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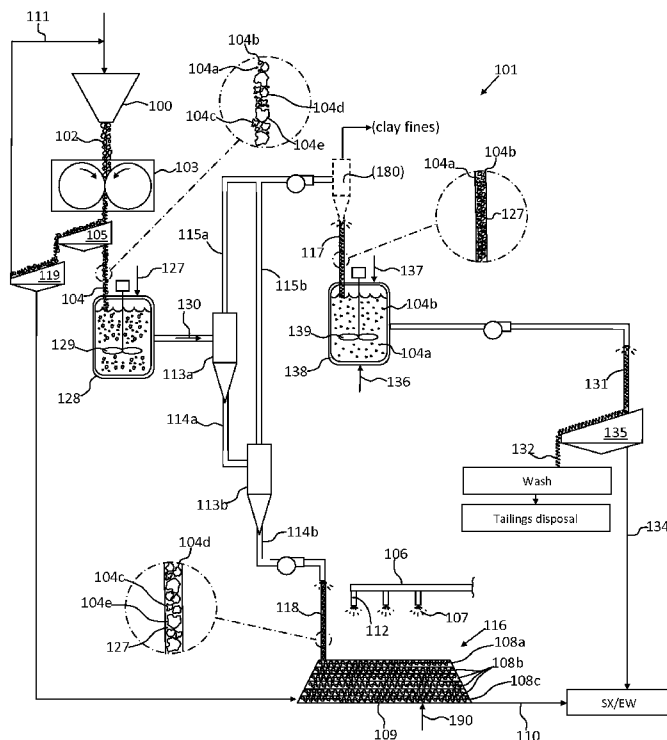
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(54) Title: SYSTEMS AND PROCESSES FOR THE ENHANCED LEACHING OF ORES THROUGH PARTICLE SIZE SE-
GREGATION(57) Abstract: A hydrometallurgy circuit for the recovery of
a metal is disclosed. The circuit may comprise a crushing or
grinding device configured to pulverize feed ore and produce
crushed ore; a first separator configured to separate the
crushed ore into a fines stream and a coarse stream; a first
metallurgical extraction process for producing a first pre-
gnant leach solution from said fines stream; and, a second me-
tallurgical extraction process configured for producing a
second pregnant leach solution from said coarse stream.



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SYSTEMS AND PROCESSES FOR THE ENHANCED LEACHING OF ORES THROUGH PARTICLE SIZE SEGREGATION

CROSS-REFERENCE TO RELATED APPLICATIONS

This is an international PCT application claiming priority to United States Provisional Patent Application Serial No. 61/736,196 filed on 12 December 2012.

FIELD OF THE INVENTION

This invention relates to methods and systems for leaching metals from metal sulfide ores and concentrates, and more particularly to methods and systems for the improved recovery of base and precious metals during leaching of metal values from ores and concentrates.

BACKGROUND OF THE INVENTION

Chalcopyrite (CuFeS_2) is the primary copper-containing mineral found in the majority of the copper sulfide ores of commercial interest. Other copper-containing ore minerals of commercial interest include chalcocite (Cu_2S), bornite (Cu_5FeS_4), covellite (CuS), digenite (Cu_2S), enargite (Cu_3AsS_4), tennantite ($\text{Cu}_{12}\text{As}_4\text{S}_{13}$), and tetrahedrite ($\text{Cu}_{12}\text{Sb}_4\text{S}_{13}$). Copper sulfide ores, aside from containing a variety of copper-containing minerals, will also contain a wide variety of gangue minerals including, but not limited to, silicates, pyrite (FeS_2) and pyrrhotite (FeS).

Low grade gold ores may include, for example, Calaverite, Sylanite, Nagyagite, Petzite, Krennerite, and other alluvial or oxide-type deposits. Most refractory gold ores are generally processed with a pre-oxidation step, for example, a roasting, a bio-oxidation, or a pressure oxidation step, since they are naturally resistant to recovery by standard cyanidation and carbon adsorption. The pre-oxidation step may help improve recoveries from subsequent cyanidation.

A first refractory component of gold ore generally relates to the liberation properties of gold, for instance, whether the gold in solution is encapsulated in sulfides (e.g., pyrite), or is in the sulfide crystal lattice. A second refractory component of gold ore generally relates to its *preg-robbing* characteristics, wherein carbonaceous matter in the ore adsorbs gold in solution and/or gold-cyanide complexes during leaching. Thiosulfate leaching has been proven to be somewhat effective on ores with high soluble copper values and ores which experience *preg-robbing*.

Conventional hydrometallurgical processing of sulfide ores, refractory gold ores, and sulfidic/carbonaceous double refractory gold ores for metals recovery has to date, utilized a single path circuit 1 as shown in FIGS. 1 and 2. Turning to FIG. 1, a conventional heap leach circuit generally incorporates a feed stream 2 of ore, which is crushed via a cone-crusher 3 forming a crushed ore 4. The crushed ore 4 comprises particles having various particle size distributions 4a-e. The particles are moved via first conveying means 5 to an agglomerator 13. There, a polymeric binder 15 is added. The agglomerator 13 lumps the various particle size distributions 4a-e within the crushed ore 4 into larger agglomerated balls 19 which are typically coin-sized. The agglomerated balls 19 are moved (via secondary conveying means 17) as agglomerated feed 14 to a heap leach pad 16 having an impermeable pad liner 9 thereunder. Leach solution 7, (e.g., sulfuric acid, lixiviant, cyanide solution, thiosulfate, or bioleach solution) is delivered via a delivery system 6 comprising drip/spray irrigation nozzles 12. As the leach solution 7 trickles through top 8a, middle 8b, and bottom 8c layers of the heap leach pad 16, it passes between the spaces and interstices created by the larger stacked agglomerated balls 19. During this percolation, target metals dissolve into the leach solution 7 thereby forming a pregnant leach solution 10, which may be recycled to the nozzles 12 or removed for further downstream processing. In the instance shown, pregnant leach solution 10 from the heap 16 is moved to a conventional solvent extraction process.

There are many problems associated with agglomerated heap leach pads 16. For example, the agglomerated balls 19 are very fragile and tend to crumble over time as the binder 15 degrades, thereby decreasing porosities within the pad 16. Additional problems include damming, leachate ponding, leach solution evaporation, erosion, bench overtopping, bench seepage, partial leaching, base pooling, impeded leaching, undesired channeling of leach solution 7, precipitation of pregnant leach solution, short-circuiting, non-uniform percolation throughout the heap leach pad, recovery losses, and increased residence times. Heavy equipment used on the leach pad 16 such as bulldozers, cranes, trucks, overland conveyors, stackers, reclaimers, and trippers may further contribute to the aforementioned problems, as they can over-compress the pad 16 and further compromise arrangements of gently-stacked agglomerates 19. Agglomerates 19 also become moist and soft causing the heap 16 to settle, thereby reducing permeability and generating channeling of the lixiviant which leads to reduced metal recovery.

Turning now to FIG. 2, fine-grinding circuits 21 are also conventionally used for metal recovery. Slurried feed ore 22 is finely ground in a fine grinding mill 23, such as a stirred media detritor, or attrition mill. The slurried fine ore 24 that exits the mill 23 has a relatively uniform first particle size distribution 24a. In other words, most of the particulate being discharged from the mill 23 is very fine – generally much finer than the particulate 4a-e that could be expected from a cone crusher 3. The slurried fine ore 24 is mixed with leach solution and aerated with oxygen gas or air 26 in a stirred reactor/agitated leach vessel 28. A rotor 29, which may comprise an axial or radial impeller, stirs the mixture and helps accelerate mass transfer and reduce residence time. Pregnant slurry 30 leaves the stirred reactor 28 and may be separated and further processed in a typical downstream solvent extraction circuit as shown.

Advantages of fine grinding circuits 21 include a much quicker leach time than possible with conventional heap leach pad circuits 1. In fact, leach times for stirred reactor circuits (FIG.

2) may be smaller than those for heap leaching (FIG. 1) by nearly a factor of ten. For example, full mass transfer may be able to take place in a stirred reactor 28 within just a few weeks time, whereas it could take more than 2 years of percolation to completely extract most of the target metals from a heap leach pad 16. Moreover, higher recoveries can be achieved sooner using a smaller footprint using fine grinding mills 23 stirred reactors 28 (it may be months before a leach pad is constructed and ready for leaching, and this delays returns on capital investment).

However, fine grinding circuits 21 can be cost prohibitive since they require a significant amount of power to grind all of the unearthed ore to the very small particle sizes necessary for tank leaching (less than about 100-200 μm). Such circuits 21 generally require 100% of the unearthed ore to be ground to the required fineness/mean particle size distribution for leaching to work.

Thus, there is a need for more efficient approaches to initiating and maintaining high dissolution rates and recoveries during leaching of minerals.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of a conventional heap leach operation;

FIG. 2 is a schematic diagram of a conventional fine grinding operation;

FIGS. 3-11 show various embodiments of metal recovery circuits, wherein different leaching operations are utilized according to particle size(s) of crushed ore;

FIG. 12 shows an extrusion reactor which may be advantageously utilized within circuits according to some embodiments;

FIG. 13 shows a counter-current leach column reactor which may be advantageously utilized within certain circuits according to some embodiments;

FIG. 14 shows an air-lift agitator reactor which may be advantageously utilized as a reactor vessel in certain circuits according to some embodiments;

FIG. 15 shows a slurry storage tank which may be advantageously utilized as a reaction vessel in accordance with certain embodiments;

FIG. 16 shows a device for applying plastic masses which may be advantageously be repurposed as a reaction vessel in circuits according to some embodiments;

FIG. 17 shows a modified flotation cell which may be advantageously utilized as a reactor vessel in some instances;

FIG. 18 shows one or more Pachuca tanks, which may be advantageously utilized as a reactor vessel(s) in circuits according to other embodiments;

FIG. 19 shows an educator jet of a pressurized pipe reactor which may be advantageously utilized as a reaction vessel in some of the circuits described;

FIG. 20 shows a bubble column reactor which may be also be utilized as a reactor vessel; and,

FIG. 21 shows a fluidized bed reactor which may be provided to circuits according to various embodiments.

SUMMARY OF THE INVENTION

A hydrometallurgy circuit for the recovery of a metal is disclosed. The circuit may comprise a crushing or grinding device configured to pulverize feed ore and produce crushed

ore; a first separator configured to separate the crushed ore into a fines stream and a coarse stream; a first metallurgical extraction process for producing a first pregnant leach solution from said fines stream; and, a second metallurgical extraction process configured for producing a second pregnant leach solution from said coarse stream. In some embodiments, the first metallurgical extraction process may comprise or use at least one of: a stirred reactor/agitated leach tank, a Pachuca tank, an autoclave, a pressure reactor (e.g., an eductor jet portion of a pressurized pipe reactor), a modified flotation cell, a counter-current leach column, a reactive extruder, and a modified thickener/clarifier (e.g., a deep-cone paste thickener). In some embodiments, the second metallurgical extraction process comprises at least one of: a heap leach pad or pad liner, a modified thickener/clarifier, an oxidation ditch, a slurry storage mechanism, a modified forced air or self-induced gas/self-aspirating flotation cell, a bubble column reactor, a fluidized bed reactor, an air lift agitator, a stirred reactor/agitated leach tank, and a Pachuca tank.

Leach solution and/or a first catalyst or reagent used may be added to a stirred reactor of the first metallurgical extraction process in order to produce the first pregnant leach solution. The first catalyst or reagent added to the stirred reactor may comprise at least one of a protein, an enzyme, a Fenton's reagent, a microbial, a quorum-sensing agent, crushed pyrite, peroxide, liquid oxygen, or compressed air. In some embodiments, the second metallurgical extraction process may comprise a heap leach pad which is composed of at least one top layer and at least one bottom layer, wherein the at least one top layer has a first mean particle size distribution which is different than a third mean particle size distribution of the at least one bottom layer. The first mean particle size distribution may be smaller than the third mean particle size distribution so as to provide a simple mean particle size distribution gradient within the heap leach pad. Regions of the heap leach pad which are adjacent the first mean particle size distribution may be treated or processed differently than areas of the heap leach pad which are

adjacent the third mean particle size distribution. For example, regions of the heap leach pad which are adjacent the first mean particle size distribution may be treated with different *concentrations* of leach solution than areas of the heap leach pad which are adjacent the third mean particle size distribution. Moreover, regions of the heap leach pad which are adjacent the first mean particle size distribution may be treated with different *amounts* or *flow rates* of leach solution than areas of the heap leach pad which are adjacent the third mean particle size distribution. Additionally, in regions of the heap leach pad which are adjacent to the first mean particle size distribution, a different *type* of leach solution may be used than what is used in areas of the heap leach pad which are adjacent the third mean particle size distribution. Moreover, regions of the heap leach pad which are adjacent the first mean particle size distribution may be treated with a different type(s) of *additive(s)* than areas of the heap leach pad which are adjacent the third mean particle size distribution. Lastly, regions of the heap leach pad which are adjacent the first mean particle size distribution may be treated with a different *amount(s) of additive* than areas of the heap leach pad which are adjacent the third mean particle size distribution. \

If a heap leach pad is used in the hydrometallurgy circuit, it may further comprise one or more middle layers having a second mean particle size distribution, which is different than both the first mean particle size distribution and the third mean particle size distribution. In this manner, a complex mean particle size distribution gradient may be provided within the heap leach pad. In some embodiments, the second mean particle size distribution may lie in between the first mean particle size distribution and the third mean particle size distribution. In some embodiments, the second metallurgical extraction process may comprise at least one of: a sterilization device and a device capable of emitting low radio waves at various frequencies and/or various powers. In yet further embodiments, the fines stream used in the first metallurgical extraction process may be less than approximately 200 μm and the coarse stream used in the first metallurgical extraction process may be greater than approximately 100 μm . In

some embodiments, the metal recovered may comprise a base metal such as copper, or it may involve the recovery of a precious metal such as gold. In some embodiments, a fine or ultra-fine grinding mill configured to reduce mean particle size distributions within an already fine slurry stream may be provided in order to produce an ultra-fine slurry.

A method of leaching is also disclosed. The method comprises providing a hydrometallurgy circuit equipped with a crushing or grinding device configured to pulverize feed ore and produce crushed ore; providing at least one separator configured to separate the crushed ore into a fines stream and a coarse stream; feeding the fines stream to a first metallurgical extraction process for producing a first pregnant leach solution; and, feeding the coarse stream to a second metallurgical extraction process for producing a second pregnant leach solution.

DETAILED DESCRIPTION OF THE INVENTION

A separation step is performed sometime after grinding and either before, or during leaching. The separation segregates crushed ore according to mean particle size distribution. Fines are separated from a stream of coarse crushed ore, and may be processed differently from said coarse crushed ore. In this manner, leaching is performed most efficiently, using apparatus and methods which are most applicable to a particular particle size distribution.

According to a first non-limiting embodiment shown in FIG. 3, a copper concentrating circuit 101 comprises a feed hopper 100 which receives sized feed ore 102. The sized feed ore 102 may come directly from a mine pit, from an upstream gyratory crusher, and/or from a cone crusher (all not shown). The sized feed ore 102 passes through a high pressure grinding roller 103 or equivalent crusher/pulverizer. A high pressure grinding roller (HPGR) is preferred due to

its ability to produce large networks of micro-fissures within the ground ore particulate. The micro-fissures are generally caused by significant pressures. They advantageously create small paths for leaching solution to pass and absorb target metals from deep within the ground ore particle. Crushed ore leaving the grinding roller 103 may be sized by a fourth separator 105 (such as a screen), and its underflow 104 may be sent to a mixer 128. The overflow from the fourth separator 105 may enter a fifth separator 119 (e.g., another screen), wherein its underflow may be diverted to a heap leach pad 116. In a particular non-limiting embodiment, said underflow from the fifth separator 119 may enter one or more bottom 108c and/or middle 108c layers of the heap leach pad 116 as will be suggested by the embodiment shown in FIG. 4 and hereinafter described. Overflow of the fifth separator 119 may be considered too big for efficient leaching, and may therefore be directed to a regrind circuit 111 as shown.

The crushed ore 104 leaving the fourth separator 105 may comprise various particles of differing diameter size distributions ranging from fine to coarse (i.e., relative mesh). For example, in some embodiments, the crushed ore 104 may comprise an ultra-fine first particle size distribution 104a, a fine second particle size distribution 104b, an intermediately-sized third particle size distribution 104c, a coarse fourth particle size distribution 104d, and a very coarse fifth particle size distribution 104e. One or more of the particle size distributions 104a-e may comprise micro-fractures (not shown) formed by the grinding nature of the roller 103. In certain preferred embodiments, all of the crushed ore 104 may be slurried in an acid solution 127 immediately after grinding and separating step, in order to begin the leaching process very early on in the circuit 101. Slurrying may be done via a mixer 128 having a rotor 129 therein for stirring. Thereafter, conveyance of the slurried ground ore 130 may be accomplished using one or more slurry pumps. After slurrying, leaching may occur at all times within the circuit 101 (including slurry transport).

A first separator 113a such as a hydrocyclone may be utilized to make a first rough cut of the slurried ground ore 130. The separator 113a may separate groups of finer particles (e.g., size distributions 104a and 104b) from coarser particles (e.g., size distributions 104c, 104d, and 104e). Underflow slurry 114a from the first separator may be sent to a second separator 113b in order to further separate trapped fines from the coarser particles 104c, 104d, 104e, and to provide robustness and redundancy to the circuit 101. It is envisaged that more or less separators 113a, 113b may be utilized for this separation process than is shown - either in parallel or in series. It is also envisaged that other mechanisms such as static or dynamic screens, sieves, grizzlies, vibration tables, cross-flow systems, reflux classifiers, gravity or counter-current classifiers, inertial classifiers, or centrifuges (including spiral classifiers, peripheral slit-type Walther classifiers, mechanical (forced vortex) rotor systems, and screw extractor-type Alpine-Mikroplex classifiers) may be used in combination with or in lieu of the shown hydrocyclones for purposes of particle separation and classification.

