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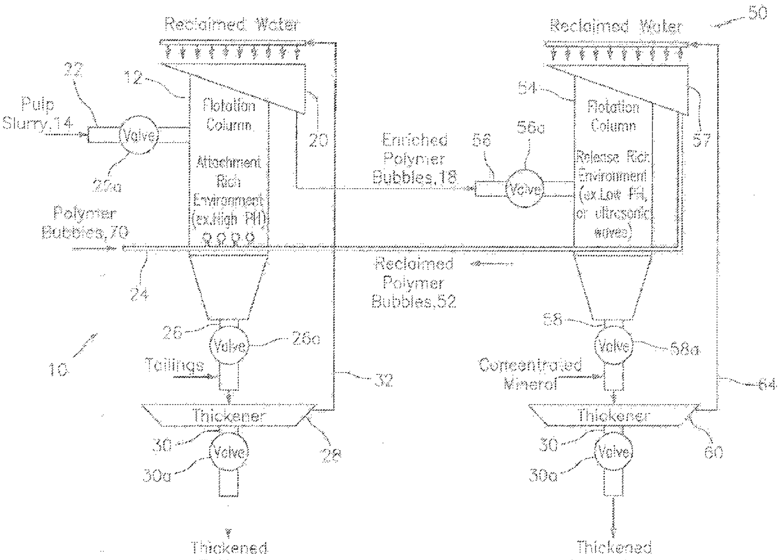

Figure 1

(57) **Abstract:** Apparatus is provided for recovering mineral particles of interest from a pulp having crushed ore in a mining process, featuring: a conditioner configured to receive and condition a pulp having crushed ore with mineral particles of interest using a hydrophobic conditioner and provide hydrophobic conditioned crushed ore having a hydrophobicity; and a further conditioner configured to receive and further condition the hydrophobic conditioned crushed ore using a promoter having a hydrophobic polymer or surfactant and provide enhanced hydrophobic further conditioned crushed ore having an enhanced hydrophobicity that is greater than the hydrophobicity of the hydrophobic conditioned crushed ore. In place of using diesel oil, the present invention uses hydrophobic polymers and surfactants that significantly improve the recovery of valuable minerals. These materials are also not malodorous, have good safety profiles, and do not chemically degrade in-situ.

[Continued on next page]

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NOVEL PROMOTERS FOR MINERAL COLLECTION

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

The present application claims the benefit of U.S. Provisional Patent Application No. 63/408,923, filed 22 September 2023, which is incorporated by reference herein in its entirety.

BACKGROUND OF THE INVENTION

1. Technical Field

This invention relates generally to techniques for separating valuable material from unwanted material in a mixture, such as a pulp slurry; and more particularly, relates to a method and apparatus for separating valuable material from unwanted material in a mixture, such as a pulp slurry, e.g., using an engineered collection media.

2. Description of Related Art

Regarding the present invention, in the prior art ore is crushed and wet ground to obtain a pulp for subsequent processing in order to recover valuable minerals. This pulp is typically treated with collector chemistry, also called promoter, in order to render the minerals of interest hydrophobic. This differentiates the minerals from the hydrophilic, unwanted, gangue particles such that the valuable minerals may be separated from the gangue and concentrated for further processing. Collectors and promoters are generally based on oils (such as diesel oil), fatty acids, xanthates, thionocarbamates, thiocarbanilides, xanthogen formates, dithiophosphates, mercaptans, amine compounds, alkyl and aryl sulfonates, and alkyl sulfides.

All known collectors and promoters have limitations in their ability to hydrophobize minerals and effectively allow hydrophobic-hydrophilic separation. Additionally, many are malodorous, have poor safety profiles, and/or chemically degrade in-situ.

SUMMARY OF THE DISCLOSURE

The Present Invention

According to the present invention, in place of using diesel oil, the inventor found that hydrophobic polymers and surfactants significantly improve the recovery of valuable minerals. Additionally, these materials are not malodorous, have good safety profiles, and do not chemically degrade in-situ.

By way of example, the present invention may take the form of apparatus for recovering mineral particles of interest from a pulp having crushed ore in a mining process, featuring:

a conditioner configured to receive and condition a pulp having crushed ore with mineral particles of interest using a hydrophobic conditioner and provide hydrophobic conditioned crushed ore having a hydrophobicity; and

a further conditioner configured to receive and further condition the hydrophobic conditioned crushed ore using a promoter having a hydrophobic polymer or surfactant and provide enhanced hydrophobic further conditioned crushed ore having an enhanced hydrophobicity that is greater than the hydrophobicity of the hydrophobic conditioned crushed ore.

