed using dotted lines in FIGS. 9 and 10.

FIG. 11 is a schematic diagram, wherein regimes A and B illustrate the pH change accompanying sulfide oxidation using soluble FeCl_3 and a solid-state oxidant such as Fe_2O_3 , FeOOH , or a combination thereof, without limitation. The Fe_2O_3 and/or FeOOH may optionally be combined with Fe^{3+} , without limitation.

For example, without limitation, in regime A, the sulfide oxidation reaction may be dominated by reaction with FeCl_3 , for example, as in equation (I), below:



Within regime B, the sulfide oxidation reaction may be dominated by reaction with the solid-state oxidant, for example, as in equation (II) or (III), below:



Where used herein, the term “reactor” may comprise a continuous stirred tank reactor (CSTR) or stirred media reactor (SMRt), without limitation.

It should be known that the particular features, processes, and benefits which are shown and described herein in detail are purely exemplary in nature and should not limit the scope of the invention. Moreover, although the invention has been described in terms of particular embodiments and applications, one of ordinary skill in the art, in light of this teaching, can generate additional embodiments and modifications without departing from the spirit of or exceeding the scope of the claimed invention.

Accordingly, it is to be understood that the drawings and descriptions herein are proffered by way of example to facilitate comprehension of the invention and should not be construed to limit the scope thereof.

REFERENCE TO ENUMERATED ITEMS IN THE FIGURES

1. System and method for recovering precious metals
2. Solids feed (e.g., whole ore and/or metal sulfide concentrate comprising one or more
5 precious metal)
3. Pre-treatment stage
4. Sulfide oxidation stage (e.g., metal sulfide leach stage, oxidative leach reactor train)
5. Solid/liquid separation step
6. Neutralization step
- 10 7. Cyanidation/Precious metal leach step
8. Optional iron removal step
9. Optional solid/liquid separation step
10. Optional impurities removal step
11. Electrolysis step (e.g., $\text{NaCl} \rightarrow \text{NaOCl}$ conversion)
- 15 12. Ferric regeneration step
13. Solids feed (e.g., whole ore and/or metal sulfide concentrate comprising one or more
precious metal)
14. Pressure oxidation step (POx)
15. Solid/liquid separation step
- 20 16. Optional filtration step
17. Source of iron (e.g., natural iron ore, goethite, hematite, basic iron sulfate, iron hydroxide,
or a combination thereof)

25

30

CLAIMS

What is claimed is:

1. A method (1) for pre-treating whole ore and/or concentrate comprising a precious metal
5 for subsequent precious metal recovery, the method (1) comprising:

processing a solids feed (2) in a pre-treatment stage (3), the pre-treatment stage (3)
comprising stirred media reactor (SMRt) comprising media; the media comprising an inert
material which is not native to the solids feed (2) and which is at least ten times larger in size
than particles in the solids feed (2); the stirred media reactor producing a processed slurry;

10 processing the processed slurry in a sulfide oxidation stage (4) comprising at least one
continuous stirred tank reactor (CSTR, CSTR_l, CSTR_n) to form a twice-processed slurry;

performing a solid-liquid separation step (5) on the twice-processed slurry to form a
solids fraction and a liquids fraction;

recovering a precious metal from the solids fraction;

15 processing the liquids fraction in a ferric regeneration stage (12) to convert iron (II)
within the liquids fraction to iron (III); and

delivering the iron (III) produced via the ferric regeneration stage (12) to the pretreatment
stage (3) and/or to the sulfide oxidation stage (4).

20 2. The method (1) according to claim 1, wherein the sulfide oxidation stage (4) further
comprises at least one stirred media reactor (SMRt_l, SMRt_n) comprising media for producing
the twice-processed slurry via the sulfide oxidation stage (4); the media comprising an inert
material which is not native to the solids feed (2) and which is at least ten times larger in size
than the particles in the solids feed (2).

25 3. The method (1) according to any one of the preceding claims, wherein the step of
recovering a precious metal from the solids fraction comprises neutralizing (6) the solids
fraction and/or leaching (7) the solids fraction.

4. The method (1) according to any one of the preceding claims, wherein the liquids fraction comprises ferric ion; and wherein a concentration of ferric ion in the liquids fraction is higher after processing the liquids fraction in the ferric regeneration stage (12).

5. The method (1) according to any one of the preceding claims, wherein the liquids fraction comprises sulfate.

6. The method (1) according to any one of the preceding claims, wherein the liquids fraction comprises chloride derived from brine and/or sea water.

10

7. The method (1) according to any one of the preceding claims, wherein prior to being processed in the ferric regeneration stage (12), the liquids fraction is processed in a second stirred media reactor (SMR_{tm}) (8) in the presence of seed iron.

15. The method (1) according to claim 7, further comprising performing a solid-liquid separation on product processed by the second stirred media reactor (SMR_{tm}) (8), using a solid-liquid separation device (9).

20. The method (1) according to any one of the preceding claims, wherein processing the liquids fraction in ferric regeneration stage (12) to convert iron (II) within the liquids fraction to iron (III) comprises processing the liquids fraction by: adding oxidants to a continuous stirred tank reactor ($CSTR_2$), adding oxygen to a pressurized oxidation vessel, adding electricity to a direct electrolysis cell, or directly contacting a catalyst with the liquids fraction in a mass-transfer column.

25

10. The method (1) according to claim 9, wherein adding oxidants to a continuous stirred tank reactor ($CSTR_2$) comprises the steps of: producing NaOCl in an electrolysis cell (11) from NaCl derived from brine or sea water; and delivering the NaOCl to the continuous stirred tank reactor ($CSTR_2$).

30

11. A system (1) for pre-treating whole ore and/or concentrate comprising a precious metal for subsequent precious metal recovery, the system (1) comprising:

5 a pre-treatment stage (3) for processing a solids feed (2), the pre-treatment stage (3) comprising a stirred media reactor (SMRt) having media therein; the media comprising an inert material which is not native to the solids feed (2) and which is at least ten times larger in size than particles in the solids feed (2); the stirred media reactor (SMRt) being configured for producing a processed slurry;

10 a sulfide oxidation stage (4) for processing the processed slurry, the sulfide oxidation stage (4) comprising at least one continuous stirred tank reactor (CSTR, CSTR_i, CSTR_n) which is configured to produce a twice-processed slurry;

a solid-liquid separation device (5) provided downstream of the sulfide oxidation stage (4) and configured to perform a solid-liquid separation of the twice-processed slurry produced in the sulfide oxidation stage (4), and configured to form a solids fraction and a liquids fraction from the twice-processed slurry;

15 means for recovering a precious metal from the solids fraction of the solid-liquid separation device (5);

a ferric regeneration stage (12) comprising means for converting iron (II) within the liquids fraction of the solid-liquid separation device (5) to iron (III); and

20 means for delivering the iron (III) produced via the ferric regeneration stage (12) to the pretreatment stage (3) and/or to the sulfide oxidation stage (4).