Overflow slurry 115a, 115b from the first 113a and/or second 113b separator(s) may contain a majority of particles which are less than approximately 100-200 microns in average diameter. Underflow slurry 114a, 114b from the first 113a and/or second 113b separator(s) may contain a majority of particles which are greater than approximately 100-200 microns. Of course, it should be understood that any cut size may be chosen to best compliment unique characteristics and advantages of a particular leaching circuit 101 with a specific type of feed ore 102. Overflow slurry 115a, 115b may be further separated by an optional fine clay removal hydrocyclone 180 or equivalent means, in order to remove colloidal clay before subsequent leaching. Fine slurry 117, formed by first and/or second separator overflow slurry components 115a, 115b may be pumped, dumped, or otherwise conveyed into a stirred reactor/agitated leach tank 138 suitable to leach target metals such as copper or gold from the fine slurry 117. The leach tank 138 may comprise a rotor 139 for better dissolution rates. Additional amounts, higher

concentrations of, or different types of leach solution 137 (e.g., sulfuric acid, lixiviant, sodium cyanide solution, thiosulfate, and/or bioleach solution) may be added to the tank 138 along with one or more optional oxidizing reagents 136 in order to further kick start the leaching process. In some non-limiting embodiments, oxidizing reagents 136 may comprise, for example, liquid oxygen, peroxide, Fenton's reagent, one or more amino acid sequences/peptides/proteins, oxidative enzymes/enzymatic compositions, microbial cultures, compressed air, finely-crushed pyrite, and/or combinations thereof. After the fine particles 104a, 104b have endured a predetermined residence time within the stirred reactor/agitated leach tank 138, they are discharged in the form of a pregnant fine slurry 131 which engages a third separation device 135 such as a screen. Overflow solids 132 from the third separation device 135 may be sent to a wash/filter step to recover pregnant leach solution 134 residues before being sent out for disposal as tailings. First pregnant leach solution 134 collected from the underflow slurry of the third separation device 135 may be sent to a conventional downstream SX/EW circuit or other conventional recovery process.

The underflow slurry 114a, 114b from the first 113a and second 113b separation devices may be conveyed as coarse slurry 118 and sent to a heap leach pad 116 for heap leaching. Since the coarse slurry already comprises an acid solution carrier 127 at this point from the earlier step of slurring in vessel 128, the leaching of suspended coarse particle size distributions 104c, 104d, 104e therein are "kick started" well *before* the heap leach pad 116 is completely constructed, and *during* heap construction itself. This "kick start" in leaching may ultimately lead to sooner investment returns. Wet-stacking may be done using a telescoping arm having a flexible hose and slurry pump, or by way of other suitable conveying means known in the art. The telescoping arm (not shown) may fill a tank or a pit lined with an impermeable pad liner 109 much in the same way as concrete is poured for foundation slabs and multi-level floors during commercial building construction. Once the lined tank or pit is full of what appears to be layers

108a-c of wet slurry, additional amounts, higher concentrations of, or different types of leach solution 107 (e.g., sulfuric acid (H_2SO_4), lixiviant, sodium cyanide solution, thiosulfate, lead nitrate, and/or bioleach solution) may be further dispensed throughout the slurry 118 via a leach solution delivery system 106 having drip/spray irrigation nozzles 112.

In use, the leach solution 107 may percolate through one or more top 108a, middle 108b, and bottom 108c layers of coarser ore particles 104a, 104b, 104c, thereby generating a second pregnant leach solution 110. During percolation, one or more catalysts or reagents 190 (e.g., air, liquid oxygen, peroxide, Fenton's reagent, microbials, quorum-sensing agents, and/or oxidative enzymatic compositions) may be selectively added to portions of or the entire heap leach pad 116 in order to further promote surface reactions and assist the dissolution and recovery of the metallic fractions. The large nature of the coarse crushed ore particles 104c, 104d, 104e sent to the heap leach pad 116 also promotes larger interstices therebetween, obviating the need for agglomeration practices. These larger interstices allow a more uniform, unrestricted flow of leach solution 117 and catalysts/reagents 190 through the pad 116 and overcome the aforementioned problems with clogging, channeling, pooling, etc.

According to a second non-limiting embodiment shown in FIG. 4, a copper concentrating circuit 201 comprises a feed hopper 200 which receives sized feed ore 202. The feed ore 202 passes through a high pressure grinding roller 203 or equivalent crusher/pulverizer, and becomes crushed ore 204 having various particle size distributions therein. For example, in some embodiments, the crushed ore 204 may comprise an ultra-fine first particle size distribution 204a, a fine second particle size distribution 204b, an intermediately-sized third particle size distribution 204c, a coarse fourth particle size distribution 204d, and a very coarse fifth particle size distribution 204e. One or more of the particle size distributions 204a-e may comprise micro fractures (not shown) due to the high grinding forces in the roller 203. The crushed ore 204 may be sized by a first separator 213a (such as a dry screen). The underflow slurry 217a of the first

separator 213a (which might comprise one or more smaller mean particle size distributions 204a 204b), may be sent to a stirred reactor/agitated leach tank 238 having a rotor 239 as shown. An amount of leach solution or reagent 237 (e.g., sulfuric acid, lixiviant, sodium cyanide solution, thiosulfate, and/or bioleach solution) may be added to the tank 238 along with one or more optional catalysts 236 in order to further “kick start” the leaching process. In some non-limiting embodiments, optional catalysts 236 may include liquid oxygen, peroxide, Fenton’s reagent, finely-crushed pyrite, oxidative enzymes, compressed air, microbes, and/or combinations thereof.

In certain preferred embodiments, all of the finely crushed ore 217a leaving the first separator 213a can be slurried with the leaching solution 237 immediately after grinding and separating, in order to begin the leaching process very early on in the process 201. Thereafter, conveyance of the pregnant fine slurry 231 may be accomplished using one or more slurry pumps or gravity means. The pregnant fine slurry 231 may undergo further solid-liquid separation by a fourth separator 235, wherein spent fines 232 flowing over the separation device 135, may be sent to a wash/filter step in order to recover residual pregnant leach solution 234. Thereafter, the spent fines 232 may be sent out for disposal as tailings. First pregnant leach solution 234 collected from the underflow of the fourth separation device 235 may be sent to a conventional downstream SX/EW circuit or other conventional recovery process.

The first separator 213a may separate groups of finer particle densities (e.g., size distributions 204a and 204b), containing a majority of particles which are less than approximately 100-200 microns in diameter) from coarser particles (e.g., size distributions 204c, 204d, and 204e). As previously indicated, it is envisaged that more or less separators 213a, 213b, 213c may be utilized for this separation process -- either in parallel or in series, and that

other mechanisms such as cyclones may be used in lieu of screens for purposes of particle separation and classification.

Overflow slurry 218a from the first 213a separator(s) may contain a majority of particles having diameters greater than approximately 100-200 microns. Of course, it should be understood that any cut size may be chosen to best compliment the unique characteristics of a particular leaching circuit 201. The overflow slurry 218a from the first separator 213a may subsequently enter a second separator 213b (e.g., another screen), wherein its underflow slurry 217b may be diverted to a heap leach pad 216 via first conveying means 205a. In a particular non-limiting embodiment said underflow slurry 217b from the second separator 213b may enter one or more upper 208a or first end layers of the heap leach pad 216. Overflow slurry 218b of the second separator 213b may be diverted to a third separator 213c (e.g., yet another screen), wherein its underflow 217c may be diverted to the heap leach pad 216 via second conveying means 205b. In a particular non-limiting embodiment said underflow 217c from the third separator 213c may enter one or more middle 208b or central layers of the heap leach pad 216. Overflow slurry 218c of the third separator 213c may be diverted to the heap leach pad 216 via third conveying means 205c. In a particular non-limiting embodiment said overflow slurry 218c from the third separator 213c may enter one or more bottom 208c or opposite end layers of the heap leach pad 216. It should be understood that alternative arrangements may be practiced without departing from the scope. For instance, the inclined slope angle of the heap leach pad 216 and flow direction 270 shown could effectively be reversed, such that overflow slurry 218 of the second separator 213b immediately enters the one or more bottom 208c or opposite end layers.

Each of the layers 208a, 208b, 208c in the heap leach pad 216 may be provided with a single leach solution delivery system, or may be provided with its own leach delivery system as shown. For example, the one or more upper/first end layers 208a may comprise a first leach

solution delivery system 206a delivering a first leach solution 207a at a first amount, a first rate, and/or at a first concentration. The one or more middle/central layers 208b may comprise a second leach solution delivery system 206b delivering a second leach solution 207b at a second amount, a second flow rate, and/or at a second concentration. The one or more bottom/opposite end layers 208c may comprise a first leach solution delivery system 206c delivering a third leach solution 207c at a third amount, a third rate, and/or at a third concentration. Leach solutions 207a, 207b, 207c may comprise different compositions, different quantities, or different concentrations of sulfuric acid, lixiviant, sodium cyanide solution, thiosulfate, and/or bioleach solution. Moreover, leach solutions 207a, 207b, 207c may comprise different additives or catalysts 240, 250, 260, which may be applied to each layer 208a, 208b, 208c at different rates or concentrations. It is within the scope of this invention that the aforementioned parameters may change over time without limitation.

In use, the leach solution 207a, 207b, 207c may percolate through one or more top 208a, middle 208b, and bottom 208c layers of coarse ore particles 204a, 204b, 204c, thereby generating a second pregnant leach solution 210. During percolation, one or more catalysts, reagents, or additives 240, 250, 260 (e.g., air, liquid oxygen, peroxide, Fenton's reagent, crushed pyrite, microbial populations, or oxidative enzymatic compositions) may be continuously or intermittently added to various portions of the heap leach pad 216 in order to promote surface reactions and/or strategically adjust the leach kinetics throughout the heap 216 over time. The heap 216 may comprise a graded structure of various sorts (e.g., average particle size, material composition) and may be situated on an incline configured for producing a gravity flow 270. An impermeable pad liner 209 provided under the heap leach pad 216 catches and diverts the second pregnant solution 210 for transport to a downstream to a conventional SX/EW circuit or other system requiring a pregnant leach solution feed. In other words, the heap 216 may comprise a plurality of sections – wherein each section is individually composed of crushed ore having a

similar mean particle size distribution 204c, 204d, 204e (or other shared attribute), and wherein the mean particle size distribution (or shared attribute) may differ between sections . In some instances, the heap 216 may be inclined for gravity flow, wherein an upper layer 208a is elevated with respect to, a middle layer 208b, and/or a lower 208c layer. As shown, the upper layer 208a may comprise a more densely-packed or smaller mean particle size distribution 204c than other portions of the heap. While less preferred, an opposite arrangement is possible, where smaller/finer particles 204c are located at a bottom section(s) 208c of the heap 216, and larger/coarser particles 204e are located at an upper section(s) 208a of the heap 216. Leach solution 207a may be applied at the upper section 208a at a lower rate than for a lower section 208c to compensate for the higher surface area and greater potential for pooling.

According to a third non-limiting embodiment shown in FIG. 5, a copper concentrating circuit 301 comprises a feed hopper 300 which receives sized feed ore 302. The sized feed ore 302 may come directly from a mine pit, or from an upstream gyratory/cone crusher (not shown). The feed ore 302 passes through a high pressure grinding roller 303 or equivalent crusher/pulverizer. The crushed ore 304 leaving the grinding roller 303 may comprise various particle size distributions ranging from fine to coarse. For example, in some embodiments, the crushed ore 304 may comprise two or more of an ultra-fine first particle size distribution 304a, a fine second particle size distribution 304b, an intermediately-sized third particle size distribution 304c, a coarse fourth particle size distribution 304d, or a very coarse fifth particle size distribution 304e. Some or all of the particle size distributions 304a-e may comprise micro fractures created by virtue of grinding stresses. As suggested in the embodiment shown in FIG. 3, all of the crushed ore 304 may be slurried in a (e.g., acidic) slurring solution 327 immediately after grinding and separating, in order to begin the leaching process very early on in the flowsheet 301. Slurring may be done via a mixer 328 having a rotor 329 therein for stirring and

maintaining the particles in suspension. Thereafter, conveyance of the slurried ground ore 330 may be accomplished using one or more slurry pumps (shown, not labeled).

A first separator 313, such as a hydrocyclone, may be utilized to make a first rough cut of the slurried ground ore 330. The separator 313 separates finer particles (e.g., size distributions 304a and 304b) from coarser particles (e.g., size distributions 304c, 304d, and 304e). While not shown, underflow 314 from the first separator 313 may be sent to one or more second separators in order to further separate trapped fines from the coarser particles 304c, 304d, 304e. As previously discussed, it is envisaged that other mechanisms such as screens or centrifuges may be used in lieu of hydrocyclones, for purposes of particle separation and classification.

In some embodiments, overflow slurry 315 from the first 313 separator may contain a majority of particles which are less than approximately 100-200 microns, and underflow 314 from the first 313 separator may contain a majority of particles which are greater than approximately 100-200 microns. Of course, it should be understood that any cut size can be chosen in order to best compliment the unique characteristics of a particular leaching circuit 301 and ore composition. Overflow slurry 315 may be further separated by an optional fines removal means 380 (e.g., hydrocyclone), in order to remove colloidal clays before subsequent leaching. Fine slurry 317, comprised of first separator overflow slurry component 315 may be pumped, dumped, or otherwise conveyed into a stirred reactor/agitated leach tank 338 suitable to leach target metals such as copper or gold from the fine slurry 317. The leach tank 338 may comprise a rotor 339 for better dissolution rates. Additional amounts, higher concentrations of, or different types of leach solution 337 (e.g., sulfuric acid, lixiviant, sodium cyanide solution, thiosulfate, and/or bioleach solution) may be added to the tank 338 along with one or more optional first catalyst/oxidizing reagents 336 in order to further “kick start” the leaching process. In some non-limiting embodiments, first catalyst/oxidizing reagents 336 may comprise liquid

oxygen, peroxide, Fenton's reagent, oxidative enzyme, compressed air, microbes, finely crushed pyrite, quorum-sensing agents, and/or various combinations thereof. After the fine particles 304a, 304b have endured a predetermined residence time within the stirred reactor/agitated leach tank 338, they are discharged in the form of pregnant fine slurry 331, which subsequently encounters a second separation device 335 such as a screen. Spent fines 332 overflow the second separation device 335 and may be sent to a wash/filter step to recover residues of pregnant leach solution 334 before being sent out for disposal as tailings. First pregnant leach solution 334 collected from the underflow slurry of the second separation device 335 may be sent to a conventional downstream SX/EW circuit or other conventional recovery process.

Underflow slurry 314 from the first 313 separation device may be conveyed as coarse slurry 316 and sent to a modified thickener/clarifier 374 for leaching. For example, said modified thickener/clarifier 374 may comprise a modified EIMCO® Deep-Cone™ paste thickener, a modified Dorr-Oliver® Paste Production Storage Mechanism (PPSM), or a rakeless E-Cat® ultra-high rate clarifier and thickener. Since the coarse slurry 316 already comprises an acid solution carrier 327, the leaching process for suspended coarse particle size distributions 304c, 304d, 304e therein is "kick started" even *before* the coarse slurry 316 enters the modified thickener/clarifier 374. This kick start may ultimately lead to sooner returns on investment. Rather than wet-stacking in a heap leach arrangement shown in FIG. 4, the coarse particle size distributions 304c, 304d, 304e may be stirred in the modified thickener/clarifier 374 by a rake 375 driven by a robust drive and gearing system (it is anticipated by the inventors that rakeless technologies, though not shown, may be employed). The contents of the modified thickener/clarifier may comprise upwards of 80-98 percent solids, and more preferably above 90 percent solids -- for example, 95 percent solids. The modified thickener/clarifier 374 may comprise a reflective cover 376, which could be configured to make the modified thickener/clarifier 374 hold a pressure above atmospheric pressure (e.g., between 1 and 10 bar,

for example, approximately 1.5 bar). The modified thickener/clarifier 374 may further comprise one or more radio wave or microwave generators 360 which emit radio waves or microwaves 362 in order to extract a number of inorganic and organic analytes from particles 304c-d in the coarse slurry 316, and/or induce redox reactions (e.g., ionic transmissions between membranes). In some non-limiting embodiments radio waves may be amplified in intensity by one or more large amplifiers 363. In some embodiments, waves 362 may comprise ultrasonic waves. In some embodiments the rake 375 may serve as an antenna or radio wave transmitter. Reflected waves 366 may bounce off of various internal portions of the modified thickener/clarifier 374 further vibrating the particles 304a-c in the presence of an added second catalyst 390. For example, reflected radio waves 366 may bounce off the reflective cover 376, metallic reflective coatings provided on portions of the rake 375, and/or prepared surfaces on side or bottom inner wall portions of the modified thickener/clarifier 374. The second catalyst 390 may comprise additional leach solution 337 (e.g., sulfuric acid, lixiviant, sodium cyanide solution, thiosulfate, and/or bioleach solution), or other additive (e.g., leaching microbes and/or quorum-sensing agents). The modified thickener/clarifier 374 may comprise a number of spargers - including spargers 370 disposed on the rake 375, spargers 372 disposed on the sidewalls of the modified thickener/clarifier 374, and/or spargers 373 disposed on bottom portions of the modified thickener/clarifier 374. The spargers 370, 372, 373 may be configured to deliver a single or a combination of oxidizing reagents including, but not limited to, compressed air, oxygen gas, liquid oxygen, peroxide, Fenton's reagent, or oxidative enzymatic compositions in solution. One or more optional sterilization devices 382, such as UV flashers, sections of antimicrobial pipe, and/or gamma irradiators, may be placed upstream and/or downstream of the modified thickener/clarifier 374 in parallel or series in order to reduce the possible external spreading of or invasion of foreign bacteria into the modified thickener/clarifier 374, thereby maintaining proper microbial consortia/enzymatic compositions for bioleaching. Advantages to leaching with the

modified thickener/clarifier 374 over conventional heap leach pads 16 include preserving the solid/liquid ratio, enabling the leached particles to be stirred for better wetting, and allowing more oxygen to be delivered to all portions of the leached particles.

Pregnant coarse slurry 387 leaving the modified thickener/clarifier 374 passes over a third separator 335 such as a hydrocyclone, centrifuge, or screen (as shown). The underflow or liquid fraction from the third separator comprises a second pregnant solution 310 which may be directed via pump to a conventional downstream SX/EW circuit. The third separator overflow solids fraction 388 may be washed to recover residual second pregnant solution 310 before final conveyance to a tailings pond.