The present invention may also include one or more of the following:

The hydrophobic polymer or surfactant may include a liquid PDMS polymer, a glycerol monooleate surfactant or an MQ Resin powder polymer.

The further conditioner may further condition the pulp using a concentration of the hydrophobic polymer or surfactant in a range of about 15-50 ppm w/w.

The conditioner may be configured to condition the pulp using potassium amyl xanthate (PAX).

The conditioner may condition the pulp using the potassium amyl xanthate (PAX) in a concentration of about 50 ppm w/w, including conditioning for about 5 minutes.

The apparatus may include a grinding stage that crushed the crushed ore to a P80 of about 370 um.

The hydrophobic polymer or surfactant may include a hydrophobic silica polymer, a polyglycol polymer, or a Br Sec Alc EtO polymer.

The mineral particles of interest may be copper or molybdenum.

The apparatus may include hydrophobic media with either hydrophobic coated reticulated foam or hydrophobic bubbles or beads for processing the enhanced hydrophobic further conditioned crushed ore.

Alternatively, the apparatus may include a mineral flotation processor for processing the further conditioned crushed ore.

The Method

The present invention may also take the form of a method for recovering mineral particles of interest from a pulp having crushed ore in a mining process, e.g., having steps for:

receiving and conditioning a pulp having crushed ore with mineral particles of interest using a hydrophobic conditioner and providing hydrophobic conditioned crushed ore having a hydrophobicity; and

receiving and further conditioning the hydrophobic conditioned crushed ore using a promoter having a hydrophobic polymer or surfactant and providing enhanced hydrophobic further conditioned crushed ore having an enhanced hydrophobicity that is greater than the hydrophobicity of the hydrophobic conditioned crushed ore.

The method may also include one or more of the features set forth herein.

BRIEF DESCRIPTION OF THE DRAWING

Referring now to the drawing, which is not necessarily drawn to scale, the foregoing and other features and advantages of the present invention will be more fully understood from the following detailed description of illustrative embodiments, taken in conjunction with the accompanying drawing in which like elements are numbered alike:

Figure 1 is a diagram of a flotation system, process or apparatus according to some embodiments of the present invention.

Figure 2 is a diagram of a flotation cell or column that may be used in place of the flotation cell or column that forms part of the flotation system, process or apparatus shown in Figure 1 according to some embodiments of the present invention.

Figure 3 is a diagram of a bead recovery processor in which the valuable material is thermally removed from the polymer bubbles or beads, according to some embodiments of the present invention.

Figure 4 is a diagram of a bead recovery processor in which the valuable material is sonically removed from the polymer bubbles or beads, according to some embodiments of the present invention.

Figure 5 is a diagram of a bead recovery processor in which the valuable material is chemically removed from the polymer bubbles or beads, according to some embodiments of the present invention.

Figure 6 is a diagram of a bead recovery processor in which the valuable material is electromagnetically removed from the polymer bubbles or beads, according to some embodiments of the present invention.

Figure 7 is a diagram of a bead recovery processor in which the valuable material is mechanically removed from the polymer bubbles or beads, according to some embodiments of the present invention.

Figure 8 is a diagram of a bead recovery processor in which the valuable material is removed from the polymer bubbles or beads in two or more stages, according to some embodiments of the present invention.

Figure 9 is a diagram of an apparatus using counter-current flow for mineral separation, according to some embodiments of the present invention.

Figure 10a illustrates a collection media taking the form of an open-cell foam in a cubic shape.

Figure 10b illustrates a filter according to some embodiments of the present invention.

Figure 10c illustrates a section of a membrane or conveyor belt according to an embodiment of the present invention.

Figure 10d illustrates a section of a membrane or conveyor belt according to another embodiment of the present invention.

Figure 11 illustrates a separation processor configured with a conveyor belt arranged therein according to some embodiments of the present invention.

Figure 12 illustrates a separation processor configured with a filter assembly according to some embodiments of the present invention.

Figure 13 illustrates a co-current tumbler cell configured to enhance the contact between the collection media and the mineral particles in a slurry, according to some embodiments of the present invention.