12. The system (1) according to claim 11, wherein the sulfide oxidation stage (4) further comprises at least one stirred media reactor (SMRt_i, SMRt_n) comprising media for producing the twice-processed slurry via the sulfide oxidation stage (4); the media comprising an inert material which is not native to the solids feed (2) and which is at least ten times larger in size than the particles in the solids feed (2).

13. The system (1) according to claim 11 or 12, further comprising a neutralization stage (6) and a leaching stage (7) for leaching the solids fraction and recovering a precious metal therefrom.

14. The system (1) according to any one of claims 11-13, wherein the liquids fraction comprises ferric ion; and wherein a concentration of ferric ion in the liquids fraction is higher after processing the liquids fraction in the ferric regeneration stage (12).

5 15. The system (1) according to any one of claims 11-14, wherein the liquids fraction comprises sulfate.

16. The system (1) according to any one of claims 11-15, wherein the liquids fraction comprises chloride derived from brine and/or sea water.

10

17. The system (1) according to any one of claims 11-16, further comprising a second stirred media reactor (SMR_{tm}) (8) upstream of the ferric regeneration stage (12); wherein the liquids fraction is processed in the second stirred media reactor (SMR_{tm}) (8) in the presence of seed iron.

15

18. The system (1) according to claim 17, further comprising a solid-liquid separation device (9) for performing a solid-liquid separation on product processed by the second stirred media reactor (SMR_{tm}) (8).

20

19. The system (1) according to any one of claims 1-18, wherein the ferric regeneration stage (12) is configured to convert iron (II) within the liquids fraction to iron (III); and wherein the ferric regeneration stage (12) comprises: a continuous stirred tank reactor ($CSTR_2$) receiving an oxidant, a pressurized oxidation vessel receiving oxygen, a direct electrolysis cell powered by electricity, or a mass-transfer column for directly contacting a catalyst with the liquids

25

20. The system (1) according to claim 19, wherein the oxidant received by the continuous stirred tank reactor ($CSTR_2$) comprises NaOCl produced in an electrolysis cell (11) from NaCl derived from brine or sea water.