According to a fourth non-limiting embodiment shown in FIG. 6, a copper concentrator circuit 401 comprises a feed hopper 400 which receives sized feed ore 402. The sized feed ore 402 may come directly from a mine pit, or from an upstream gyratory and/or cone crusher (not shown). The feed ore 402 passes through a high pressure grinding roller 403 or equivalent crusher/pulverizer. The crushed ore 404 leaving the grinding roller 403 may comprise various particle size distributions ranging from fine to coarse. In some instances, the crushed ore 404 may comprise an ultra-fine first particle size distribution 404a, a fine second particle size distribution 404b, an intermediately-sized third particle size distribution 404c, a coarse fourth particle size distribution 404d, and a very coarse fifth particle size distribution 404e. One or more of the particle size distributions 404a-e may comprise micro fractures (not shown) formed therein due to the grinding forces experienced within the roller 403. Some or all of the crushed ore 404 may be slurried in a slurring solution 427 (e.g., acidic) immediately after grinding and separating, in order to begin the leaching process very early on in the circuit 401. Slurring of the crushed ore 404 may be done via a mixer 428 having a rotor 429 therein for stirring. Thereafter, conveyance of the slurried ground ore 430 may be accomplished using one or more slurry pumps.

A first separator 413, such as a hydrocyclone, may be utilized to make a first rough cut of the slurried ground ore 430. The separator 413 may separate groups of finer particles (e.g., size distributions 404a and 404b) from groups of coarser particles (e.g., size distributions 404c, 404d, and 404e). While not shown, the underflow 414 from the first separator may be sent to one or more second separators in order to further separate trapped fines within the separated coarser particles 404c, 404d, 404e. It is envisaged that other mechanisms such as screens or centrifuges may be used in lieu of hydrocyclones, for purposes of particle separation and classification as previously discussed herein.

Overflow slurry 415 from the first 413 separator may contain a majority of particles which have diameters less than approximately 100-200 microns. Underflow slurry 414 from the first 413 separator may contain a majority of particles having diameters greater than approximately 100-200 microns. Of course, it should be understood that any cut size may be chosen to best compliment the unique characteristics of a particular leaching circuit 401. Overflow slurry 415 may be further separated by an optional fines removal hydrocyclone 480 or equivalent means, in order to remove suspended colloidal clays prior to subsequent leaching processes. Fine slurry 417, formed by first separator overflow slurry component 415 may be pumped or otherwise conveyed or dumped into a stirred reactor/agitated leach tank 438 suitable to leach target metals such as copper or gold from the fine slurry 417. The leach tank 438 may comprise one or more rotors 439 and/or baffles for better dissolution rates and improved fluid mechanics. Additional amounts, higher concentrations of, or different types of leach solution 437 (e.g., sulfuric acid, lixiviant, sodium cyanide solution, thiosulfate, and/or bioleach solution) may be added to the tank 438 along with one or more optional first catalyst/oxidizing reagents 436 in order to further “kick start” the leaching process. In some non-limiting embodiments, first catalyst/oxidizing reagents 436 may comprise liquid oxygen, peroxide, Fenton’s reagent, oxidative enzyme, air, microbes, and/or combinations thereof. After the fine particles 404a,

404b have endured a predetermined residence time within the stirred reactor/agitated leach tank 438, they are discharged in the form of pregnant fine slurry 431 which then engages a second separation device 435 such as a screen. Spent fine solids 432 overflow the second separation device 435 and may be sent to a wash/filter step to recover residues of pregnant leach solution 434 before being sent out for disposal as tailings. First pregnant leach solution 434 collected from the underflow slurry of the second separation device 435 may be sent to a conventional downstream SX/EW circuit or other conventional recovery process.

Underflow slurry 414 from the first 413 separation device may be conveyed as coarse slurry 416 and sent to an oxidation ditch 474 for leaching. The oxidation ditch may comprise one or more aerators or rotating biological contactors 475 in order to increase the dissolved oxygen within the coarse slurry 416, as well as increase surface areas, and create waves, currents, turbulence, or other movement within portions of the oxidation ditch. Residence time of slurry 416 within the ditch 474 may be controlled by adjusting the inlet and outlet flow rates or using a series of gates or weirs which open and close periodically in batch form.

Oxidation ditches are typically used in the treatment of wastewater as replacements to the aeration basin and arguably provide better sludge treatment. As schematically shown in FIG. 6, they normally comprise circular or oval basins through which the wastewater flows. Activated sludge is added to the oxidation ditch so that microorganisms will digest the biochemical oxygen demand (B.O.D.) in the water. This mixture of raw wastewater and returned sludge is known as mixed liquor.

Turning back to FIG. 6, one or more second catalysts/reagents may be added to the coarse slurry 416 within the oxidation ditch 474. The one or more second catalysts may include, for instance, air, oxygen gas, liquid oxygen, peroxide, microbials, quorum-sensing agents, and/or one or more oxidative enzymatic compositions in solution. The addition of the one or more second catalysts may be done with peripheral or centralized nozzles, spargers, aeration pumps, or

other conventional means known in the art. In some instances, delivery mechanisms for the second catalysts may be provided on picket fences (not shown) which are distributed throughout portions of the ditch 474 along flow paths.

Since the coarse slurry 416 already comprises an acid solution carrier 427, the leaching process for the suspended coarse particle size distributions 404c, 404d, 404e therein is “kick started” even *before* the coarse slurry 416 enters the oxidation ditch 474. This kick start may ultimately lead to sooner investment returns when compared to typical leaching processes 1 (where the construction of the heap leach pad 16 must be completed before leaching can begin). Rather than wet-stacking in the heap leach arrangement shown in FIG. 4, the coarse particle size distributions 404c, 404d, 404e may be fluidized within the small-footprint oxidation ditch 474 for a predetermined residence time – in a sense, creating a “dynamic” heap leach pad which is resistant to pooling, channeling, and other disadvantages which are common to static dry-stacked heaps 16. In this manner particulate 404c-e may experience improved constant submersion and movement within leach solution.

In some non-limiting embodiments, flow rate may be adjusted in such a way that the coarse slurry 416 may continuously enter and leave the oxidation ditch 474, thereby obviating the need to construct and take down a leach pad and operate in batch cycles. The continuous nature of the oxidation ditch 474 may further obviate the need for large plots of land required for larger heap leaching operations.

The contents of the oxidation ditch 474 may comprise upwards of 80-98 percent solids, and more preferably above 90 percent solids, for example, 95 percent solids. The oxidation ditch 474 may be modified or otherwise differentiated from conventional apparatus by employing a reflective cover 476, which could be configured to allow the oxidation ditch 474 to hold a pressure above atmospheric pressure (e.g., between 1 and 10 bar, for example, approximately 1.5 bar) and further prevent evaporation commonly seen in heap leach pads. The oxidation ditch 474

may further comprise one or more radio wave or microwave generators 460 which emit radio waves or microwaves 462 in order to extract a number of inorganic and organic analytes from particles 404c-d in the coarse slurry 416, and/or improve dissolution. In some non-limiting embodiments radio waves may be amplified in intensity by one or more large amplifiers 463. In some embodiments, radio waves 462 may comprise ultrasonic waves. In some embodiments, portions of the aerators/rotating biological contactors 475 common to oxidation ditches may serve as transmitters for emitting the electromagnetic waves 462. For example, one or more ultrasound probes may be placed on, around, or adjacent to portions of the aerators/biological contactors 475, in order to encourage cavitations of leaching solution 427. Such cavitations may, in turn, create high elective temperatures (which increase solubility and dilusivity) and pressures (which favor penetration and transport) within the coarse slurry 416, particularly at the interfaces between solution 427 and the suspended solid matrix (particulate 404c-e). When combined with the oxidative energy of increased free radicals, higher extractive potentials may be realized.

Reflected radio waves 466 may bounce off of various internal portions of the oxidation ditch 474 further vibrating the particles 404a-c in the presence of an added second catalyst 490. For example, reflected radio waves 466 may bounce off the reflective cover 476, reflective portions of the aerators/rotating biological contactors 475, and/or prepped surfaces of side or bottom inner wall portions of the oxidation ditch 474. The second catalyst 490 may comprise additional leach solution 437 (e.g., sulfuric acid, lixiviant, sodium cyanide solution, thiosulfate, and/or bioleach solution), or other additive (e.g., leaching microbes, quorum-sensing agent(s)). The modified thickener/clarifier 474 may comprise a number of spargers - including spargers disposed on the aerators 475 and/or sidewalls or bottom walls of the oxidation ditch 474. The spargers may be configured to deliver one or a combination of oxidizing reagents including, air, oxygen gas, liquid oxygen, peroxide, or oxidative enzymatic compositions in solution). One or more optional sterilization devices 482, such as UV flashers, antimicrobial pipe sections, and/or

gamma irradiators, may be placed upstream and/or downstream of the oxidation ditch 474 in order to reduce the possible external spreading of or invasion of foreign bacteria into the oxidation ditch 474, thereby maintaining proper microbial consortia/enzymatic compositions for bioleaching. In instances of larger operations, one or more oxidation ditches 474 may be daisy-chained in series or parallel.

Pregnant coarse slurry 487 leaving the oxidation ditch 474 passes over a third separator 435 such as a hydrocyclone, centrifuge, or screen (as shown). The underflow slurry from the third separator 435 (i.e., liquid fraction) comprises a second pregnant solution 410 which may be directed via pump to a conventional downstream SX/EW circuit. The third separator overflow solid fraction 488 may be washed to recover residual second pregnant solution 410 before disposal in a tailings pond.

According to a fifth non-limiting embodiment shown in FIG. 7, a single or double refractory gold circuit 501 comprises a feed hopper 500 which receives sized feed ore 502. The sized feed ore 502 may come directly from a mine pit, from an upstream gyratory crusher, and/or from a cone crusher (none of which are shown for clarity). The feed ore 502 passes through a high pressure grinding roller 503 or equivalent crusher/pulverizer. Crushed ore 570 leaving the grinding roller 503 may enter a roaster 560 prior to being sized by a fourth separator 505 (e.g., a screen). The underflow slurry of the fourth separator 505 (roasted crushed ore 504) may be sent directly or indirectly to a mixer 528. The overflow slurry from the fourth separator 505 may enter a fifth separator 519 (e.g., another screen), wherein its underflow slurry may be diverted to a heap leach pad 516. In particular non-limiting embodiments, the underflow slurry from the fifth separator 519 may enter one or more bottom 508c, middle 508b, and/or top 508a layers of the heap leach pad 516. Overflow slurry of the fifth separator 519 may be considered too big for efficient leaching, and may therefore be directed to a regrind circuit 511 as shown.

The roasted crushed ore 504 leaving the fourth separator 505 may comprise various particle size distributions ranging from fine to coarse. For example, in some embodiments, the roasted crushed ore 504 may comprise an ultra-fine first particle size distribution 504a, a fine second particle size distribution 504b, an intermediately-sized third particle size distribution 504c, a coarse fourth particle size distribution 504d, and a very coarse fifth particle size distribution 504e. One or more of the particle size distributions 504a-e may comprise micro fractures (not shown) formed during grinding in the roller 503. In certain preferred embodiments, all of the roasted crushed ore 504 may be slurried in a caustic cyanide or thiosulfate solution 527 immediately after grinding and separating, in order to begin the leaching process very early on in the process 501. Slurrying may be done via a mixer 528 having a rotor 529 therein for stirring. Thereafter, conveyance of the slurried ground ore 530 may be accomplished using one or more slurry pumps.

A first separator 513a such as a hydrocyclone may be utilized to make a first rough cut of the slurried ground ore 530. The separator 513a may separate groups of finer particles (e.g., smaller size distributions 504a and 504b) from coarser particles (e.g., larger size distributions 504c, 504d, and 504e). Underflow slurry 514a from the first separator may be sent to a second separator 513b in order to further separate trapped fines from the coarse particle underflow slurry 514a. It is envisaged that more or less separators 513a, 513b may be utilized for this separation process either in parallel or in series, and that other equivalent means may be used for purposes of particle separation and size classification.

Overflow slurry 515a, 515b from the first 513a and/or second 513b separator(s) may generally contain a majority of particles which are less than approximately 100-200 microns. Underflow slurry 514a, 514b from the first 513a and/or second 513b separator(s) may generally contain a majority of particles which are greater than approximately 100-200 microns. Of

course, it should be understood that any cut size may be chosen to best compliment the unique characteristics and advantages of a particular leaching circuit 501, and that other cut size thresholds are within the purview of this application. Overflow slurry 515a, 515b may be further separated by an optional fine clay removal hydrocyclone 580 or equivalent means, so that colloidal clays may be removed before subsequent leaching and electrowinning. Fine slurry 517, formed by first and/or second separator overflow slurry components 515a, 515b may be pumped or otherwise conveyed and dumped into a stirred reactor/agitated leach tank 538 configured to leach gold fractions from the fine slurry 517 into solution. The leach tank 538 may comprise one or more rotors 539 (e.g., axial and/or radial impellers in various combinations) for improved dissolution rates. Additional amounts, higher concentrations of, or different types of leach solution 537 (e.g., sodium cyanide solution, thiosulfate, and/or bioleach solution) may be added to the tank 538 along with one or more optional oxidizing reagents 536 in order to further “kick start” the leaching process. In some non-limiting embodiments, oxidizing reagents 536 may comprise liquid oxygen, peroxide, Fenton’s reagent, oxidative enzyme, air, and/or combinations thereof. After the fine particles 504a, 504b have endured a predetermined residence time within the stirred reactor/agitated leach tank 538, they are discharged in the form of pregnant fine slurry 531 which encounters a third separating device 535 such as a screen. Spent fine solids 532 may cascade over the third separation device 535 and be sent to a wash/filter step to recover residue pregnant leach solution 534, before being sent out for disposal as tailings. First pregnant leach solution 534 (liquids) collected from the underflow of the third separating device 535 may be sent to a conventional downstream SX/EW circuit or other conventional recovery process.

The underflow slurry 514a, 514b from the first 513a and second 513b separation devices may be conveyed as coarse slurry 518 and sent to a heap leach pad 516 for heap leaching according to the novel aspects of the invention. Since the coarse slurry 518 already comprises an acid solution carrier 527, the leaching of suspended coarse particle size distributions 504c, 504d,

504e therein are also “kick started” *before* the heap leach pad 516 is completely constructed, and *during* heap construction. This kick start may ultimately lead to sooner recovery of capital investment. Wet-stacking may be performed via telescoping arm having a flexible hose and conventional slurry pump, or by way of other suitable conveying means known in the art. The telescoping arm (not shown) may fill a tank or a pit lined with an impermeable pad liner 509 much in the same way as concrete is poured on multi-level flooring during commercial building construction. Once the lined tank or pit is full of wet layers 508a-c of slurry, additional amounts, higher concentrations of, or different types of leach solution 507 (e.g., sodium cyanide solution, thiosulfate, lead nitrate, and/or bioleach solution) may be dispensed throughout the coarse slurry 518 via a leach solution delivery system 506 having drip/spray irrigation nozzles 512. The slurry 518 may reach saturation or just below-saturation levels further expediting the leach process.

In use, leach solution 507 may percolate through one or more top 508a, middle 508b, and bottom 508c layers of coarse ore particles 504a, 504b, 504c, thereby generating a second pregnant leach solution 510. During percolation, one or more catalysts or reagents 590 (e.g., air, liquid oxygen, peroxide, or oxidative enzymatic compositions) may be introduced to various portions of the heap leach pad 516 to promote surface reactions. The coarse nature of the third, fourth, and fifth particle size distributions 504c, 504d, 504e sent to the heap leach pad 516 promotes larger interstices within the heap, since the finer first 504a and second 504b particle size distributions are removed upstream. These larger interstices between adjacent particles allow for more uniform, unrestricted flow of leach solution 507 and catalysts/reagents 590 throughout the pad 516.

According to a sixth non-limiting embodiment shown in FIG. 8, a copper concentrator circuit 601 comprises a feed hopper 600 which receives sized feed ore 602. The sized feed ore 602 may come directly from a mine pit, or from an upstream gyratory and/or cone crusher (not shown). The feed ore 602 passes through a high pressure grinding roller 603 or equivalent

crusher/pulverizer. Crushed ore 604 leaving the grinding roller 603 may be subsequently delivered to a mixer 628. In some particular non-limiting embodiments, some of the crushed ore 604 (e.g., which may be too large for high-recovery leaching) may enter a regrind circuit 611 as shown.

The crushed ore 604 leaving the grinding roller 603 may comprise various particle size distributions ranging from fine to coarse. For example, in some embodiments, the crushed ore 604 may comprise an ultra-fine first particle size distribution 604a, a fine second particle size distribution 604b, an intermediately-sized third particle size distribution 604c, a coarse fourth particle size distribution 604d, and a very coarse fifth particle size distribution 604e. One or more of the particle size distributions 604a-e may comprise micro fractures (not shown) formed by the inherent grinding properties of the roller 603. In certain preferred embodiments, all of the crushed ore 604 may be slurried in an acidic slurring solution 627 immediately after grinding and separating, in order to begin the leaching process very early in the flowsheet 601. Slurring may be done via a mixer 628 having one or more rotors 629 therein for stirring. Thereafter, conveyance of the slurried ground ore 630 may be accomplished using one or more slurry pumps.

A first separator 613a such as a hydrocyclone may be utilized to make a first rough cut of the slurried ground ore 630. The separator 613a may separate groups of finer particle densities (e.g., size distributions 604a and 604b) from coarser particles (e.g., size distributions 604c, 604d, and 604e). Underflow slurry 614a from the first separator may be sent to a second separator 613b in order to further separate trapped fines within the coarser particles 604c, 604d, 604e. It is envisaged that more or less separators 613a, 613b may be utilized for this separation process either in parallel or in series, and that other mechanisms such as screens or centrifuges may be used in lieu of hydrocyclones for purposes of particle separation and classification.