Figure 14 illustrates a cross-current tumbler cell configured to enhance the contact between the collection media and the mineral particles in a slurry, according to some embodiments of the present invention.

Figure 15a illustrates a synthetic bead having a body made of the hydrophobic foam, according to some embodiments of the present invention.

Figure 15b illustrates a synthetic bead having a body with a surface layer made of the hydrophobic foam, according to some embodiments of the present invention.

Figure 16 is a picture showing reticulated foam with Cu Mineral entrained throughout the structure.

Figure 17 is a graph showing Total Mass Pull, % of Cu recovery and % of Mo Recovery for further conditioned crushed ore using diesel as a secondary promotor (prior art) in comparison to enhanced hydrophobic further conditioned crushed ore using a second hydrophobic promoter according to the present invention.

Figure 18 is a graph showing Total Mass Pull, % of Cu recovery and % of Mo Recovery for hydrophobic conditioned crushed ore using diesel as a secondary promotor (prior art) in comparison to enhanced hydrophobic further conditioned crushed ore using a second hydrophobic promoter according to the present invention.

Figure 19 is a block diagraph of apparatus having a conditioner and further conditioner according to some embodiments of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

This application builds and improves on the Assignee's technology for recovering or collecting mineral particles of interest from crushed ore, including copper and molybdenum.

By way of example, Assignee's technology includes that disclosed in PCT/US2019/017003, filed 07 February 2019 (Atty docket no. 712-002.363-1/CCS-0205WO), which is hereby incorporated by reference, as well as the family of technologies, including those set forth and incorporated by reference below.

In the present application, Figures 1-16 form part of the aforementioned PCT application no. PCT/US2019/017003, filed 07 February 2019 (Atty docket no. 712-002.363-1/CCS-0205WO); and Figures 17-19 form part of the present improvement to the Assignee's overall family of technology, including that disclosed in relation to Figures 1-16 herein.

Figures 17-18

In the mining industry, the common collector, potassium amyl xanthate (PAX) was used to hydrophobize the mineral. For example, after conditioning the ore with the PAX for five minutes, diesel oil was added to further improve mineral collection; again conditioning the ore for another five minutes. This collector scheme is common in the mining industry and used as the control for comparison in the experiments conducted in relation to the present invention.

According to the present invention, and experimentation set forth below, diesel oil is replaced with various hydrophobic polymers and surfactants which increased both copper and molybdenum recovery. Mineral collection can then be achieved by contacting the treated or conditioned crushed ore with hydrophobic coated reticulated foam. Moreover, similar results are envisioned and likely with the standard mineral flotation process, e.g., using air bubbles, etc.

Figure 17 (Example 1):

According to the present invention, and by way of example, an experiment known as Example 1 was conducted, as follows:

Ore containing small amounts of chalcopyrite and molybdenite was ground to a P_{80} of 370 microns (µm). The ore slurry was conditioned for five minutes with PAX at approximately 50 ppm w/w based on ore solids. The ore was then conditioned for another five minutes with a second hydrophobic promoter at concentrations varying from 15 – 50 ppm w/w (weight-to-weight). The Assignee's hydrophobic coated Media 1 was then placed in agitated contact with the conditioned ore slurry for one minute, removed from the ore slurry, and rinsed with water. The hydrophobic coated Media 1, well-coated with minerals, was then placed in a dilute surfactant solution and agitated to remove the minerals. The minerals were then separated from the surfactant solution, rinsed, dried, and weighed. The minerals collected were then analyzed, e.g., via an Inductively Coupled Plasma Mass Spectrometer (ICP) for copper and molybdenum content.

Diesel oil was used as a control in these experiments. The novel hydrophobic promoters used in place of diesel achieved improved collection of the mineral (6.3 – 6.5 g vs 6.0 g), increased Cu recovery (66.2 – 66.9% vs 62.7%), and increased Mo recovery (83.5 – 84.8% vs 81.0%).

Figure 18 (Example 2):

The same experimental procedure was used from Example 1; however, the Assignee's hydrophobic Media 2 was used instead of its hydrophobic Media 1 and some different hydrophobic promoters were used.