30

SULFATE SYSTEM

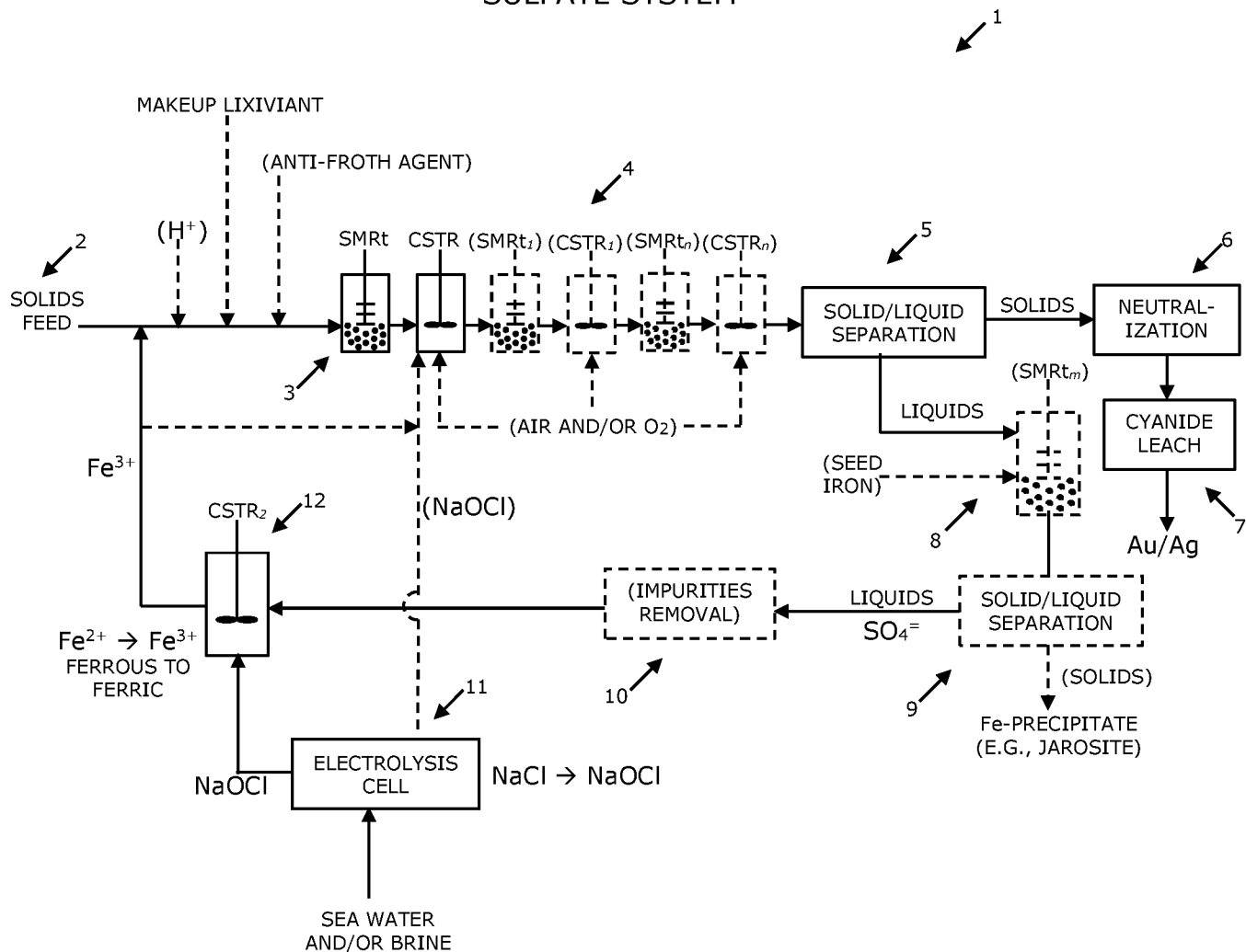


FIG. 1

CHLORIDE SYSTEM

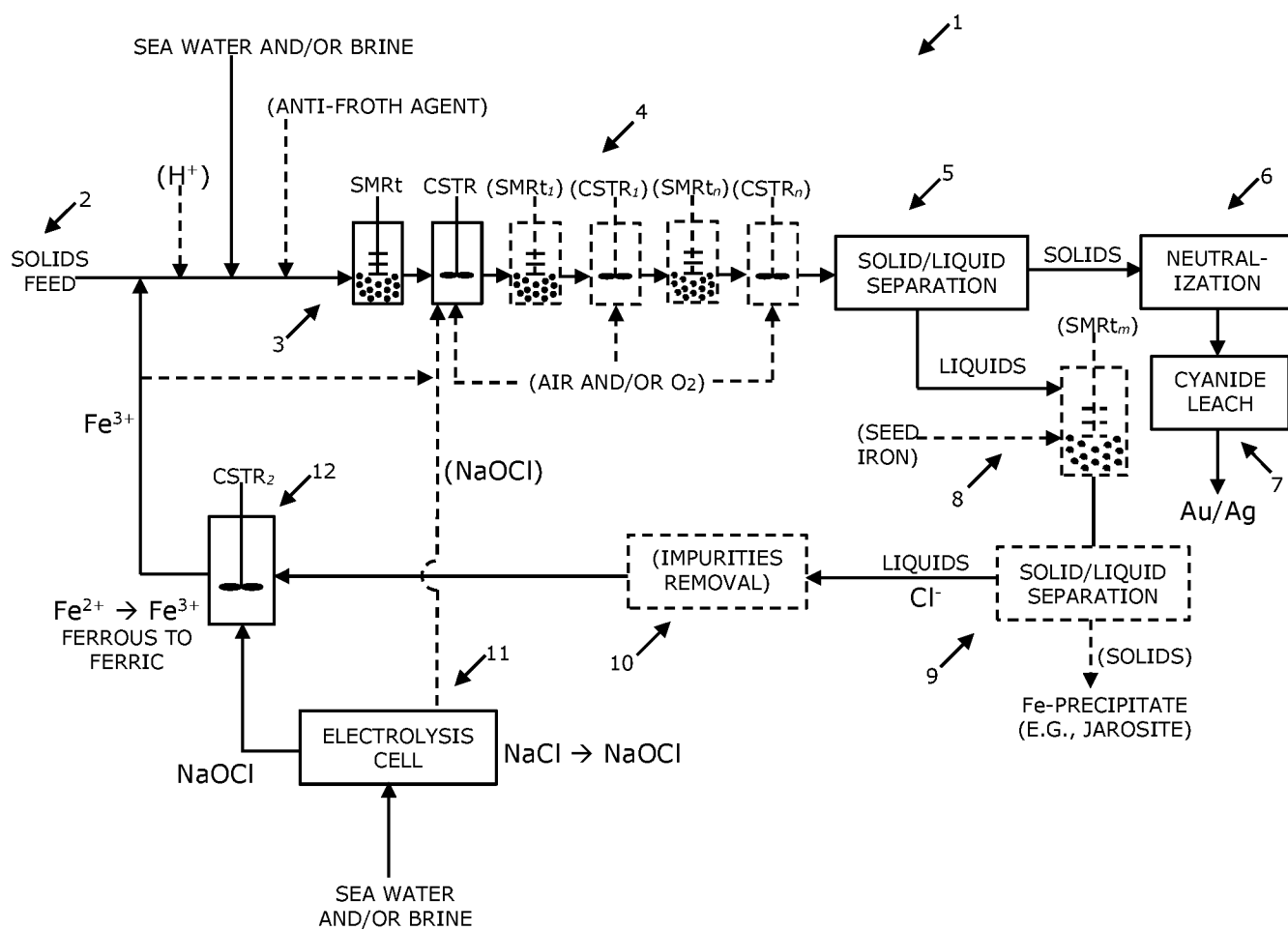


FIG. 2

MIXED CHLORIDE AND SULFATE SYSTEM

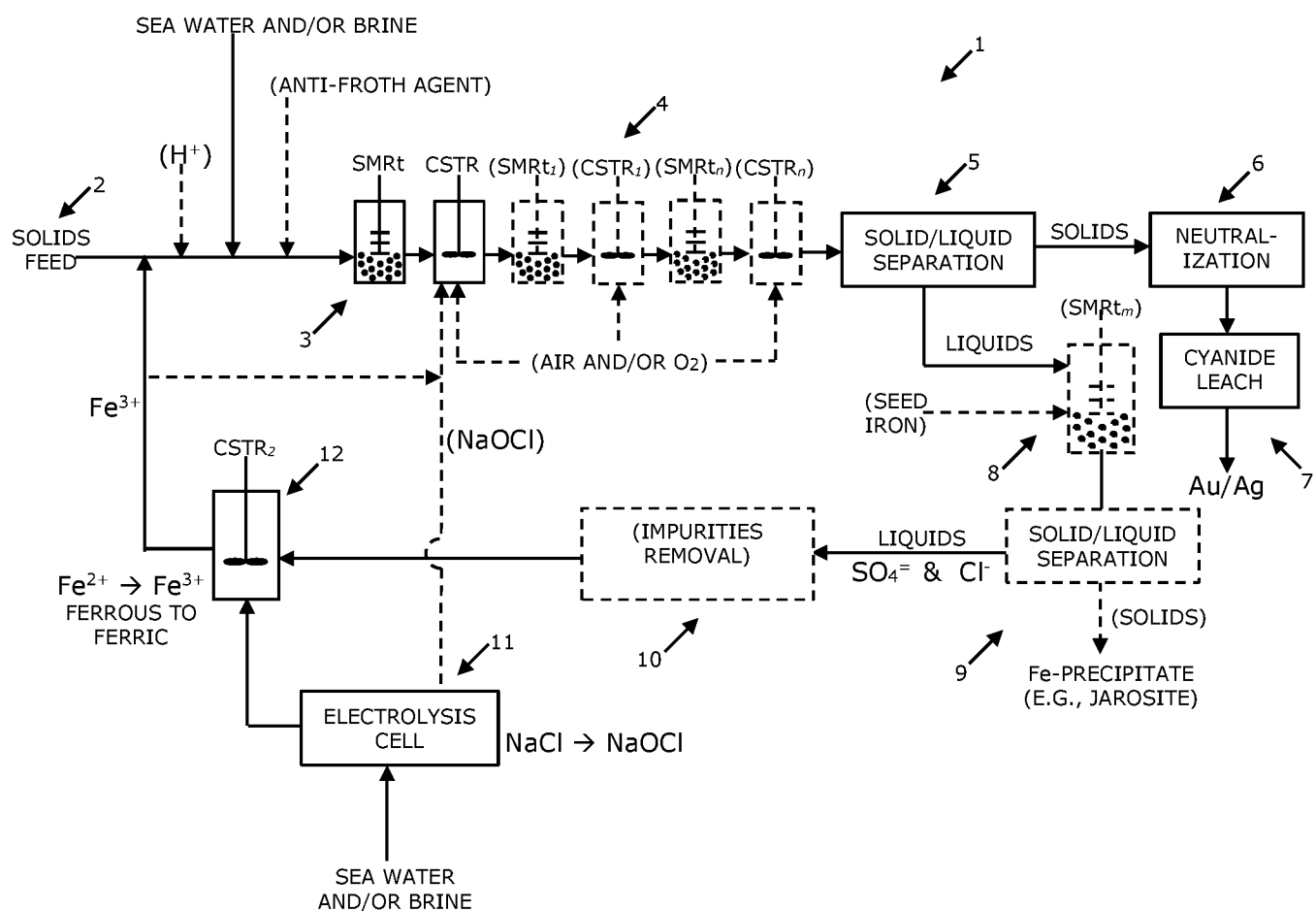


FIG. 3

SULFATE SYSTEM

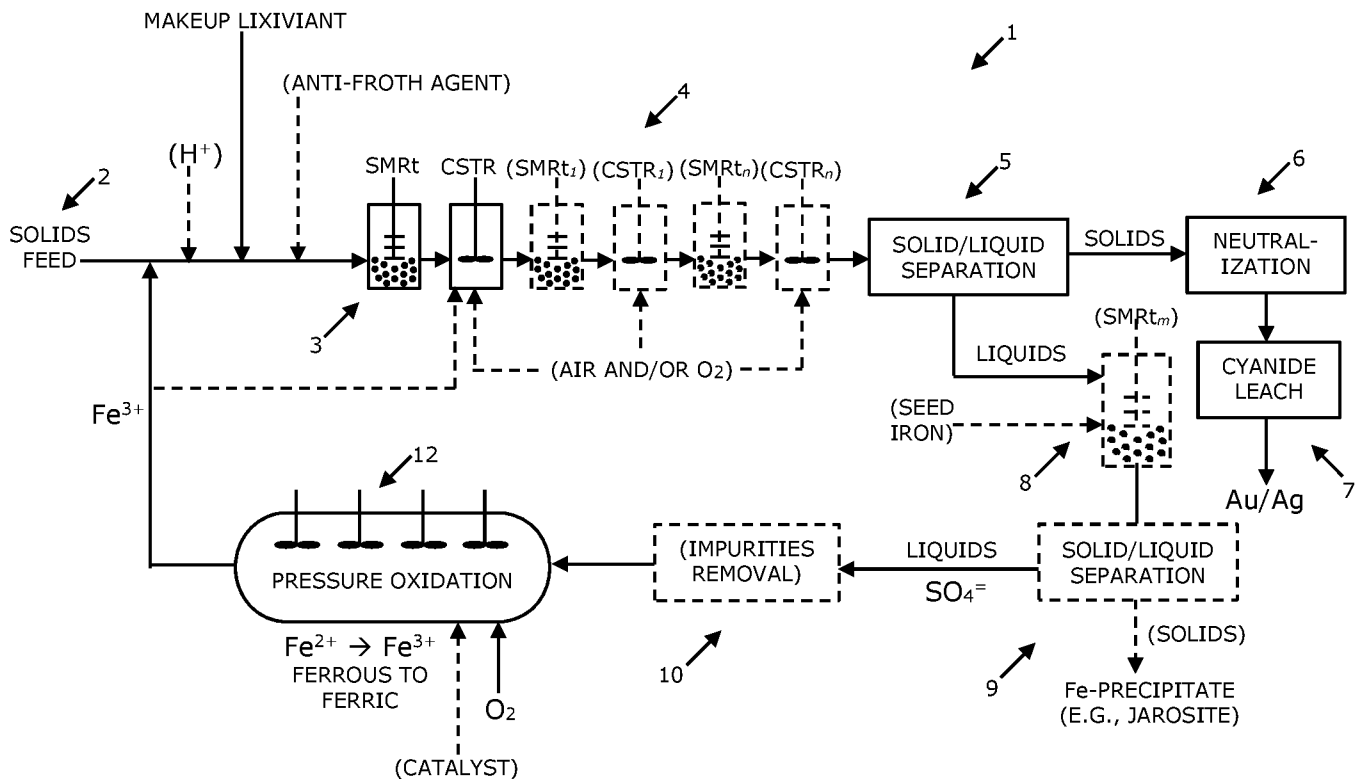


FIG. 4

CHLORIDE SYSTEM

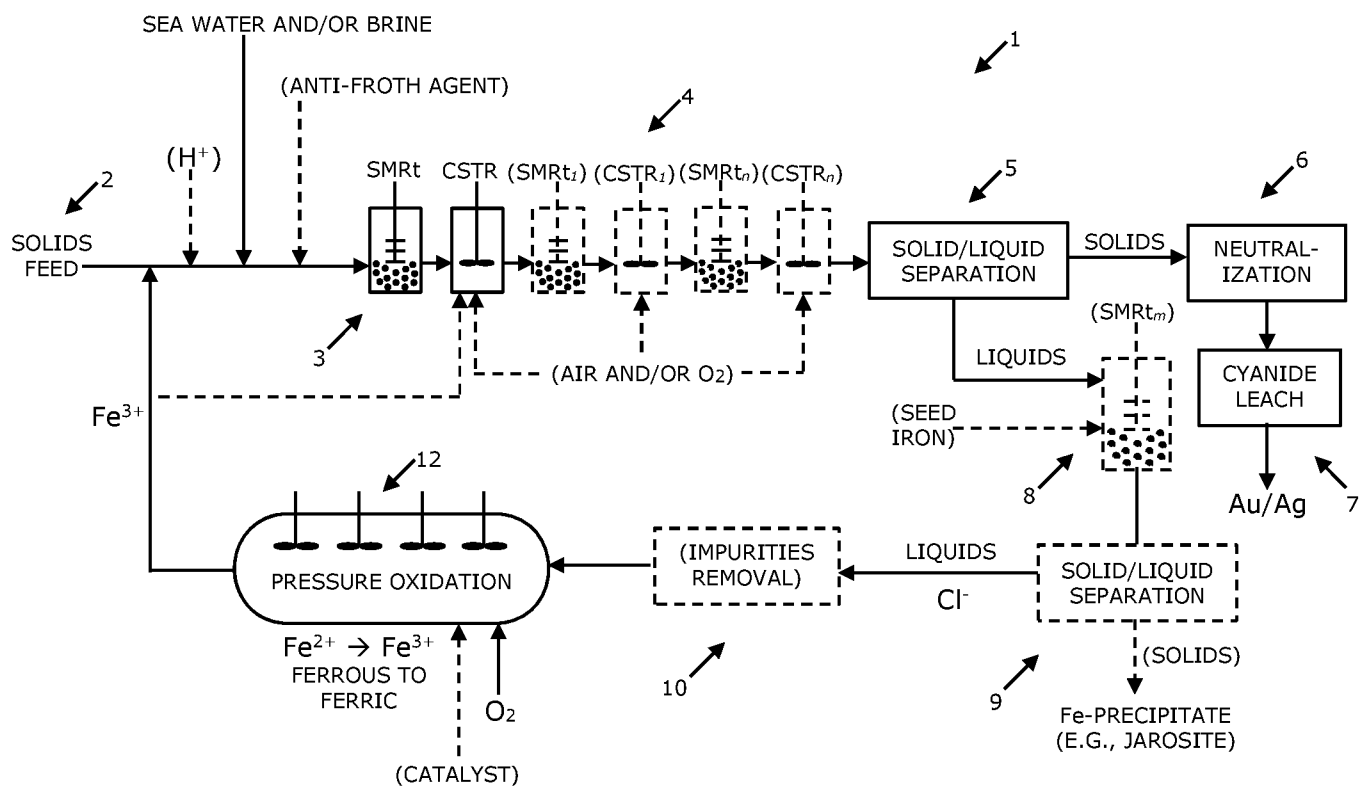


FIG. 5

MIXED CHLORIDE AND SULFATE SYSTEM

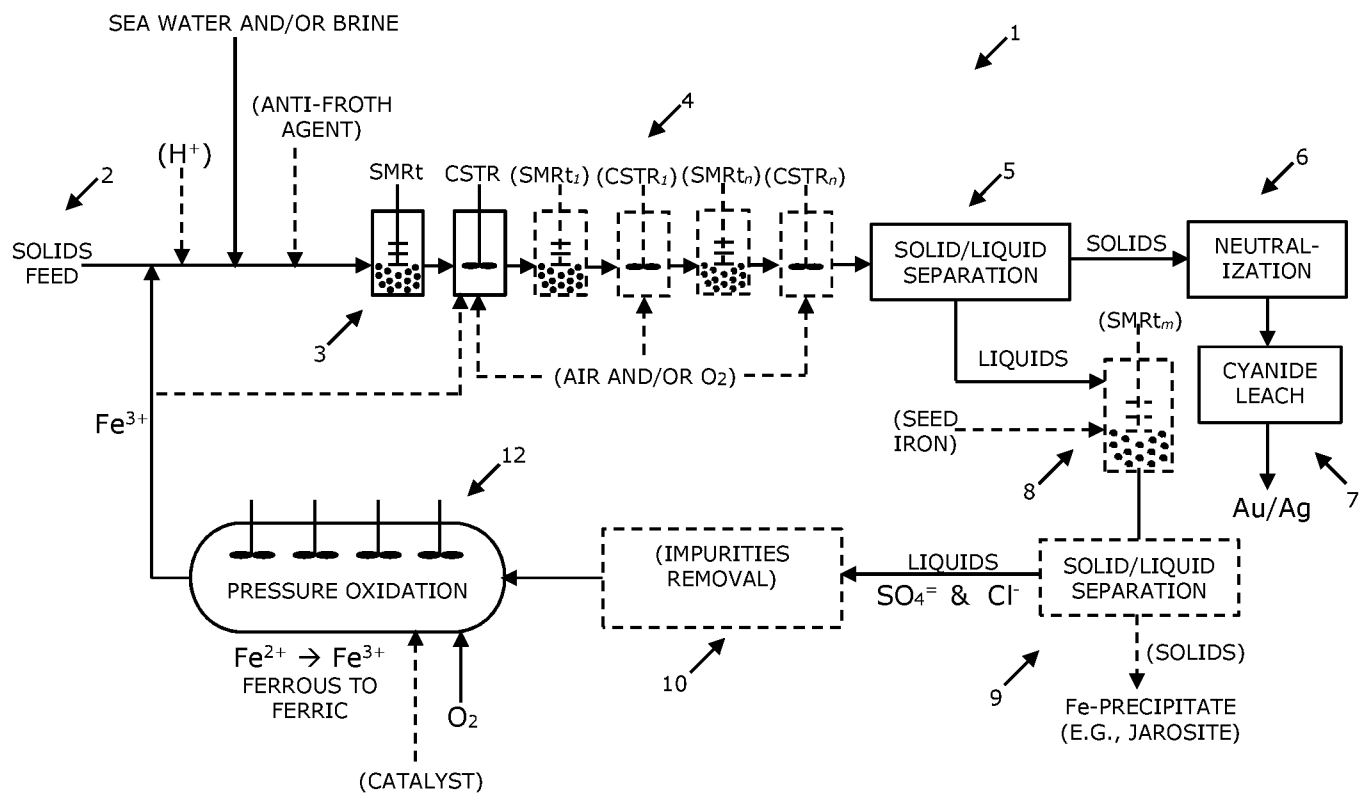


FIG. 6

ALTERNATIVE SYSTEM

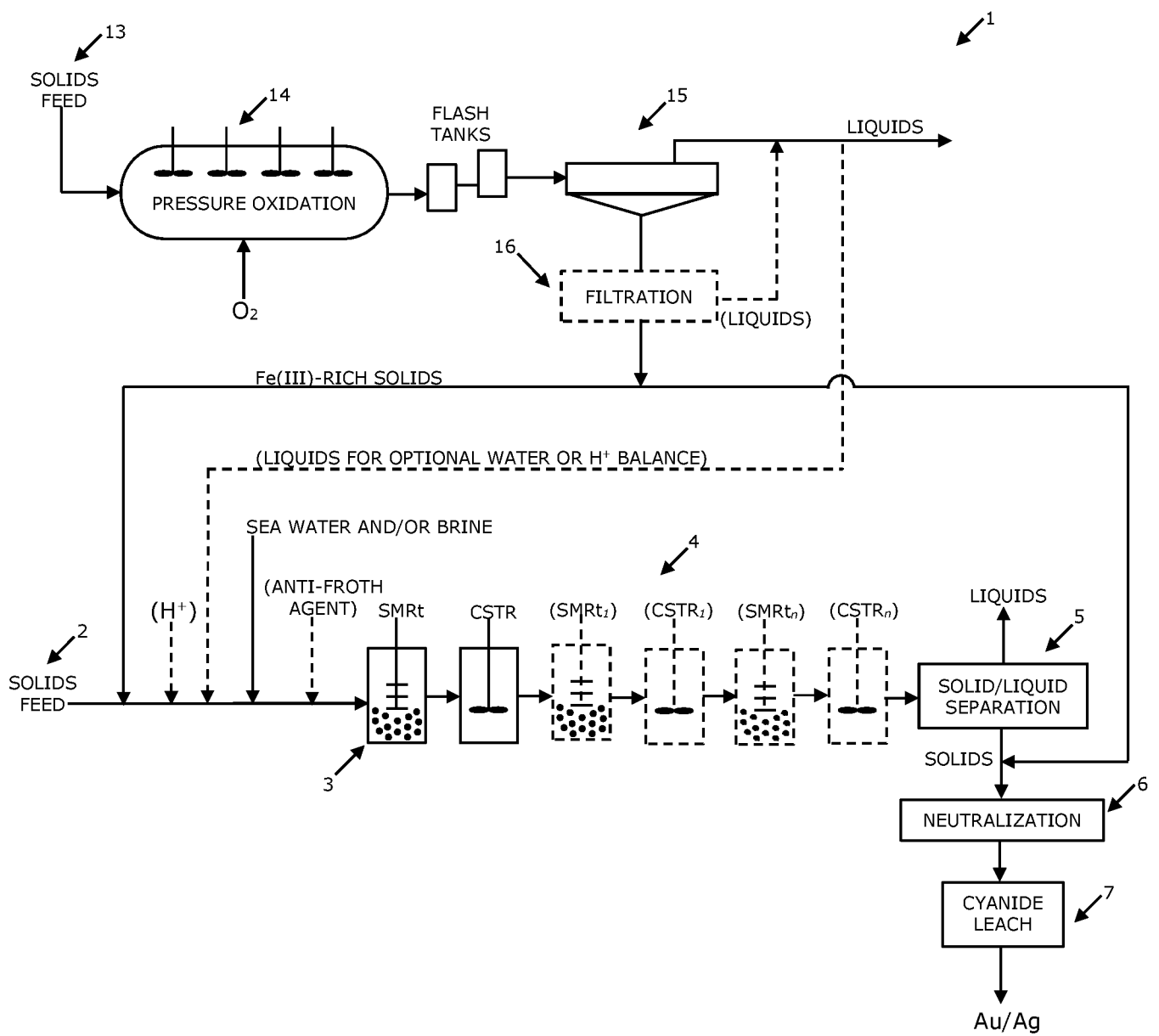


FIG. 7

ALTERNATIVE SYSTEM

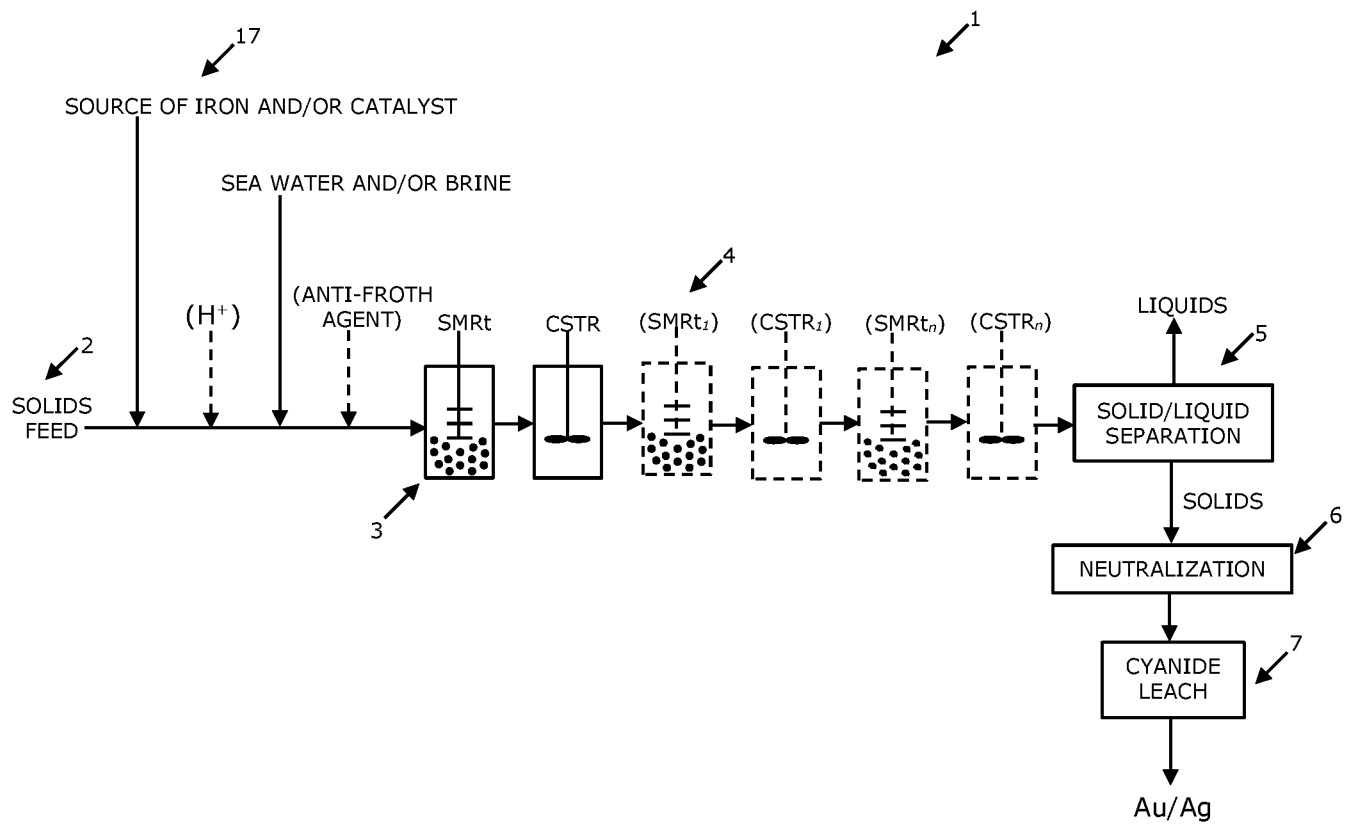


FIG. 8