Overflow slurry 615a, 615b from the first 613a and/or second 613b separator(s) may contain a majority of particles which are less than approximately 100-200 microns in diameter. Underflow slurry 614a, 614b from the first 613a and/or second 613b separator(s) may contain a majority of particles which have diameters that are greater than approximately 100-200 microns. Of course, it should be understood that any cut size may be chosen to best compliment the unique characteristics and advantages of a particular leaching circuit 601 and/or specific ore type. Overflow slurry 615a, 615b may be further separated by an optional fines removal hydrocyclone 680 or equivalent means, in order to remove colloidal clay before subsequent leaching. Fine slurry 617, formed by first and/or second separator overflow slurry components 615a, 615b may be pumped or otherwise conveyed to a stirred reactor/agitated leach tank 638 suitable for leaching copper, gold, and other target minerals from the fine slurry 617. The leach tank 638 may comprise one or more rotors 639 for better dissolution rates. Additional amounts, higher concentrations of, or different types of leach solution 637 (e.g. H_2SO_4 , lixiviant, sodium cyanide solution, thiosulfate, and/or bioleach solution) may be added to the tank 638 along with one or more optional oxidizing reagents 636 in order to further kick start the leaching process. In some non-limiting embodiments, oxidizing reagents 636 may comprise liquid oxygen, peroxide, Fenton's reagent, oxidative enzymes/enzyme combinations, compressed air, finely-crushed pyrite, peptides, proteins, amino acids, and/or combinations thereof. After the fine particles 604a, 604b have endured a predetermined residence time within the stirred reactor/agitated leach tank 638, they are discharged in the form of pregnant fine slurry 631 which then encounters a third separation 635 such as a screening step. Spent fine solids 632 may cascade over the third separation device 635 and be sent to a wash/filter step to recover residue pregnant leach solution 634, before being sent out for disposal as tailings. First pregnant leach solution 634 collected from the underflow liquid of the third separation device 635 may be sent to a conventional downstream SX/EW circuit or other conventional recovery process.

The underflow slurry 614a, 614b from the first 613a and/or second 613b separation devices may be conveyed as coarse slurry 618 and sent to a heap leach pad 616 for heap leaching. Since the coarse slurry 618 already comprises an acid solution carrier 627, the leaching of suspended coarse particle size distributions 604c, 604d, 604e therein are “kick started” both *before* the heap leach pad 616 is completely constructed, and also *during* heap construction. This kick start may ultimately lead to sooner recovery of capital expenditure. Wet-stacking may be done using a telescoping arm having a flexible hose and slurry pump, or by way of other suitable conveying means known in the art. The telescoping arm (not shown) may fill a tank or a pit lined with an impermeable pad liner 609, much in the same way as concrete may be poured on multi-level floors during commercial building construction. Once the lined tank or pit is full of wet layers 608a-c of slurry, additional amounts, higher concentrations of, or different types of leach solution 607 (e.g., sodium cyanide solution, thiosulfate, lead nitrate, and/or bioleach solution) may be dispersed throughout the heap 616 via a leach solution delivery system 606 having drip/spray irrigation nozzles 612. Additional dispensing systems may be employed en-route. For example, a first delivery system 697 comprising a first valve 698 may be used to add a first additive 692 to the coarse slurry 618 prior to or during delivery to the heap 616. A second delivery system 695 comprising a second valve 696 may also be used to add a second additive 694 to the coarse slurry 618. More or less delivery systems may be employed. The first 692 and/or second 694 additive may comprise a reagent, a bacteria, an enzyme or enzymatic compound, or a quorum-sensing agent, liquid oxygen, air, peroxide, or Fenton’s reagent. In some embodiments, additives may include lubricants to prevent clogging within the delivery means. It is preferred that such additives are not disruptive to downstream leaching and/or electrowinning processes.

In use, the leach solution 607 may percolate through one or more top 608a, middle 608b, and bottom 608c layers of coarse ore particles 604a, 604b, 604c, thereby generating a second

pregnant leach solution 610. During percolation, one or more catalysts or reagents 690 (e.g., air, liquid oxygen, peroxide, oxidative enzymatic compositions in solution, etc.) may be added to various portions of the heap leach pad 616 to promote surface reactions. As previously discussed, the coarse nature of the crushed ore particles 604c, 604d, 604e sent to the heap leach pad 616 promotes larger interstices within the heap. These larger interstices allow more uniform, unrestricted flow of leach solution 607 (and/or catalysts/reagents 690) through the pad 616.

According to a seventh non-limiting embodiment shown in FIG. 9, a copper concentrator circuit 701 comprises a feed hopper 700 which receives sized feed ore 702. The sized feed ore 702 may come directly from a mine pit, or from an upstream gyratory and/or cone crusher (not shown). The feed ore 702 passes through a high pressure grinding roller 703 or equivalent crusher/pulverizer. Crushed ore leaving the grinding roller 703 may operatively engage a fourth separator 705 (such as a screen). The underflow solids of the fourth separator 705 (crushed ore 704) may be sent to a mixer 728. The overflow solids from the fourth separator 705 may encounter a fifth separator 719 (e.g., another screen), wherein its underflow solids may be diverted to a heap leach pad 716. In a particular non-limiting embodiment said underflow solids from the fifth separator 719 may enter one or more bottom 708c, middle 708b, and/or top 708a layers of the heap leach pad 716. The fifth separator 719 may be constructed such that its overflow solids are considered too large for practical leaching for a given leaching operation 701. In such cases, the overflow solids may be directed to a regrind feed circuit 711 using conventional means as shown.

The crushed ore 704 leaving the fourth separator 705 may comprise various particle size distributions ranging from fine to coarse. For example, in some embodiments, the crushed ore 704 may comprise an ultra-fine first particle size distribution 704a, a fine second particle size distribution 704b, an intermediately-sized third particle size distribution 704c, a coarse fourth particle size distribution 704d, and a very coarse fifth particle size distribution 704e. One or

more of the particle size distributions 704a-e may comprise small cracks and fissures (not shown) formed by crushing forces within the roller 703. In certain preferred embodiments, some or all of the crushed ore 704 may be slurried in an acidic slurring solution 727 immediately after grinding and separating, in order to begin the leaching process very early on in the circuit 701. Slurring may be done via a mixer 728 having a rotor 729 therein for stirring. Thereafter, conveyance of the slurried ground ore 730 may be accomplished using one or more slurry pumps.

A first separator 713a (e.g., a hydrocyclone) may be utilized to make a first rough cut of the slurried ground ore 730. The separator 713a may separate groups of finer particle densities (e.g., size distributions 704a and 704b) from coarser particles (e.g., size distributions 704c, 704d, and 704e). Underflow slurry 714a from the first separator may be sent to a second separator 713b in order to further separate trapped fines from the coarser particles 704c, 704d, 704e. It is envisaged that more or less separators 713a, 713b may be utilized for this separation process, and that such devices may be used in parallel or in series. As previously mentioned, other mechanisms such as screens or centrifuges may be used in lieu of hydrocyclones for purposes of particle separation and classification.

Overflow slurry 715a, 715b from the first 713a and/or second 713b separator(s) forms fine slurry 715, which may contain a majority of particles which are less than approximately 100-200 microns in diameter (average). Underflow slurry 714a, 714b from the first 713a and/or second 713b separator(s) may contain a majority of particles which are greater than approximately 100-200 microns in average diameter. Of course, it should be understood that any cut size may be chosen to best compliment the unique characteristics and advantages of an optimized leaching circuit 701 designed specifically for a particular ore or target mineral. Overflow slurry 715a, 715b may be further ground by a fine or ultra-fine grinding mill 740 such

as an attrition mill or stirred media detritor (SMD) mill -- for example, a Knelson-Deswik fine grinding mill currently manufactured by FLSmidth. Thereafter, the ultra-fine slurry 717 may be further separated using an optional hydrocyclone 780 or equivalent means, in order to remove colloidal clays from the slurry 717. The ultra-fine slurry 717, may be pumped or otherwise conveyed or dumped into a reactor extruder 738 (FIG. 12), which may comprise a single screw or dual screws (counter-rotating or co-rotating).

The reactor extruder 738 may comprise, for instance, a drive 772, a barrel 770, and a screw 769 disposed within the barrel 770. At one portion of the barrel 770, an inlet section 761 may be provided, and at another end of the barrel 770 may be provided an outlet section 767. An exit valve 768 may further be provided to the outlet section 767 to maintain high pressures within the reactor 738. Just inside the inlet section 761 may be provided a feed zone pump 762, for instance an area defined by a region where the screw 769 might have lesser-pronounced flights, a larger number of flights, or flights which are angled differently than the inlet section 761. Just before the outlet section 767, a discharge zone pump 766 may be provided, for instance, defined by a region where the screw 769 might have lesser-pronounced flights, a larger number of flights, or flights which are angled differently than the outlet section 767. A central reaction chamber 763 may be situated between the feed zone pump 762 and the discharge zone pump 766. The reaction chamber 763 may be defined as the area between first 765a and second 764b plugs provided on the screw 769, which is maintained at much higher pressures than the inlet 761 and/or outlet 767 sections. One or more heat sources or heating elements 773 may be provided to various portions of the reactor extruder 738, for example, under central portions of the barrel 770 adjacent the reaction chamber 763.

One or more inputs may be provided to the barrel 770 in, around, or adjacent to the reaction chamber 763 as shown – for example, to accommodate a first additive 736 prior to a second additive 737. As shown, inputs for the additives 736, 737 may be spaced out and

provided at different locations relative to the reaction chamber 763 to influence surface reactions at different stages of the leaching process. Portions of the reactor extruder 738 may comprise manual or digital gauges 765a-c in order for an operator or computer-controller to optimally adjust parameters such as screw rotational velocity and feed rate(s). Moreover, a delivery system 795 comprising a valve 796 may be provided downstream of the grinding mill 740 to add a third additive to the ultra-fine slurry 717 prior to its entry in the reactor extruder 738. Additives 736, 737, 794 may include lubricants, and depending on the type of ore 702 being provided, natural oils, graphite, and/or other compositions in the particles 704a, 704b themselves may act as lubricants when finely ground by the mill 740 and heated under pressure.

In some non-limiting embodiments, the reaction chamber 763 may carry a pressure of upwards of greater than 10,000 psi. Additives 736, 737, 794 may comprise various reagents or catalysts. In one particular embodiment first additive 736 might comprise liquid oxygen, the second additive 737 may comprise peroxide or a Fenton's reagent, and the third additive 794 might comprise an acidic leach solution, an oxidative enzyme, compressed air, and/or a combination thereof. After the fine particles 704a, 704b have endured a predetermined residence time within reactor extruder 738, they are discharged in the form of pregnant fine slurry 731 which undergoes a third separation 735. Spent fine solids 732 may cascade over the third separation device 735 and enter a wash/filter step which recovers residual pregnant leach solution 734 prior to disposal as tailings. First pregnant leach solution 734 collected from the underflow slurry of the third separation device 735 may be sent to a conventional downstream SX/EW circuit or other conventional recovery process.

The underflow slurry 714a, 714b from the first 713a and second 713b separation devices may be conveyed as coarse slurry 718 and sent to a heap leach pad 716 for heap leaching. Since the coarse slurry 718 already comprises an acid solution carrier 727, the leaching process for suspended coarse particle size distributions 704c, 704d, 704e therein are "kick started" even

before the heap leach pad 716 is completely constructed, and also *during* heap construction.

This head start in the leaching process may help expedite capital recovery. Wet-stacking may be performed by a telescoping arm (e.g., crane, jib, or luffing conveyor) equipped a flexible hose and slurry pump, or by way of other suitable conveying means known in the art. The telescoping arm (not shown) may fill a tank or a pit lined with an impermeable pad liner 709 much in the same way as concrete may be poured on multi-level floors during commercial building construction. Once the lined tank or pit is full of layers 708a-c of slurry, additional amounts, higher concentrations of, or different types of leach solution 707 (e.g., sulfuric acid, lixiviant, and/or bioleach solution) may be dispensed throughout the coarse slurry 718 via a leach solution delivery system 706 having drip/spray irrigation nozzles 712.

In use, the leach solution 707 may percolate through one or more top 708a, middle 708b, and bottom 708c layers of coarse ore particles 704a, 704b, 704c, thereby generating a second pregnant leach solution 710. During percolation, one or more catalysts or reagents 790 (e.g., air, liquid oxygen, peroxide, or oxidative enzymatic compositions) may be added to various portions of the heap leach pad 716 to promote surface reactions. The coarse nature of the crushed ore particles 704c, 704d, 704e sent to the heap leach pad 716 encourages the formation of larger interstices therebetween. These larger interstices allow a more uniform, unrestricted flow of both leach solution 707 and catalysts/reagents 790 throughout the pad 716.

According to an eighth non-limiting embodiment shown in FIG. 10, a single refractory gold circuit 801 comprises a feed hopper 800 which receives sized feed ore 802. The sized feed ore 802 may come directly from a mine pit, or from an upstream gyratory/cone crusher (not shown). The feed ore 802 passes through a high pressure grinding roller 803 or equivalent crusher/pulverizer (e.g., jaw crusher). Crushed ore leaving the grinding roller 803 may be sized by a fourth separator 805 (such as a screen), and its underflow 804 sent to a mixer 828. The overflow from the fourth separator 805 may enter a fifth separator 819 (e.g., another screen),

wherein its underflow may be diverted to a heap leach pad 816. In a particular non-limiting embodiment the underflow from the fifth separator 819 may enter one or more bottom 808c and/or middle 808c layers of the heap leach pad 816 to ensure large interstices at its base. Overflow solids of the fifth separator 819 may be considered too big for efficient leaching, and may therefore be directed to a regrind circuit 811 or a third leaching circuit (not shown) optimized for larger particles.

The crushed ore 804 leaving the fourth separator 805 may comprise various particle size distributions ranging from fine to coarse. For example, in some embodiments, the crushed ore 804 may comprise an ultra-fine first particle size distribution 804a, a fine second particle size distribution 804b, an intermediately-sized third particle size distribution 804c, a coarse fourth particle size distribution 804d, and a very coarse fifth particle size distribution 804e. One or more of the particle size distributions 804a-e may comprise micro fractures (not shown) formed via the nature of the grinding roller 803. In certain preferred embodiments, all of the crushed ore 804 may be slurried in water or an aqueous slurring solution 827 immediately after grinding and separating. Slurring may be done via a mixer 828 having a rotor 829 therein for stirring. Thereafter, conveyance of the slurried ground ore 830 may be accomplished using one or more slurry pumps.

The slurried ground ore 830 enters an autoclave 895 where oxygen 896 and/or other catalysts oxidize all particle size distributions 804a-e within the crushed ore 804. Slurried ground ore which has been autoclaved 840 may then be pumped into a neutralization tank 848 filled with a neutralizing agent 847. Neutralized slurried ground ore 850 may then enter a mixer 858 where leach solution 856 such as caustic cyanide or thiosulfate is added in order to begin the leaching process within the circuit 801 early.

A first separator 813a (e.g., a hydrocyclone) may be utilized to make a first rough cut of caustic slurried ground ore 860 leaving the mixer 858. The separator 813a may separate groups of finer particles (e.g., first and second size distributions 804a and 804b) from coarser particles (e.g., size distributions 804c, 804d, and 804e). Underflow slurry 814a from the first separator 813a may be sent to a second separator 813b in order to further liberate fines trapped within the coarser particles 804c, 804d, 804e. It is envisaged that more or less separators 813a, 813b may be utilized for this separation process (in parallel, series, or combinations thereof) and that other mechanisms such as screens or centrifuges may be used in lieu of hydrocyclones for purposes of particle separation and classification.

Overflow slurry 815a, 815b from the first 813a and/or second 813b separator(s) may contain a majority of smaller particles which are less than approximately 100-200 microns and suitable for stirred reactor leaching. Underflow slurry 814a, 814b from the first 813a and/or second 813b separator(s) may contain a majority of larger particles which are greater than approximately 100-200 microns and more suited for heap leaching. Of course, it should be understood that any cut size may be chosen to best compliment the unique characteristics and advantages of a particular leaching circuit 801. Moreover, while not shown, additional leaching circuits may be employed depending on the number and/or variation of particle size distributions 804a-e. Overflow slurry 815a, 815b may be further separated by an optional fine clay removal hydrocyclone 880 or equivalent means, in order to remove colloidal clays. Fine slurry 817, formed from the combination of first and second separator overflow slurry components 815a, 815b may be pumped or otherwise conveyed to a stirred reactor/agitated leach tank 838 suitable for leaching target metals such as copper or gold from the fine slurry 817. The stirred reactor 838 may comprise one or more rotors 839 for better dissolution rates and may include axial and/or radial impeller designs. Additional amounts, higher concentrations of, or different types of leach solution 837 (e.g., sulfuric acid, lixiviant, sodium cyanide solution, thiosulfate, and/or

bioleach solution) may be added to the tank 838, along with one or more optional oxidizing reagents 836 in order to further kick start leach reactions. In some non-limiting embodiments, oxidizing reagents 836 may comprise liquid oxygen, peroxide, Fenton's reagent, specialized enzymes, proteins, peptides, air, and/or combinations thereof. After the fine particles 804a, 804b have endured a predetermined residence time within the stirred reactor/agitated leach tank 838, they may be discharged in the form of pregnant fine slurry 831, which then engages a third separating device 835 (e.g., a screen). Overflow solids 832 from the third separation device 835 may be sent to a wash/filter step for the recovery of remaining pregnant leach solution 834 before being sent out for disposal as tailings. First pregnant leach solution 834 collected from the underflow of the third separation device 835 may be sent to a conventional downstream SX/EW circuit or other conventional recovery process.

The underflow slurry 814a, 814b from the first 813a and second 813b separation devices may be conveyed as coarse slurry 818 and sent to a heap leach pad 816 for heap leaching. Alternatively, while not shown, the coarse slurry 818 may be sent to other apparatus 374, 474 and circuits described herein, without limitation. Since the coarse slurry 818 already comprises a caustic solution carrier 856 from mixer 858, leaching reactions between the carrier 856 and the suspended coarse particle size distributions 804c, 804d, 804e therein begin well *before* the heap leach pad 816 is completely constructed, and also *during* construction of the heap 816. This kick start may lead to quicker investment recovery. Wet-stacking may be done using a telescoping arm (crane, jib, backhoe) having a flexible hose and slurry pump, or by way of other suitable conveying means known in the art. The telescoping arm (not shown) may fill a tank or a pit lined with an impermeable pad liner 809 much in the same way as concrete may be poured on multi-level floors during commercial building construction. Once the lined tank or pit is full of wet layers 808a-c of slurry, additional amounts, higher concentrations of, or different types of leach solution 807 (e.g., sulfuric acid (H_2SO_4), lixiviant, sodium cyanide solution, thiosulfate,

lead nitrate, and/or bioleach solution) may be dispensed throughout the coarse slurry 818 via a leach solution delivery system 806 having drip/spray irrigation nozzles 812.

In use, the leach solution 807 may percolate through one or more top 808a, middle 808b, and bottom 808c layers of coarse ore particles 804a, 804b, 804c, thereby generating a second pregnant leach solution 810. During percolation, one or more catalysts or reagents 890 (e.g., air, liquid oxygen, peroxide, or oxidative enzymatic compositions) may be added to various portions of the heap leach pad 816 to promote surface reactions and surgically adjust leaching kinetics within the heap. The coarse nature of the crushed ore particles 804c, 804d, 804e sent to the heap leach pad 816 promotes larger interstices therebetween and encourages a more uniform, unrestricted flow of both leach solution 817 and catalysts/reagents 890 through the pad 816.