The following novel hydrophobic promoters (Liquid PDMS 1k cP, Vinyl PDMS 20K cP, Glycerol monooleate surfactant, MQ resin powder, Polyglycol 2000, and Ethoxylated acetylenic gem diol surfactant) used in place of diesel achieved improved collection of the mineral (6.8 – 7.5 g vs 6.5 g), increased Cu recovery (68.0 – 72.2% vs 66.7%), and increased Mo recovery (83.4 – 84.9% vs 82.9%).

Examples 1 & 2 Results Table:

The following is a resulting table showing Total Mass Pull, % of Cu recovery and % of Mo Recovery for hydrophobic Media 1 and 2 using diesel as a secondary promotor (prior art) in comparison to the hydrophobic Media 1 and 2 using a second hydrophobic promoter according to the present invention.

	Total Mass Pull	% Cu Grade	% Cu Rec	% Mo Grade	% Mo Rec
Media1 Collector(5)+Diesel(5)	6.0	10.8	62.7	1.5	81.0
Media1 Collector(5)+Liquid PDMS-1K(5)	6.4	10.4	66.2	1.4	83.5
Media1 Collector(5)+Glycerol Monooleate Surfac	6.5	10.5	66.6	1.5	84.8
Media1 Collector(5)+MQ Resin Powder(5)	6.3	10.5	66.9	1.5	83.6
Media2 Col(5)+Diesel(5)	6.5	10.3	66.7	1.5	82.9
Media2 Col(5)+Liquid PDMS-1K(5)	6.8	10.2	69.7	1.4	84.0
Media2 Col(5)+Liquid PDMSVi-20K(5)	6.6	10.2	67.9	1.6	84.9
Media2 Col(5)+Liquid PDMS-4 (5)	6.4	10.2	65.0	1.3	77.4
Media2 Col(5)+Liquid PDMSOH-750(5)	6.4	10.4	65.5	1.4	80.5
Media2 Col(5)+Hydrophobic silica(5)	6.8	10.0	66.9	1.4	79.4
Media2 Col(5)+Glycerol Monooleate Surf(5)	7.5	9.5	72.2	1.2	84.1
Media2 Col(5)+MQ Resin Powder(5)	7.2	9.8	72.0	1.3	83.4
Media2 Col(5)+Polyglycol2000(5)	7.2	9.4	69.8	1.2	83.4
Media2 Col(5)+Silicone Polyether surfactant(5)	6.1	10.8	67.4	1.5	82.4
Media2 Col(5)+Br Sec Alc EtO HLB=8.1 (5)	6.8	9.0	67.0	1.2	81.8
Media2 Col(5)+EtO Acetylenic Gem Surf(5)	6.6	9.9	68.0	1.3	81.0
Media2 NoCol Glycerol Monooleate Surf (5)	3.0	18.5	54.8	2.9	81.3
Media2 NoCol Liquid PDMS(5)	3.0	18.9	54.4	3.1	81.6

As one can see from the Table, low molecular weight PDMS (4 cP) had a negative effect on mineral collection (6.4g/ 65.0% Cu Recovery/ 77.4% Mo Recovery). Hydroxy PDMS also had a negative effect on mineral collection (6.4g/ 65.5% Cu Recovery/ 80.5% Mo Recovery). Hydrophobic silica had a negative effect on Mo recovery (79.4%). Silicone polyether surfactant and the branched secondary alcohol ethoxylate had a neutral impact on mineral collection.

Not being held to theory, it is considered that higher molecular weight hydrophobes associate with the reacted collector on the collectorized mineral and thereby increase mineral hydrophobicity. This increased hydrophobicity further enhances mineral collection to the hydrophobic media in the aqueous system. In the case of lower molecular weight hydrophobes, very small hydrophobic particles, or materials that are insufficiently hydrophobic, the effect on mineral collection is neutral or negative.

Figure 19

By way of example, the present invention may take the form of apparatus generally indicated as 100 for recovering mineral particles of interest from a pulp having crushed ore in a mining process, comprising:

a conditioner 1002 configured to receive and condition a pulp having crushed ore with mineral particles of interest using a hydrophobic conditioner and provide hydrophobic conditioned crushed ore having a hydrophobicity; and

a further conditioner 1004 configured to receive and further condition the hydrophobic conditioned crushed ore using a promoter having a hydrophobic polymer or surfactant and provide an enhanced hydrophobic further conditioned crushed ore having an enhanced hydrophobicity that is greater than the hydrophobicity of the hydrophobic conditioned crushed ore.