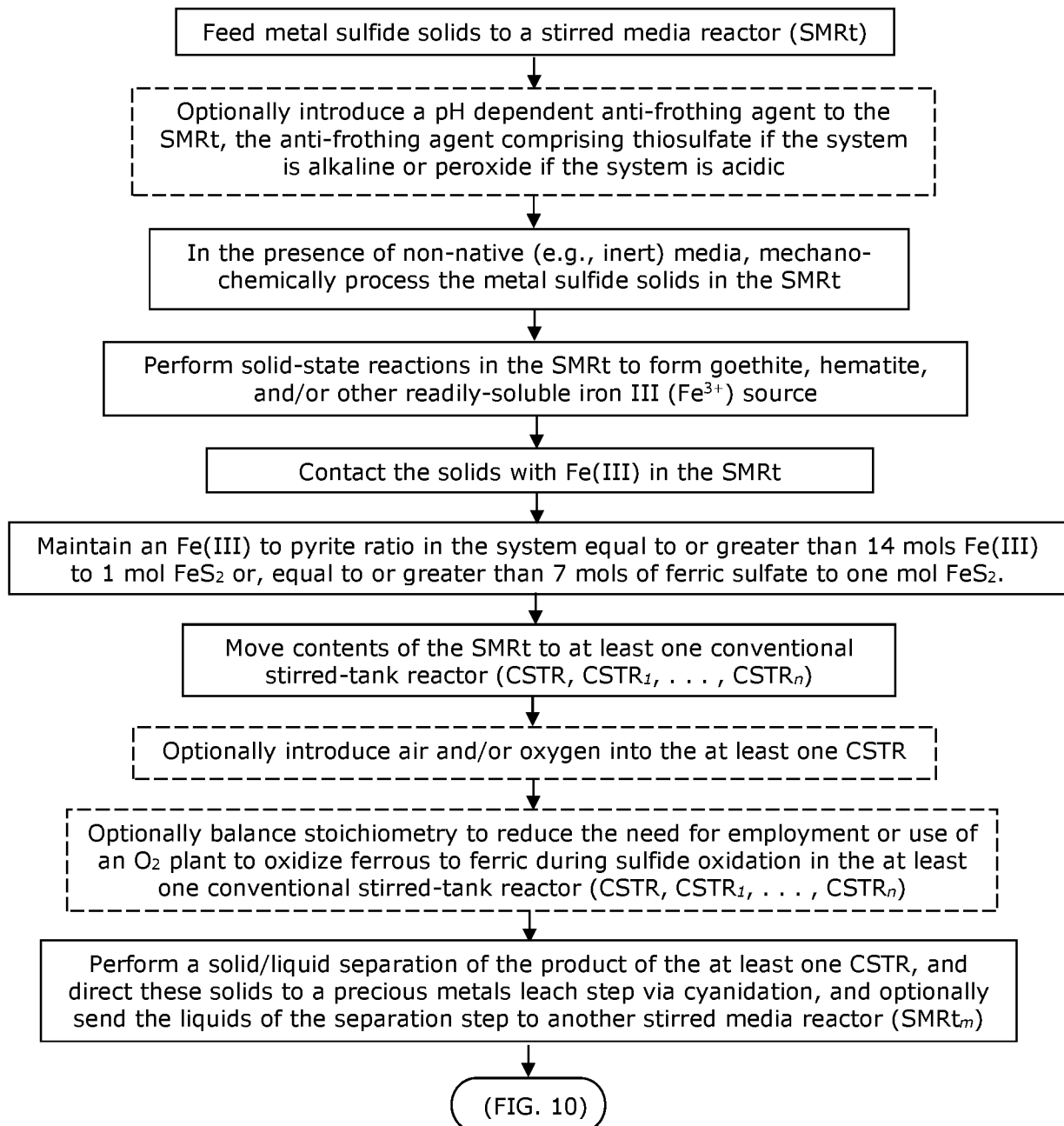


FIG. 9

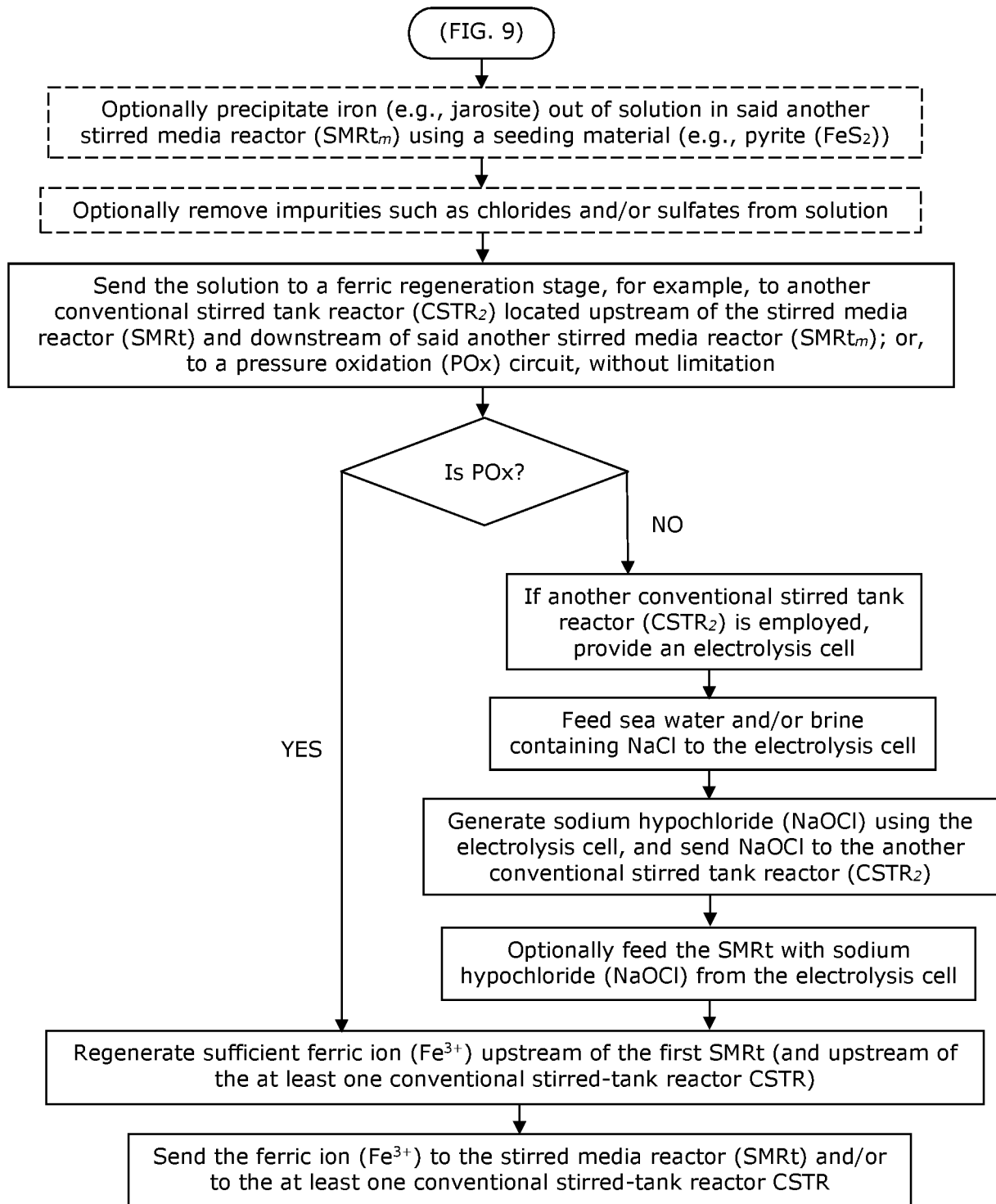


FIG. 10

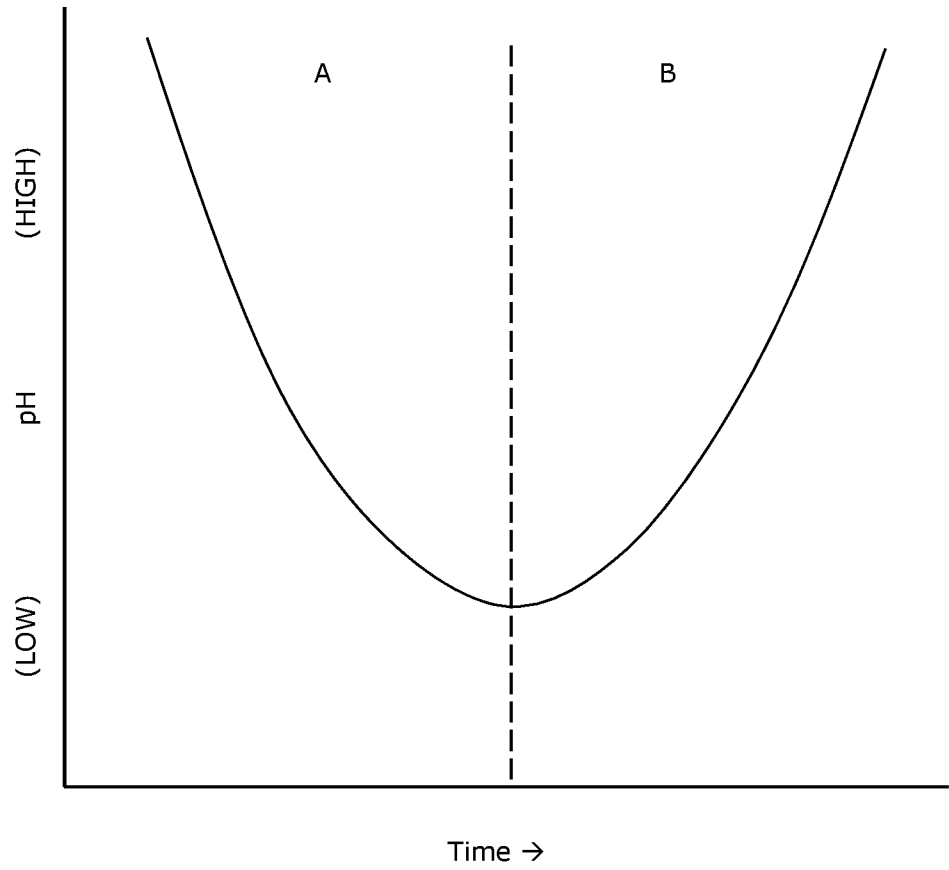


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2020/051218

A. CLASSIFICATION OF SUBJECT MATTER

INV. C22B1/11 C22B3/02 C22B3/08 C22B3/10 C22B3/22
C22B3/44 C22B11/08

ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22B

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

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

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013/001093 A1 (MARSDEN JOHN O [US] ET AL) 3 January 2013 (2013-01-03)	1-20