According to a ninth non-limiting embodiment shown in FIG. 11, a copper concentrator circuit 901 comprises a feed hopper 900 which receives sized feed ore 902. The sized feed ore 902 may come directly from a mine pit, or from an upstream gyratory and/or cone crusher (not shown). The feed ore 902 passes through a high pressure grinding roller 903 or equivalent crusher/pulverizer. The crushed ore 904 leaving the grinding roller 903 may comprise various particle size distributions ranging from fine to coarse. For example, in some embodiments, the crushed ore 904 may comprise an ultra-fine first particle size distribution 904a, a fine second particle size distribution 904b, an intermediately-sized third particle size distribution 904c, a coarse fourth particle size distribution 904d, and a very coarse fifth particle size distribution 904e. One or more of the particle size distributions 904a-e may comprise micro fractures (not shown) formed by the grinding nature of the roller 903. As suggested in the embodiment shown in FIG. 9, all of the crushed ore 904 may be slurried in a slurring solution 927 (e.g., an acidic aqueous solution) immediately after grinding and separating, in order to begin the leaching process very early on in the circuit 901. Slurring may be done via a mixer 928 having a rotor

929 therein for stirring. Thereafter, conveyance of the slurried ground ore 930 may be accomplished using one or more slurry pumps.

A first separator 913, such as a hydrocyclone, may be utilized to make a first rough cut of the slurried ground ore 930. The separator 913 may separate groups of finer particles (e.g., size distributions 904a and 904b) from coarser particles (e.g., size distributions 904c, 904d, and 904e). While not shown, underflow 914 from the first separator 913 may be sent to one or more second separators in order to further remove trapped fines from the coarser particles 904c, 904d, 904e. As stated earlier, it should be understood that other mechanisms such as screens or centrifuges may be equally used in combination with or in lieu of hydrocyclones, for purposes of particle separation and classification.

Overflow slurry 915 from the first 913 separator may contain a majority of small particles which are less than approximately 100-200 microns in diameter. Underflow slurry 914 from the first separator 913 may contain a majority of larger particles which are greater than approximately 100-200 microns in diameter. Of course, it is contemplated that any cut size may be chosen to best compliment the unique characteristics of a particular leaching circuit 901. While not shown in FIG. 11, overflow slurry 915 may encounter an optional fine clay removal process as shown in the other figures, in order to remove colloidal clays before subsequent leaching/electrowinning.

Fine slurry 917, formed by first separator overflow slurry component 915 may be sent to a first reactor 938a for leaching. Since the fine slurry 917 already comprises an acid solution carrier 927, surface reactions begin occurring on the suspended fine particle size distributions 904a, 904b, therein *before* the fine slurry 917 even enters the first reactor 938a. The fine particle size distributions 904a, 904b may be stirred in the first reactor 938a by a rake 975a driven by a robust drive and gearing system, or by rakeless means previously discussed for FIG. 5 (e.g., E-

Cat® technology from FLSmidth). The contents of the first reactor 938a may comprise upwards of 80-98 percent solids, and more preferably above 90 percent solids, for example, 95 percent solids – and may resemble cake batter or ready-to pour cement. The first reactor 938a may comprise a reflective cover 976a, which could be configured to make the first reactor 938a hold a pressure above atmospheric pressure (e.g., between 1 and 10 bar, for example, approximately 1.5 bar). The cover 976a may also serve to prevent escape of one or more unpressurized or pressurized gasses which could help accelerate the leaching process as will be described hereinafter. The first reactor 938a may further comprise one or more first radio wave or microwave generators 960a which emit first radio waves or microwaves 962a in order to extract a number of inorganic and organic analytes from particles 904c-d in the fine slurry 917, and/or induce redox reactions (e.g., ionic transmissions between membranes). In some non-limiting embodiments radio waves may be amplified in intensity by one or more first amplifiers 963a. In some embodiments, the waves 962a may comprise ultrasonic waves. In some embodiments the rake 975a may serve as an antenna/transmitter itself. Reflected waves 966a may bounce off of various internal portions of the first reactor 938a, including reflective cover 976a, further vibrating the particles 904a-c in the presence of an added second catalyst 990a and conserving energy. For example, reflected radio waves 966a may bounce off the reflective cover 976a, reflective portions of the rake 975a, or side or bottom inner wall portions of the first reactor 938a. The second catalyst 990a may comprise additional leach solution 927 (e.g., sulfuric acid, lixiviant, sodium cyanide solution, thiosulfate, and/or bioleach solution), or other additive (leaching microbes, quorum-sensing agents), or combinations thereof. The first reactor 938a may comprise a number of spargers - including spargers 970a disposed on the rake 975a, spargers 972a disposed on the sidewalls of the first reactor 938a, and/or spargers 973a disposed on bottom portions of the first reactor 938a. The spargers 970a, 972a, 973a may be configured to deliver one or a combination of oxidizing reagents including, air, oxygen gas, liquid oxygen,

peroxide, Fenton's reagent, oxidative enzymatic compositions in solution, microbes, or quorum-sensing agents). One or more sterilization devices 982a, such as UV flashers, antimicrobial pipe sections, and/or gamma irradiators, may be placed upstream and/or downstream of the first reactor 938a in order to reduce the possible external spreading of or invasion of foreign bacteria into the reactor 938a, thereby maintaining proper microbial consortia/enzymatic compositions needed for bioleaching.

Pregnant fine slurry 931 leaving the first reactor 938a passes over a second separator 935 such as a hydrocyclone, centrifuge, or screen as shown. The underflow slurry from the second separator 935 comprises first pregnant solution 934 which may be directed via pump to a conventional downstream SX/EW circuit. The second separator overflow slurry 932 may be washed to recover residual first pregnant solution 934 before its disposal in a tailings pond.

Underflow slurry 914 from the first separation device 913 may be conveyed as coarse slurry 918 and sent to a second reactor 938b for leaching. Since the coarse slurry 918 already comprises a leaching solution carrier 927, leaching processes for the suspended coarse particle size distributions 904c, 904d, 904e therein are also accelerated. Rather than wet-stacking in a heap leach arrangement shown in FIG. 4, the coarse particle size distributions 904c, 904d, 904e may instead be stirred in the second reactor 938b by a rake 975b which is driven by a robust drive and gearing system. The contents of the second reactor 938b may comprise upwards of 80-98 percent solids, and more preferably above 90 percent solids, for example, 95 percent solids. The second reactor 938b may also comprise a reflective cover 976b, which may be configured to make the second reactor 938b hold a pressure above atmospheric pressure (e.g., between 1 and 10 bar, for example, approximately 1.5 bar). The cover 976b may also serve to prevent escape of one or more unpressurized or pressurized gasses which accelerate the leaching process. The second reactor 938b may further comprise one or more radio wave or microwave generators 960b which emit radio or microwaves 962b thereby extracting a number of inorganic and organic

analytes from particles 904c-d in the coarse slurry 918, and/or inducing redox reactions (e.g., ionic transmissions between membranes). In some non-limiting embodiments radio waves may be amplified in intensity by one or more large amplifiers 963b. In some embodiments, waves 962b may comprise ultrasonic waves. In some embodiments the rake 975b may serve as an antenna or transmitter itself. Reflected waves 966b may bounce off of various internal portions of the second reactor 938b further vibrating the particles 904a-c in the presence of an added second catalyst 990b. For example, reflected radio waves 966b may bounce off the reflective cover 976b, reflective portions of the rake 975b, or side or bottom inner wall portions of the second reactor 938b, thereby minimizing energy inputs required. The second catalyst 990b may comprise additional leach solution 927 (e.g., sulfuric acid, lixiviant, sodium cyanide solution, thiosulfate, and/or bioleach solution), or other additives (e.g., leaching microbes, quorum-sensing agents). The second reactor 938b may comprise a number of spargers - including spargers 970b provided on the rake 975b, spargers 972b disposed on the sidewalls of the second reactor, and/or spargers 973b strategically placed at bottom portions of the second reactor 938b. The spargers 970b, 972b, 973b may be configured to deliver one or a combination of oxidizing reagents including, air, oxygen gas, liquid oxygen, peroxide, Fenton's reagent, microbes, quorum-sensing agents, or one or more oxidative enzymatic compositions in solution). One or more sterilization devices 982b such as UV flashers, antimicrobial pipes, silver-impregnated pump parts, and/or a gamma irradiators, may be placed upstream and/or downstream of the second reactor 938b in order to reduce the possible external spreading of or invasion of foreign bacteria into the second reactor 938b, thereby maintaining proper microbial consortia/enzymatic compositions for bioleaching (as well as preventing cross-contamination between the first 938a and second 938b reactors and downstream mixer settlers not shown).

Advantages to leaching with the first 938a and second 938b reactors over conventional heap leach pads 16 include: the preservation of solid/liquid ratios, dynamic leached particles,

which achieve better wetting, and more oxygen that can be delivered to all surfaces of the leached particles in high, but non-wasteful quantities.

Pregnant coarse slurry 987 leaving the second reactor 938b passes over a third separator 985 such as a hydrocyclone, centrifuge, or screen (as shown). The underflow slurry from the third separator 985 comprises a second pregnant solution 910 which may be directed via pump to a conventional downstream SX/EW circuit. The third separator overflow slurry 988 may be washed to recover residual second pregnant solution 910 before being disposed of in a tailings pond.

It should be known that the particular features of the leaching circuits 101, 201, 301, 401, 501, 601, 701, 801, 901 and methods thereof which are shown and described herein in detail are purely exemplary in nature and should not limit the scope of the invention. For example, a counter-current leach column 1000 such as the one shown in FIG. 13 may be utilized in lieu of or in combination with any one of the aforementioned leaching apparatuses shown and described in the drawings. Moreover, an air lift agitator 1100 as shown in FIG. 14 and described in U.S. Pat. No. 2,239,194 may be utilized in lieu of or in combination with any one or more of the aforementioned circuits as an equally-adapted apparatus for leaching (for instance, much in the same way modified thickener/clarifier 374 and reactors 938a-b are used). Alternatively, a slurry storage tank 1200, as shown in FIG. 15 and described in U.S. Pat. No. 4,367,048, may be utilized with any one or more of the aforementioned circuits as a leaching apparatus for fine or coarse slurry streams. Devices for applying plastic masses 1300, such as the one shown in FIG. 16 and described in U.S. Pat. No. 3,704,865 may further be utilized with any one or more of the aforementioned circuits as a suitable leaching apparatus for fine or coarse slurry streams. In some non-limiting embodiments, a modified forced air or self-aspirating flotation cell 1400, such as a WEMCO® DEPURATOR® float cell system with a cap for pressurization may be used as a leaching apparatus (e.g., in lieu of the stirred reactor/agitated leach tanks 138, 238 described

throughout this specification). Additionally, as suggested in FIG. 18, One or more Pachuca tanks 1500 (e.g., such as the ones shown and described in WO/2009149521A) may be advantageously utilized to selectively leach ore having various mean particle size distributions. Even more alternatively, one or more educator jets or pressurized pipe reactors 1600 as shown in FIG. 19 may be used as a mechanism for leaching whereby leach solution may be forcibly combined under pressure and high velocity with crushed ore having a mean particle size that compliments the properties of the leach solution. Moreover, bubble column reactors 1700, such as the one shown in FIG. 20 may be employed to leach slurry and create pregnant slurries. Additionally, fluidized bed reactors 1800 such as the one shown in FIG. 21 may be used in combination with, or in lieu of any one of the aforementioned leaching apparatuses shown and described in the drawings.

A contractor or other entity may provide circuits in part or in whole as shown and described. For instance, the contractor may receive a bid request for a project related to designing a leaching circuit, or the contractor may offer to design such a system for a client. The contractor may then provide, for example, any one or more of the devices or features thereof shown and/or described in the embodiments discussed above. The contractor may provide such devices by selling those devices or by offering to sell those devices. The contractor may provide various embodiments that are sized, shaped, and/or otherwise configured to meet the design criteria of a particular client or customer. The contractor may subcontract the fabrication, delivery, sale, or installation of a component of the devices or of other devices used to provide such devices. The contractor may also survey a site and design or designate one or more storage areas for stacking the material used to manufacture the devices. The contractor may also maintain, modify, or upgrade the provided devices. The contractor may provide such maintenance or modifications by subcontracting such services or by directly providing those services or components needed for said maintenance or modifications, and in some cases, the

contractor may modify an existing leaching system with one or more “retrofit kits” or added “islands” to arrive at a modified leaching circuit comprising one or more devices or features of the systems and processes discussed herein.

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.

CLAIMS

We claim:

- 1) A hydrometallurgy circuit [101, 201, 301, 401] for recovery of a metal comprising:
 - a crushing or grinding device [103, 203, 303, 403] configured to pulverize feed ore [102, 202, 302, 402] and produce crushed ore [104, 204, 304, 404];
 - a first separator [113a, 213a, 313, 413] configured to separate the crushed ore [104, 204, 304, 404] into a fines stream [117, 217a, 317, 417] and a coarse stream [118, 218a, 316, 416];
 - a first metallurgical extraction process for producing a first pregnant leach solution [134, 234, 334, 434] from said fines stream [117, 217a, 317, 417] and,
 - a second metallurgical extraction process for producing a second pregnant leach solution [110, 210, 310, 410] from said coarse stream [118, 218a, 316, 416].
- 2) The hydrometallurgy circuit [101, 201, 301, 401] according to claim 1, wherein the first metallurgical extraction process comprises at least one of: a stirred reactor/agitated leach tank [138, 238, 338, 438, 638], a Pachuca tank [1500], an autoclave [595], a pressure reactor (e.g., an educator jet or a pressurized pipe reactor [1600]), a modified forced air or self-aspirating flotation cell [1400], a counter current leach column [900], a reactive extruder [780], and a modified thickener/clarifier [938a].

3) The hydrometallurgy circuit [101, 201, 301, 401] according to claim 1, wherein the second metallurgical extraction process comprises at least one of: a heap leach pad [116, 216, 516, 616, 716, 816] or pad liner [109, 209, 509, 609, 709, 809], a modified thickener/clarifier [374, 938b], an oxidation ditch [474], a slurry storage mechanism [1200], a modified forced air or self-induced gas/self-aspirating flotation cell [1400], a bubble column reactor [1700], a fluidized bed reactor [1800], an air lift agitator [1000], a stirred reactor/agitated leach tank [138, 238, 338, 438], and a Patchuca tank [1500].

4) The hydrometallurgy circuit [101, 201, 301, 401] according to claim 2, wherein leach solution [137, 237, 337, 437] and a first catalyst or reagent [136, 236, 336, 436] is added to a stirred reactor [138, 238, 338, 438] of the first metallurgical extraction process in order to produce said first pregnant leach solution [134, 234, 334, 434].

5) The hydrometallurgy circuit [101, 201, 301, 401] according to claim 4, wherein the first catalyst or reagent [136, 236, 336, 436] added to the stirred reactor [138, 238, 338, 438] comprises at least one of a protein, an enzyme, a Fenton's reagent, a microbial, a quorum-sensing agent, crushed pyrite, peroxide, liquid oxygen, or compressed air.

6) The hydrometallurgy circuit [101, 201, 301, 401] according to claim 3, wherein the second metallurgical extraction process comprises a heap leach pad [116, 216] which is comprised of at least one top layer [108a, 208a] and at least one bottom layer [108c, 208c], and wherein the at least one top layer [108a, 208a] has a first mean particle size distribution [104c, 204c] which is

different than a third mean particle size distribution [104e, 204e] of the at least one bottom layer [108c, 208c].

7) The hydrometallurgy circuit [101, 201, 301, 401] according to claim 6, wherein the first mean particle size distribution [104c, 204c] is smaller than the third mean particle size distribution [104e, 204e] so as to provide a simple mean particle size distribution gradient within the heap leach pad [116, 216].

8) The hydrometallurgy circuit [101, 201] according to claim 5, regions of the heap leach pad [116, 216] which are adjacent the first mean particle size distribution [104c, 204c] are treated or processed differently than areas of the heap leach pad [116, 216] which are adjacent the third mean particle size distribution [104e, 204e].

9) The hydrometallurgy circuit [101, 201, 301, 401] according to claim 7, wherein regions of the heap leach pad [116, 216] which are adjacent the first mean particle size distribution [104c, 204c] are treated with different concentrations of leach solution [107, 207a] than areas of the heap leach pad [116, 216] which are adjacent the third mean particle size distribution [104e, 204e].

10) The hydrometallurgy circuit [101, 201, 301, 401] according to claim 7, wherein regions of the heap leach pad [116, 216] which are adjacent the first mean particle size distribution [104c, 204c] are treated with a different amount or flow rate of leach solution [107, 207a] than areas of

the heap leach pad [116, 216] which are adjacent the third mean particle size distribution [104e, 204e].

11) The hydrometallurgy circuit [101, 201, 301, 401] according to claim 7, wherein regions of the heap leach pad [116, 216] which are adjacent the first mean particle size distribution [104c, 204c] are treated with a different type of leach solution [107, 207a] than areas of the heap leach pad [116, 216] which are adjacent the third mean particle size distribution [104e, 204e].

12) The hydrometallurgy circuit [101, 201, 301, 401] according to claim 7, wherein regions of the heap leach pad [216] which are adjacent the first mean particle size distribution [204c] are treated with a different type of additive [240] than areas of the heap leach pad [216] which are adjacent the third mean particle size distribution [204e].

13) The hydrometallurgy circuit [101, 201, 301, 401] according to claim 7, wherein regions of the heap leach pad [216] which are adjacent the first mean particle size distribution [204c] are treated with a different amount of additive [240] than areas of the heap leach pad [216] which are adjacent the third mean particle size distribution [204e].

14) The hydrometallurgy circuit [101, 201] according to claim 5, wherein the heap leach pad [116, 216] further comprises one or more middle layers [108b, 208b] having a second mean particle size distribution [104b, 204b], which is different than both the first mean particle size distribution [104c, 204c] and the third mean particle size distribution [104e, 204e] so as to provide a complex mean particle size distribution gradient within the heap leach pad [116, 216].

15) The hydrometallurgy circuit [101, 201, 301, 401] according to claim 14, wherein the second mean particle size distribution [104b, 204b] is in between the first mean particle size distribution [104c, 204c] and the third mean particle size distribution [104e, 204e].