The enhanced hydrophobic further conditioned crushed ore may then be further processed consistent with that disclosed herein, e.g., using the Assignee's hydrophobic media, e.g., including coated reticulated foam, hydrophobic coated bubbles/bead, as well as by using a known mineral flotation apparatus along with air bubble, etc.

Figures 1-16 from the Earlier Application

The earlier application disclosed a new and improved hydrophobic foam which can be used as synthetic beads, filters, conveyor belts or any collection substrates for attracting mineral particles in an aqueous slurry. In particular, the hydrophobic foam is a reticulated foam, an open-network structure or three-dimensional open-cell structure made from a hydrophobic material, which is a reaction product of an isocyanate and a polyol.

As used herein, the reaction product of isocyanate and polyol described above having the open-network structure, reticulated structure or three-dimensional open-cell structure is also referred as the hydrophobic foam. The engineered collection medium made of the hydrophobic foam taken the form of a cube or sphere is also referred to as synthetic bead or polymer bubble. For example, Figure 15a illustrates a synthetic bead having a body entirely made of the hydrophobic foam. Figure 15b illustrates a synthetic bead having a surface layer made of the hydrophobic foam, whereas the core of the synthetic bead is made of a different material.

Figure 1

By way of example, Figure 1 shows apparatus 10 having a flotation cell or column 12 configured to receive a mixture of fluid (e.g. water), valuable material and unwanted material, e.g., a pulp slurry 14; receive synthetic bubbles or beads 70 that are constructed to be buoyant when submerged in the pulp slurry or mixture 14 and be hydrophobic to attach to the valuable material in the pulp slurry or mixture 14; and provide enriched synthetic beads 18 having the valuable material attached thereon. The terms “synthetic bubbles or beads” and “polymer bubbles or beads” are used interchangeably in this disclosure. Also, the terms “polymer bubbles” and “synthetic beads” are synonymous with the “engineered collection media” made of the hydrophobic foam in a cube or spherical form. The terms “valuable material”, “valuable mineral” and “mineral particle” are also used interchangeably. By way of example, the synthetic beads 70 may be cubes or spheres made entirely from a hydrophobic material which is a reaction product of isocyanate and polyol and have an open-network structure, reticulated foam structure or three-dimensional open-cell structure. The hydrophobic material is also referred to as a hydrophobic foam. The synthetic beads 70 may have a core made of polymer or polymer-based materials, or silica or silica-based materials, or glass or glass-based materials, and a surface layer made of the hydrophobic foam. For the purpose of describing one example of the present invention, in Figure 1 the synthetic beads 70 and the enriched synthetic beads 18 are shown. The flotation cell or column 12 is configured with a top portion or piping 20 to provide the enriched synthetic beads 18 from the flotation cell or column 12 for further processing consistent with that set forth herein.

The flotation cell or column 12 may be configured with a top part or piping 22, e.g., having a valve 22a, to receive the pulp slurry or mixture 14 and also with a bottom part or piping 24 to receive the synthetic beads 70. In operation, the buoyancy of the synthetic beads 70 causes them to float upwardly from the bottom to the top of the flotation cell or column 12 through the pulp slurry or mixture 14 in the flotation cell or column 12 so as to collide with the water, valuable material and unwanted material in the pulp slurry or mixture 14. The hydrophobicity of the synthetic beads 70 causes them to attach to the valuable material in the pulp slurry or mixture 14. As being made of a hydrophobic foam, the synthetic beads 70 attract the valuable material to the surface structure, so that the valuable material is lifted through the cell or column 12 due to the buoyancy of the synthetic beads 70. As a result of the collision between the synthetic beads 70 and the water, valuable material and unwanted material in the pulp slurry or mixture 14, and the attachment of the synthetic beads 70 and the valuable material in the pulp slurry or mixture 14, the enriched synthetic beads 18 having the valuable material attached thereto will float to the top of the flotation cell 12 and form part of the froth formed at the top of the flotation cell 12. The flotation cell 12 may include a top part or piping 20 configured to provide the enriched synthetic beads 18 having the valuable material attached thereto, which may be further processed consistent with that set forth herein. In effect, the enriched synthetic beads 18 may be taken off the top of the flotation cell 12 or may be drained off by the top part or piping 20.