Y	paragraphs [0049] - [0083]; figures 2-6 -----	1-20
Y	US 2017/356063 A1 (CHAIKO DAVID J [US] ET AL) 14 December 2017 (2017-12-14) paragraphs [0049] - [0054]; figures 1,7,8; example 3 ----- -/-	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"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)

"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

"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

"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

"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

"&" document member of the same patent family

Date of the actual completion of the international search

29 April 2020

Date of mailing of the international search report

11/05/2020

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Panitz, J

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2020/051218

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	ROCHA DANIELLE ET AL: "Predicting the product particle size distribution from a laboratory vertical stirred mill", MINERALS ENGINEERING, ELSEVIER, AMSTERDAM, NL, vol. 129, 28 September 2018 (2018-09-28), pages 85-92, XP085509767, ISSN: 0892-6875, DOI: 10.1016/J.MINENG.2018.09.016 pages 85-89; figure 5 -----	1-20
A	US 5 007 589 A (EVANS DENNIS E [ZA] ET AL) 16 April 1991 (1991-04-16) column 3, line 37 - column 5, line 16; figures 1,2 -----	1-20

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2020/051218

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2013001093 A1	03-01-2013	AU 2009206007 A1 BR PI0906929 A2 CA 2712274 A1 CL 2009000103 A1 EP 2245200 A1 PE 20091541 A1 US 2009183997 A1 US 2013001093 A1 WO 2009092023 A1	23-07-2009 21-07-2015 23-07-2009 21-08-2009 03-11-2010 27-09-2009 23-07-2009 03-01-2013 23-07-2009
US 2017356063 A1	14-12-2017	AU 2015349677 B2 AU 2015349747 B2 AU 2017221773 A1 AU 2017221775 A1 CA 2968245 A1 CA 2968256 A1 CL 2017001285 A1 CL 2017001286 A1 CN 107106942 A CN 107109521 A MX 365127 B PE 20170798 A1 PE 20170836 A1 US 2017356063 A1 WO 2016081799 A1 WO 2016081908 A1 ZA 201703302 B	15-06-2017 15-06-2017 21-09-2017 21-09-2017 26-05-2016 26-05-2016 15-12-2017 15-12-2017 29-08-2017 29-08-2017 24-05-2019 04-07-2017 04-07-2017 14-12-2017 26-05-2016 26-05-2016 18-12-2019
US 5007589 A	16-04-1991	AU 608301 B2 BR 8801384 A US 5007589 A	28-03-1991 01-11-1988 16-04-1991