16) The hydrometallurgy circuit [101, 201, 301, 401] according to claim 1, wherein the second metallurgical extraction process comprises at least one of: a sterilization device [382, 482] and a device [360, 460] capable of emitting low radio waves [362, 462] at various frequencies and/or various powers.

17) The hydrometallurgy circuit [101, 201, 301, 401] according to claim 1, wherein the fines stream [117, 217a, 317, 417] used in the first metallurgical extraction process is less than approximately 200 μm and the coarse stream [118, 218a, 316, 416] used in the first metallurgical extraction process is greater than approximately 100 μm ;

18) The hydrometallurgy circuit [101, 201, 301, 401] according to claim 1, wherein the recovery of a metal comprises the recovery of a base metal such as copper.

19) The hydrometallurgy circuit [101, 201, 301, 401] according to claim 1, wherein the recovery of a metal comprises the recovery of a precious metal such as gold.

20) The hydrometallurgy circuit [701] according to claim 1, wherein the first metallurgical extraction process further comprises a fine or ultra-fine grinding mill [740], which is configured to further reduce the mean particle size distribution [704a, 704b] of the fines stream [715] to produce an ultra-fine slurry [717].

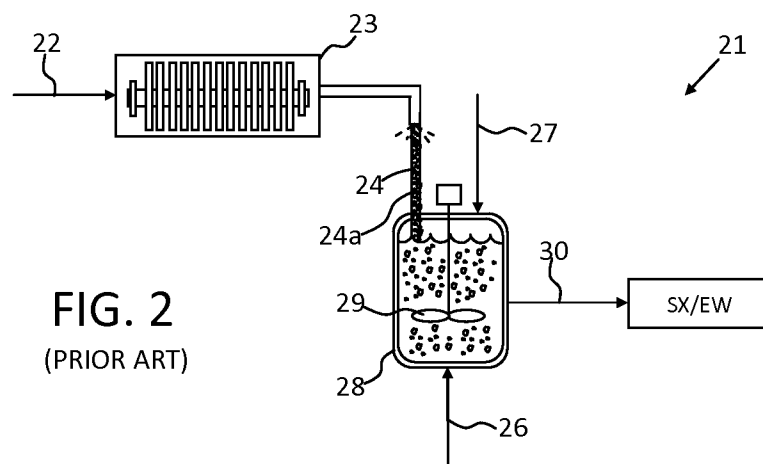
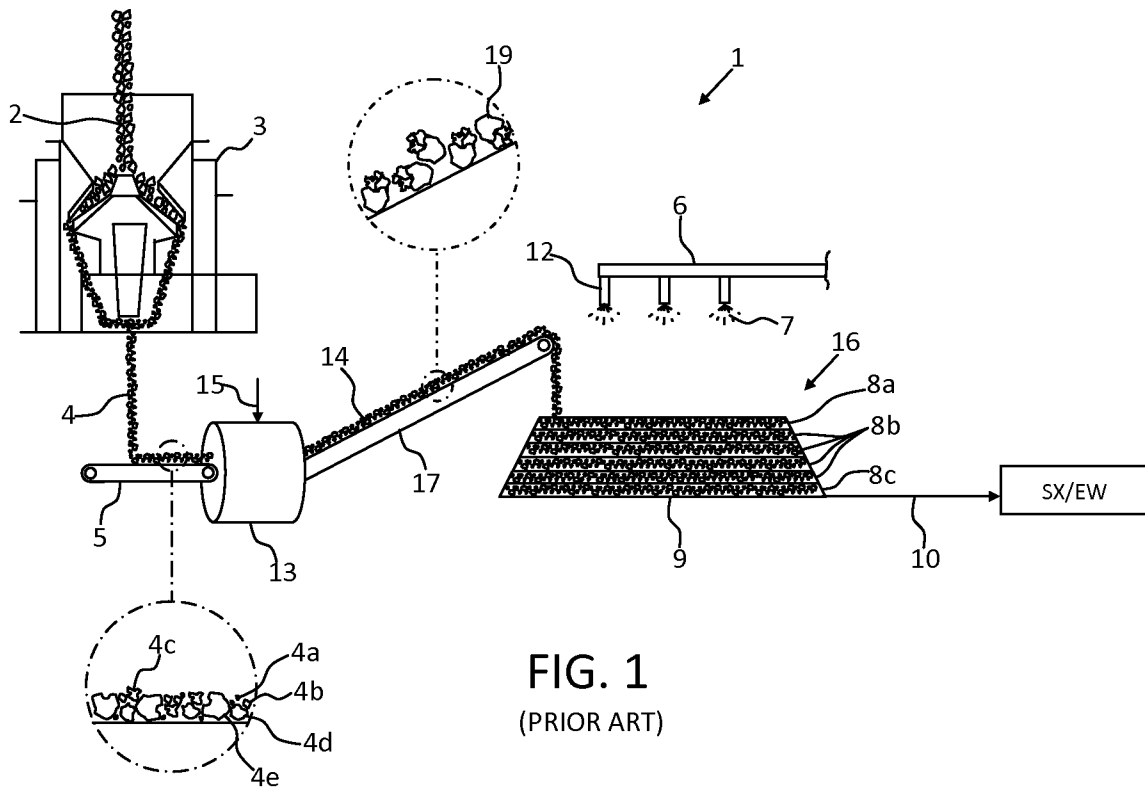
21) A method of leaching comprising:

providing a hydrometallurgy circuit [101, 201, 301, 401] comprising a crushing or grinding device [103, 203, 303, 403] configured to pulverize feed ore [102, 202, 302, 402] and produce crushed ore [104, 204, 304, 404];

providing at least one separator [113a, 213a, 313, 413] configured to separate the crushed ore [104, 204, 304, 404] into a fines stream [117, 217a, 317, 417] and a coarse stream [118, 218a, 316, 416];

feeding the fines stream [117, 217a, 317, 417] to a first metallurgical extraction process for producing a first pregnant leach solution [134, 234, 334, 434]; and,

feeding the coarse stream [118, 218a, 316, 416] to a second metallurgical extraction process for producing a second pregnant leach solution [110, 210, 310, 410].



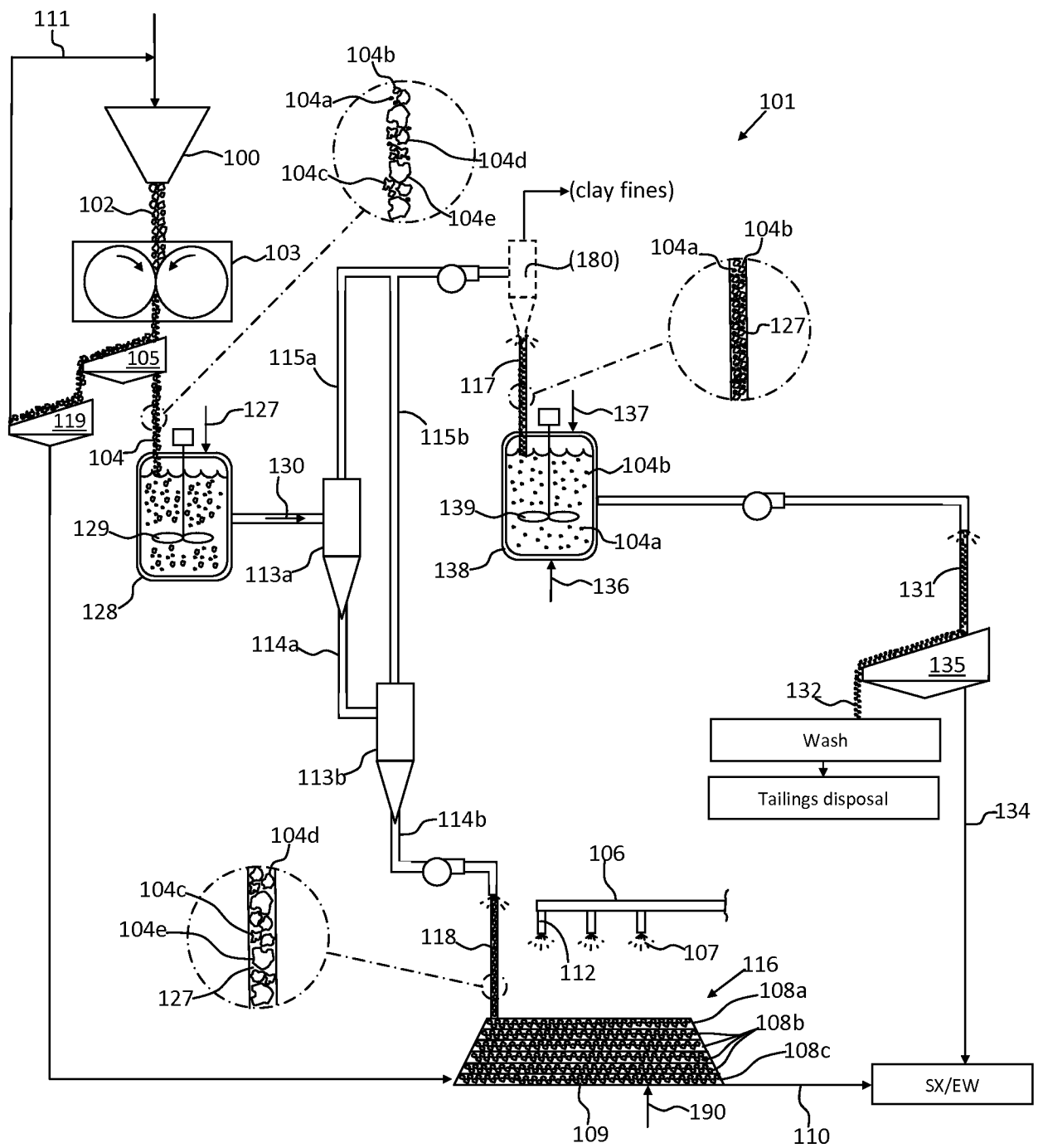


FIG. 3

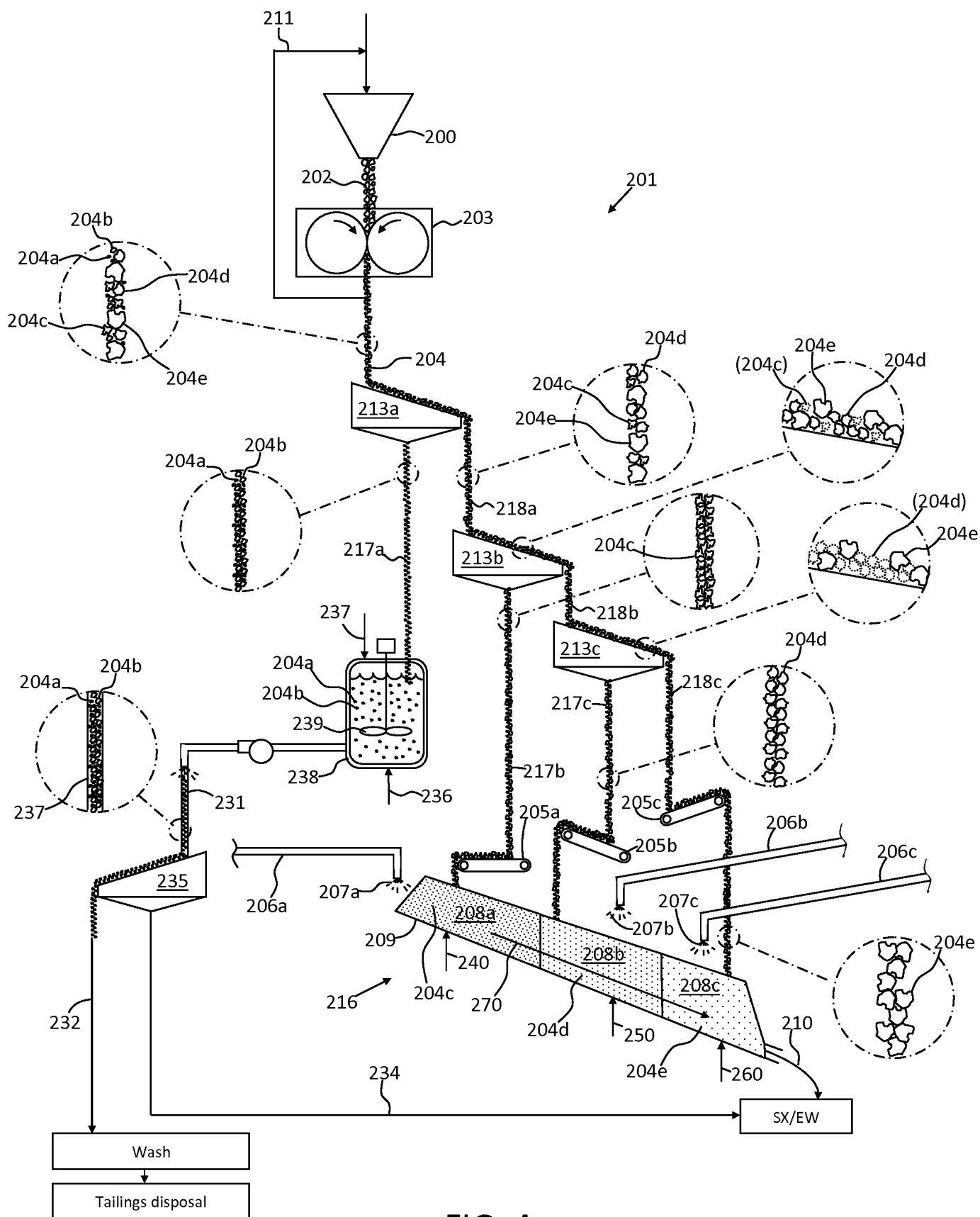
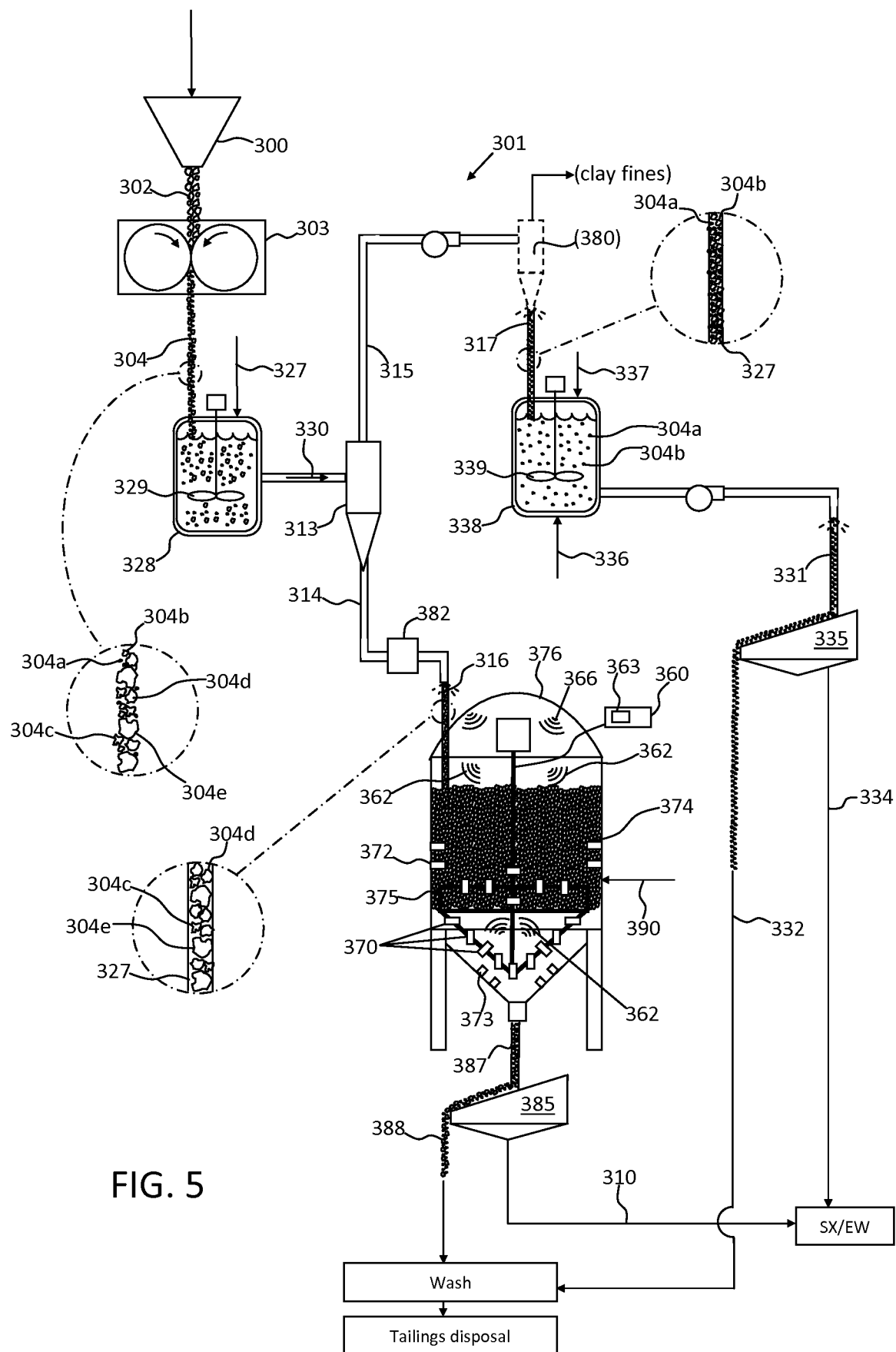
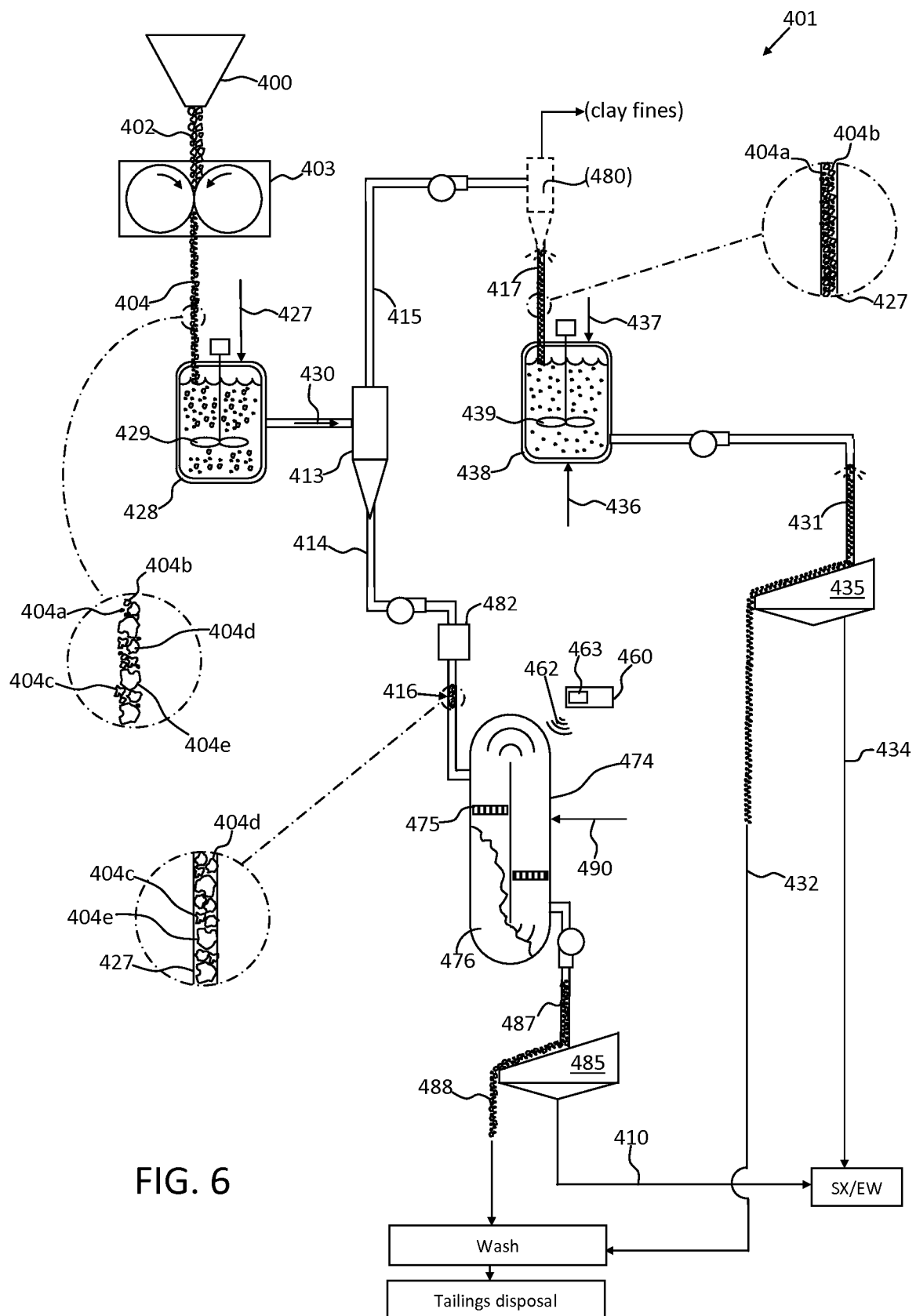
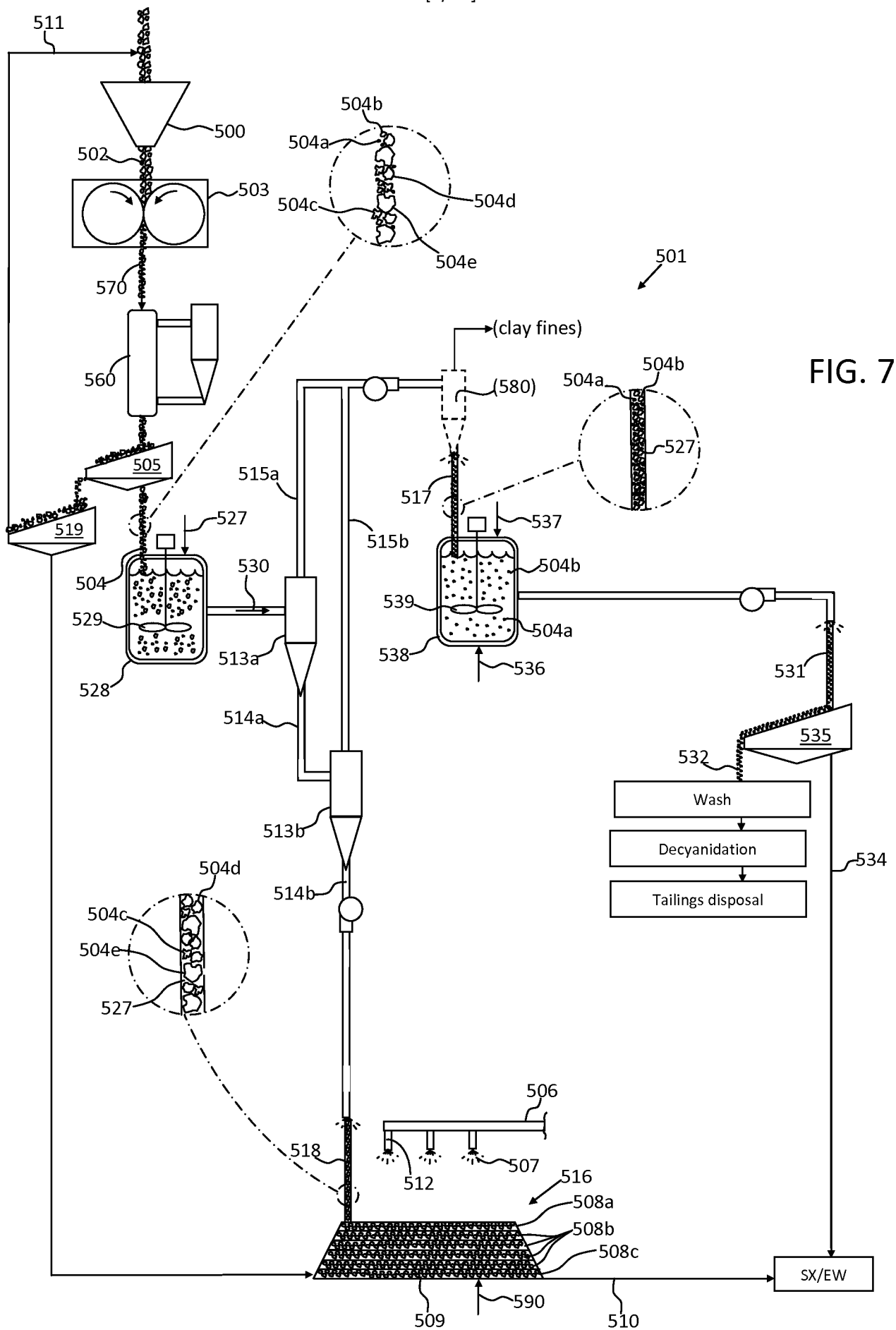
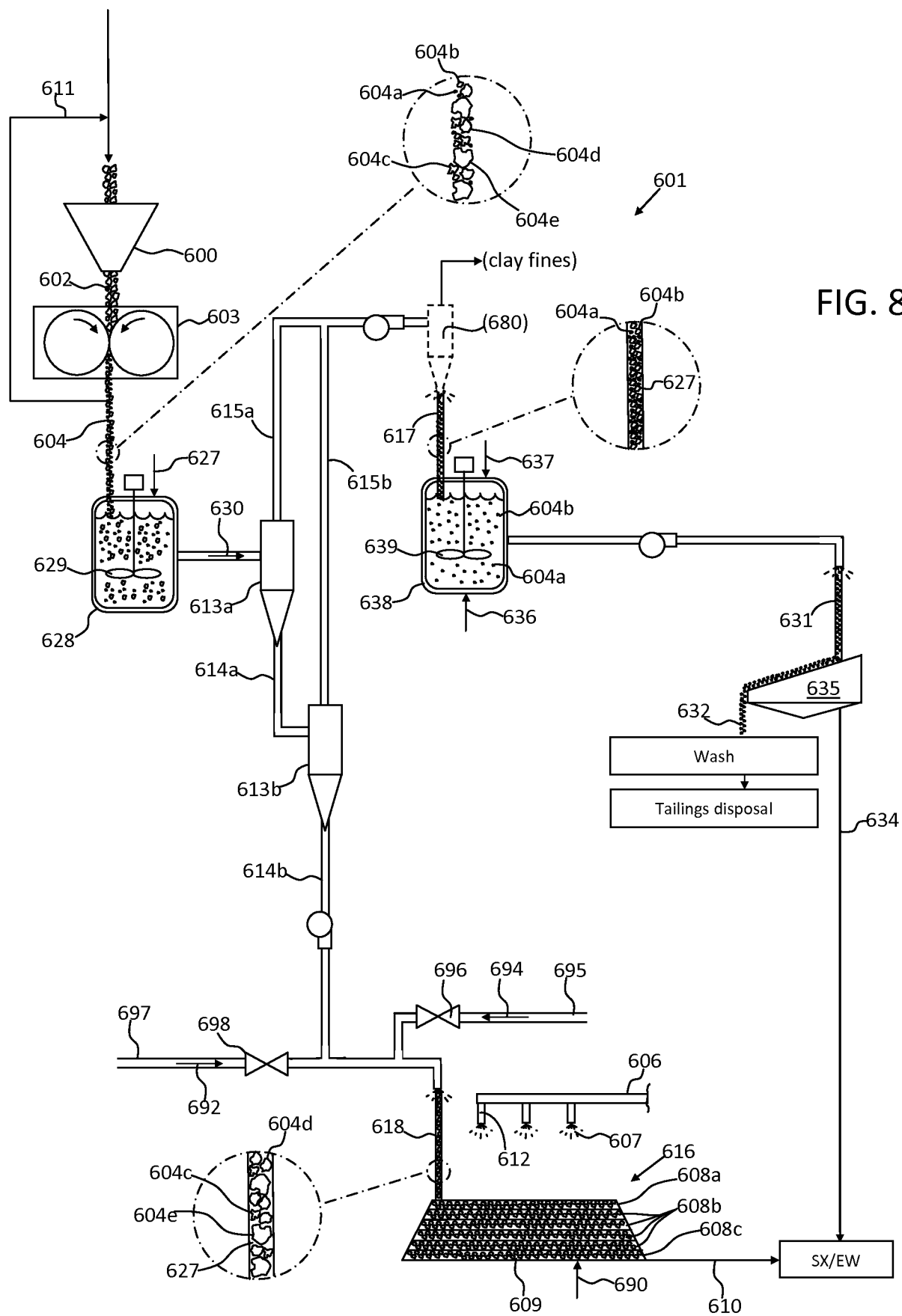


FIG. 4









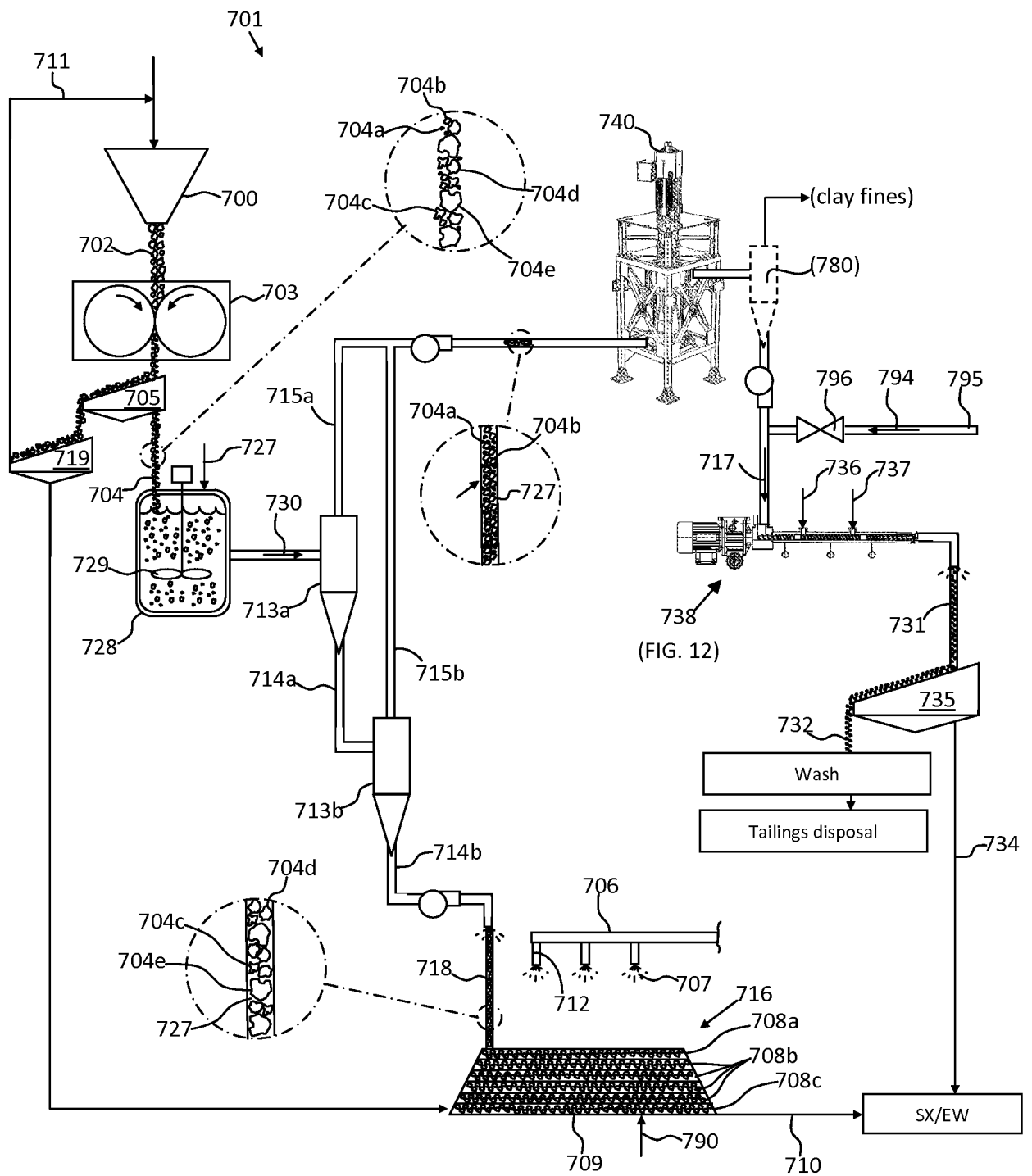
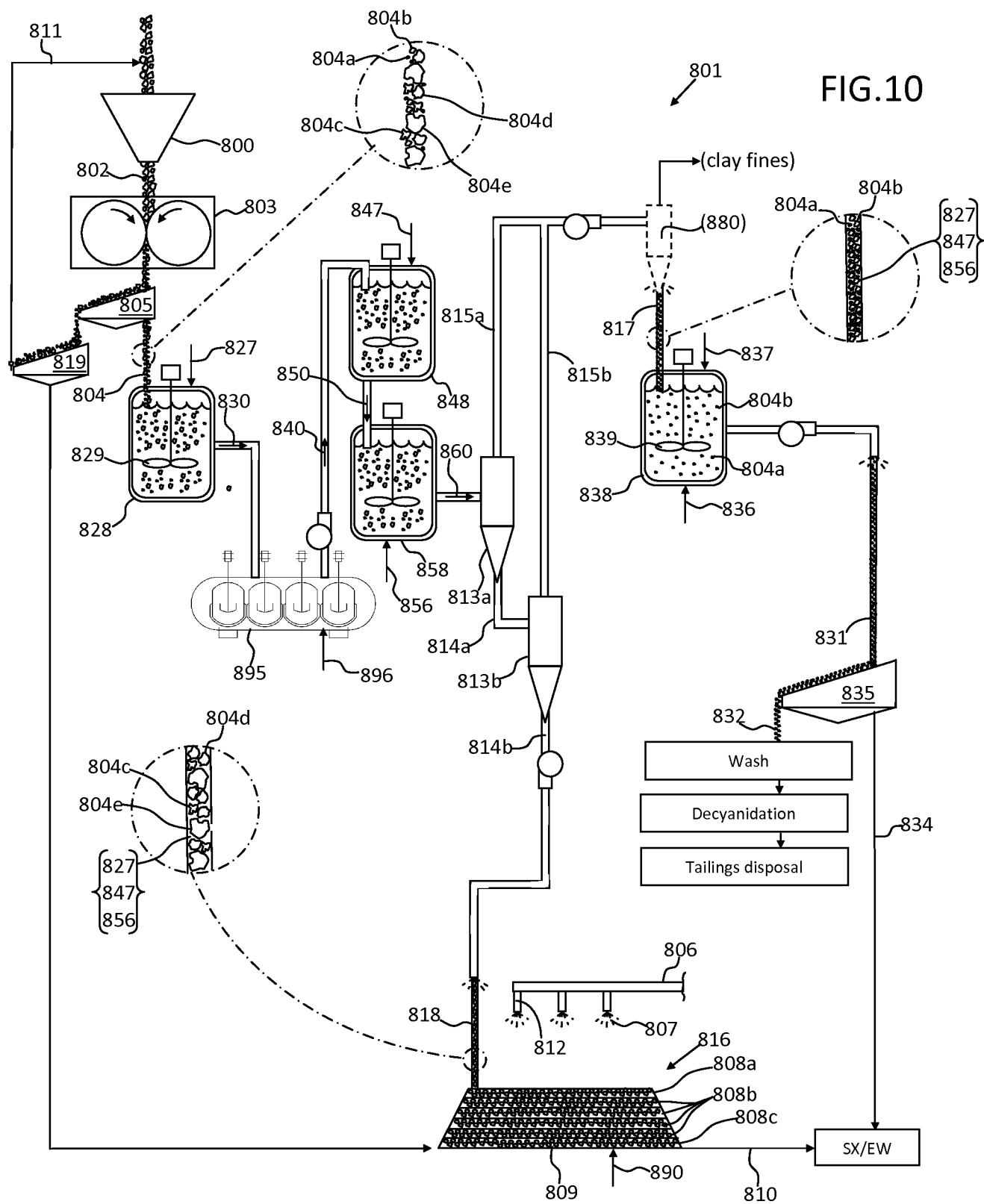
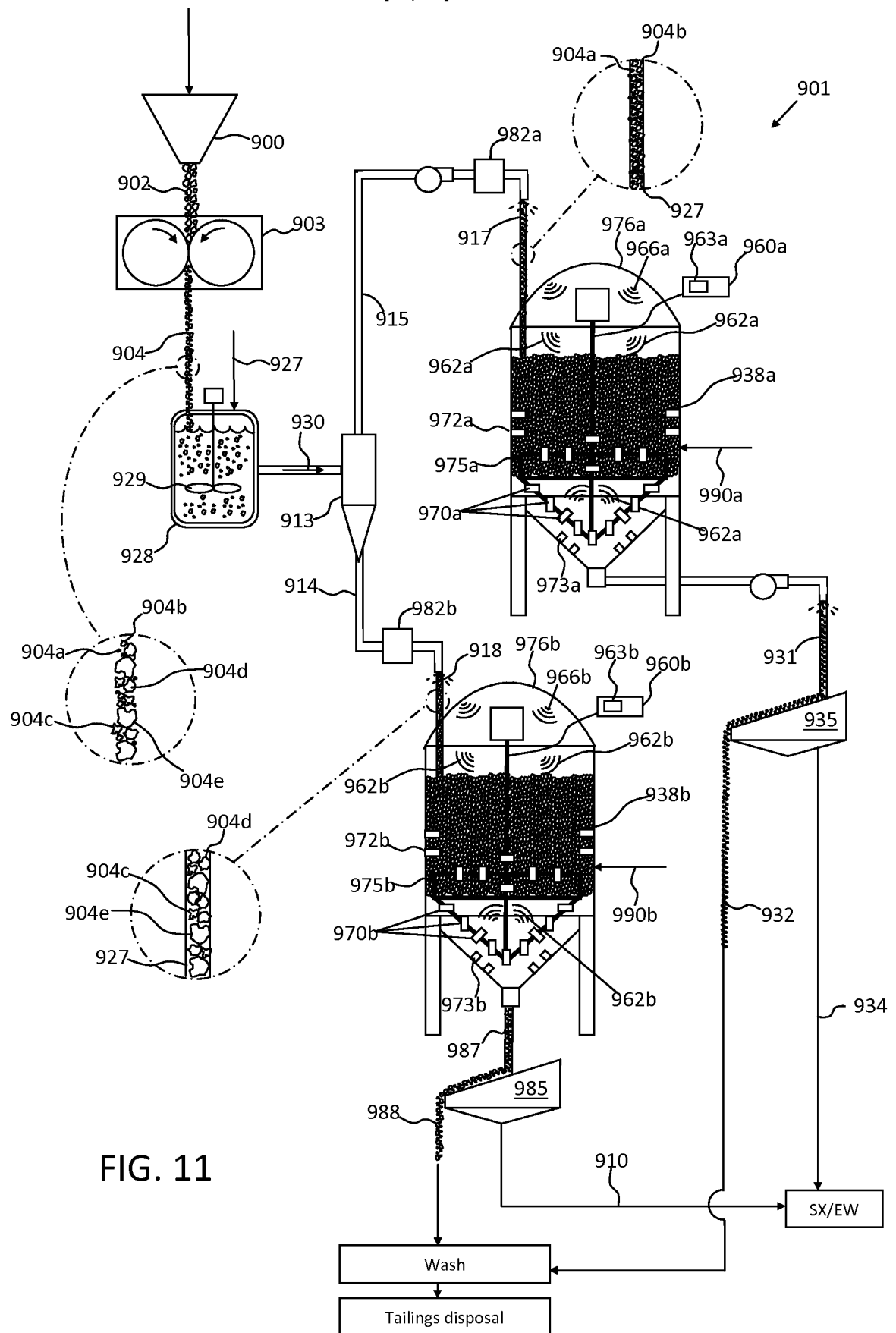


FIG. 9

FIG.10





[11/13]

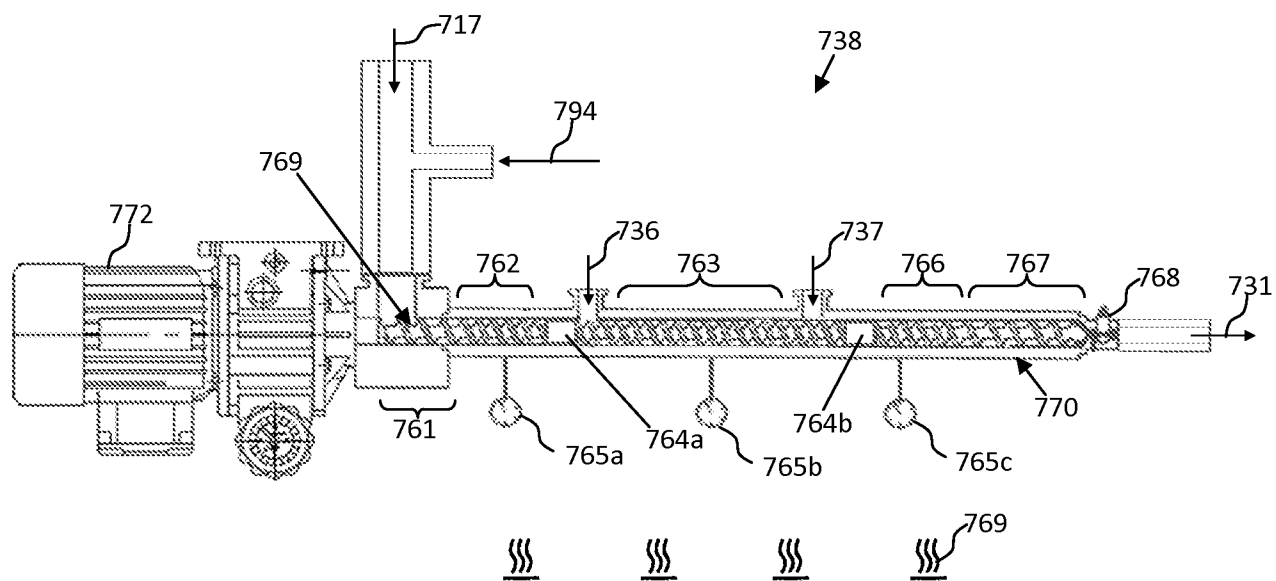


FIG. 12

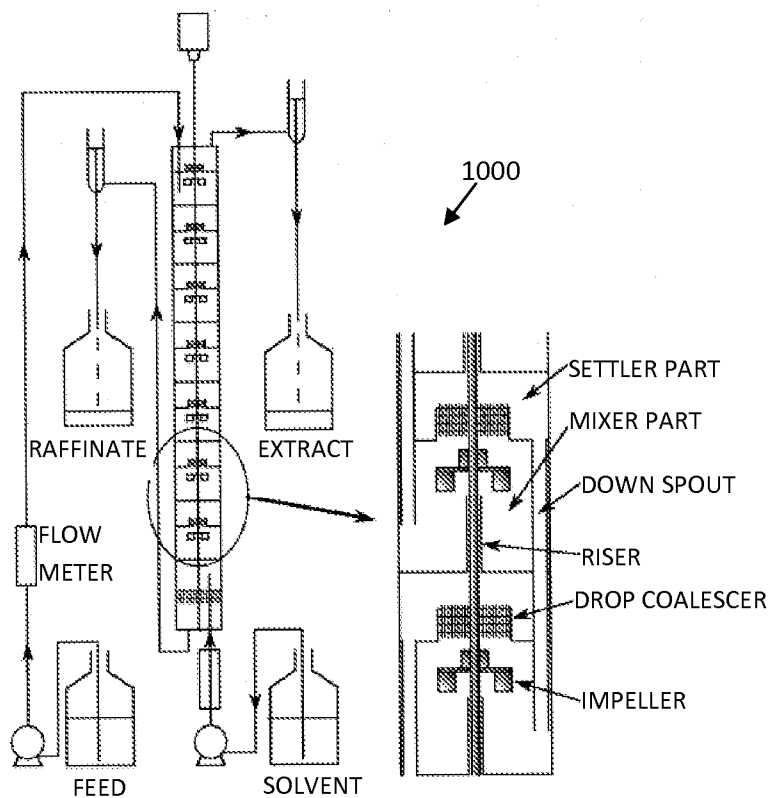


FIG. 13

[12/13]

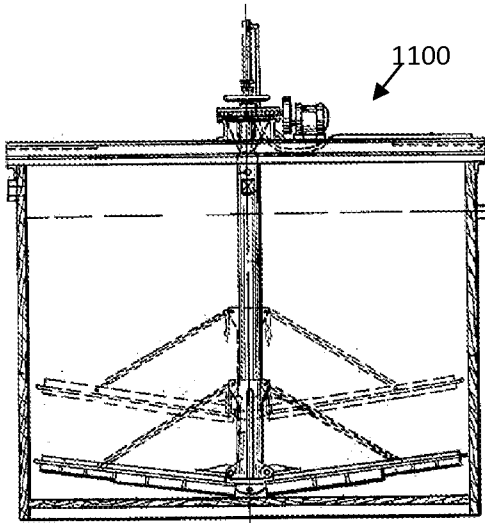


FIG. 14

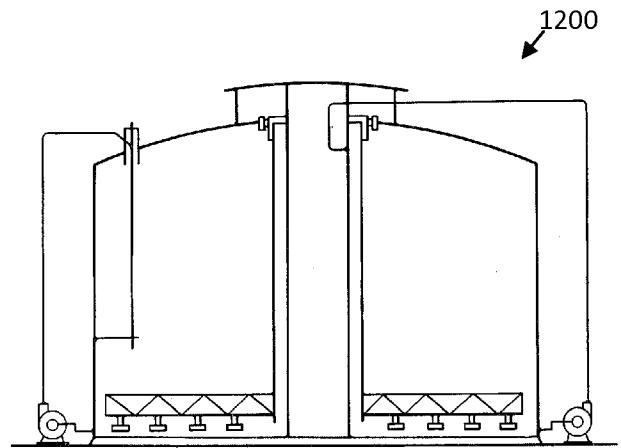


FIG. 15

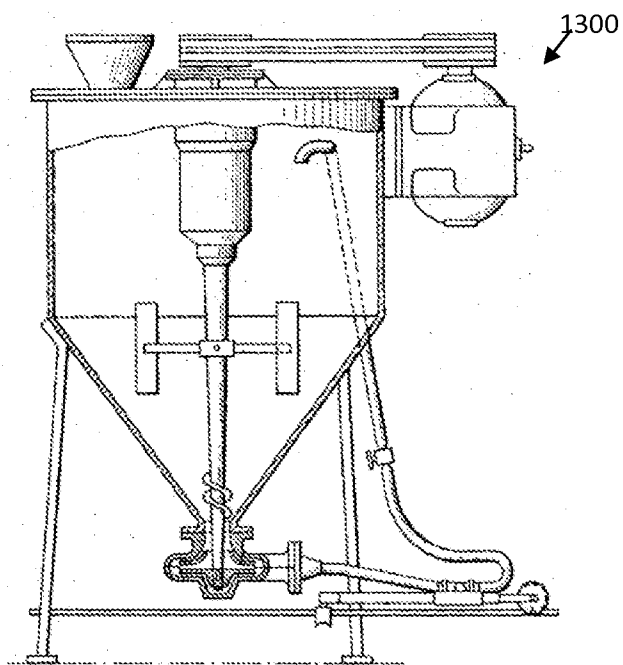


FIG. 16

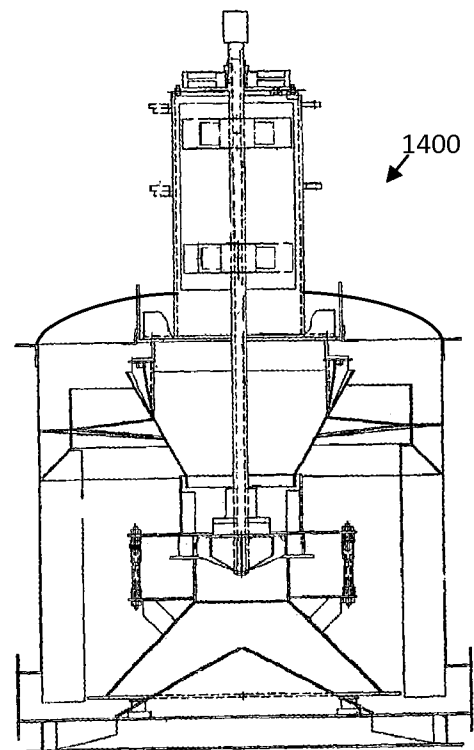


FIG. 17

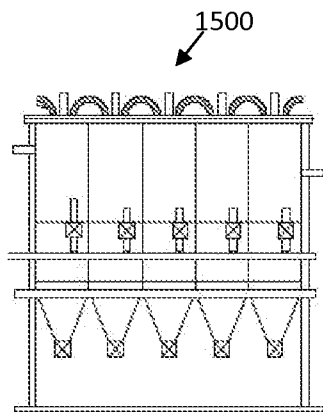


FIG. 18

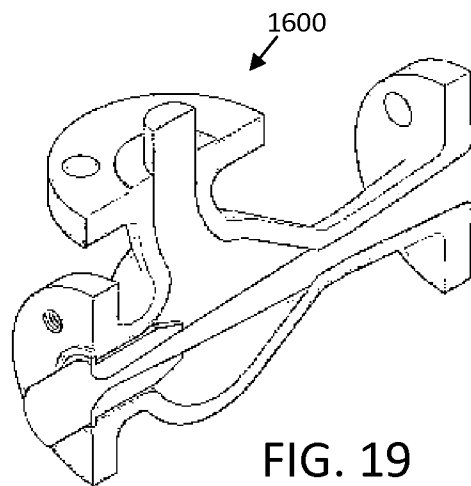


FIG. 19

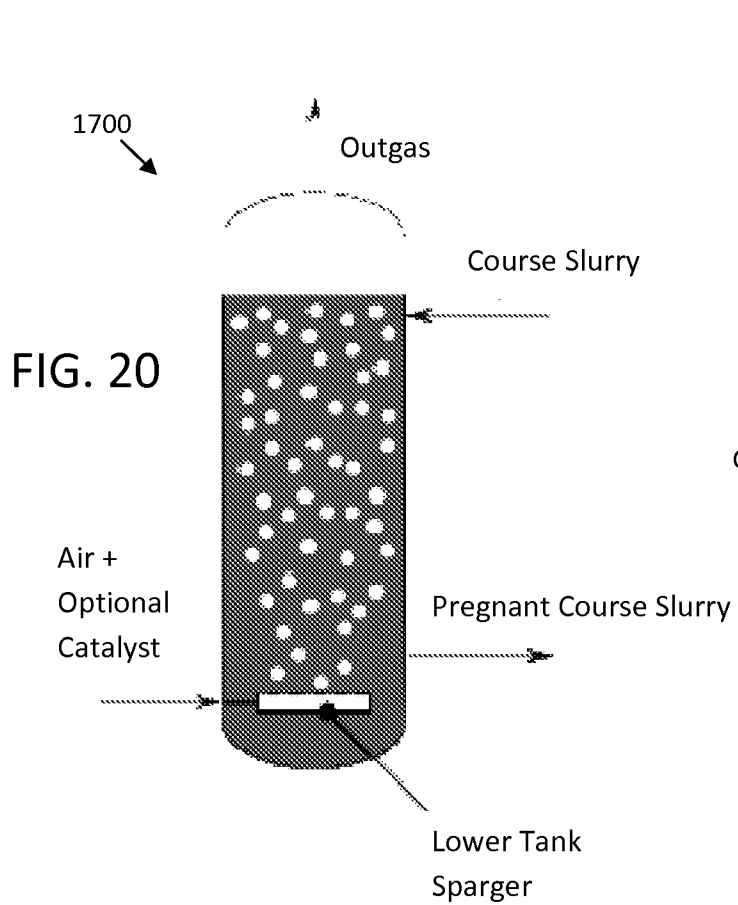


FIG. 20

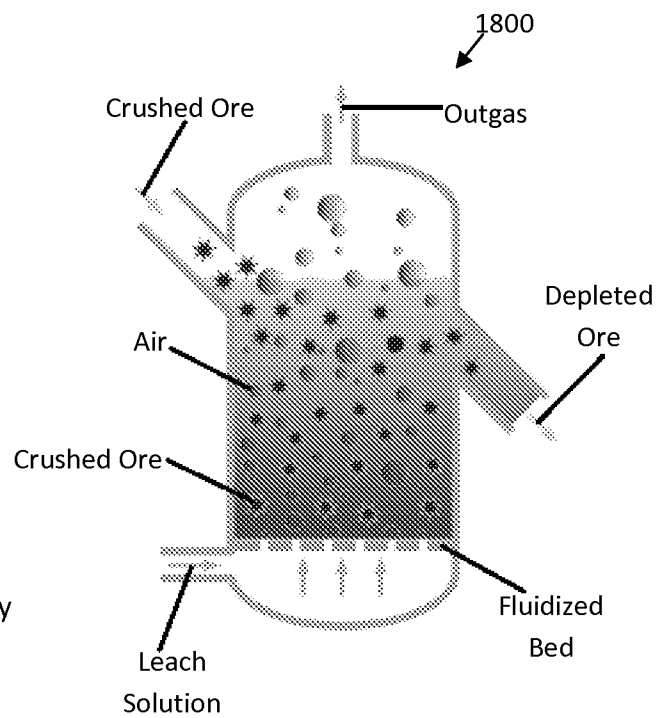


FIG. 21

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/074589

A. CLASSIFICATION OF SUBJECT MATTER.

IPC(8) - C22B 3/04 (2014.01)

USPC - 75/711

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(8) - C22B 3/04, C22B 15/00, C22B 11/00 (2014.01)

USPC - 75/354, 711, 743, 744; 266/101, 137

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - C22B 3/04, C22B 11/04, C22B 15/0065 (2013.01)

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

PatFt, AppFt, Orbit, Google Scholar

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6,319,389 B1 (FOUNTAIN et al) 20 November 2001 (20.11.2001) entire document	1-4, 17, 18, 20, 21
---		5-16, 19
Y	US 8,003,064 B2 (SAVAGE et al) 23 August 2011 (23.08.2011) entire document	5, 8, 14, 15, 19
Y	US 2011/0113928 A1 (HOLLITT et al) 19 May 2011 (19.05.2011) entire document	6-15
Y	US 4,365,975 A (WILLIAMS et al) 28 December 1982 (28.12.1982) entire document	16
A	US 7,964,016 B2 (PEREIRA et al) 21 June 2011 (21.06.2011) entire document	1-21
A	US 5,527,382 A (PINCHEIRA ALVAREZ et al) 18 June 1996 (18.06.1996) entire document	1-21

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:

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

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"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

10 March 2014

Date of mailing of the international search report

04 APR 2014

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