The flotation cell or column 12 may be configured to contain an attachment rich environment, including where the attachment rich environment has a high pH, so as to encourage the flotation recovery process therein. The flotation recovery process may include the recovery of ore particles in mining, including copper. The scope of the invention is not intended to be limited to any particular type or kind of flotation recovery process either now known or later developed in the future. The scope of the invention is also not intended to be limited to any particular type or kind of mineral of interest that may form part of the flotation recovery process either now known or later developed in the future.

The synthetic beads 70 may be configured with a surface area flux by controlling some combination of the size of the polymer or polymer-based bubbles and/or the injection rate that the pulp slurry or mixture 14 is received in the flotation cell or column 12. The synthetic beads 70 may also be configured with a low density so as to behave like air bubbles. The synthetic beads 70 may also be configured with a controlled size distribution of medium that may be customized to maximize recovery of different feed matrixes to flotation as valuable material quality changes, including as ore quality changes.

The flotation cell or column 12 may be configured to receive the synthetic beads 70 together with air, where the air is used to create a desired froth layer in the mixture in the flotation cell or column 12 in order to achieve a desired grade of valuable material. The synthetic beads 70 may be configured to lift the valuable material to the surface of the mixture in the flotation cell or column.

The Thickener 28

The apparatus 10 may also include piping 26 having a valve 26a for providing tailings to a thickener 28 configured to receive the tailings from the flotation cell or column 12. The thickener 28 includes piping 30 having a valve 30a to provide thickened tailings. The thickener 28 also includes suitable piping 32 for providing reclaimed water back to the flotation cell or column 12 for reuse in the process. Thickeners like element 28 are known in the art, and the scope of the invention is not intended to be limited to any particular type or kind either now known or later developed in the future.

The Bead Recovery Process or Processor 50

The apparatus 10 may further include a bead recovery process or processor generally indicated as 50 configured to receive the enriched synthetic beads 18 and provide reclaimed synthetic beads 52 without the valuable material attached thereon so as to enable the reuse of the synthetic beads 52 in a closed loop process. By way of example, the bead recovery process or processor 50 may take the form of a washing station whereby the valuable mineral is mechanically, chemically, or electro-statically removed from the enriched synthetic beads 18.

The bead recovery process or processor 50 may include a releasing apparatus in the form of a second flotation cell or column 54 having piping 56 with a valve 56a configured to receive the enriched synthetic beads 18; and substantially release the valuable material from the synthetic beads 18, and also having a top part or piping 57 configured to provide the reclaimed synthetic beads 52, substantially without the valuable material attached thereon The second flotation cell or column 54 may be configured to contain a release rich environment, including where the release rich environment has a low pH, or including where the release rich environment results from ultrasonic waves pulsed into the second flotation cell or column 54.

The bead recovery process or processor 50 may also include piping 58 having a valve 56a for providing concentrated minerals to a thickener 60 configured to receive the concentrated minerals from the flotation cell or column 54. The thickener 60 includes piping 62 having a valve 62a to provide thickened concentrate. The thickener 60 also includes suitable piping 64 for providing reclaimed water back to the second flotation cell or column 54 for reuse in the process. Thickeners like element 60 are known in the art, and the scope of the invention is not intended to be limited to any particular type or kind either now known or later developed in the future.

Embodiments are also envisioned in which the enriched synthetic beads are placed in a chemical solution so the valuable material is dissolved off, or are sent to a smelter where the valuable material is burned off, including where the synthetic beads are reused afterwards.

According to the present invention, and by way of example, the apparatus 1000 (Fig. 19) may be implemented to process the crushed ore before the pulp slurry 14 is provided to the flotation column 12.

Figure 2

Figure 2 shows alternative apparatus generally indicated as 200 in the form of an alternative flotation cell 201 that is based at least partly on a collision technique between the mixture and the synthetic beads. The mixture 202, e.g. the pulp slurry, may be received in a top part or piping 204, and the synthetic beads 206 may be received in a bottom part or piping 208. The flotation cell 201 may be configured to include a first device 210 for receiving the mixture 202, and also may be configured to include a second device 212 for receiving the polymer-based materials. The first device 210 and the second device 212 are configured to face towards one another so as to provide the mixture 202 and the synthetic beads 206, using the collision technique. In Figure 2, the arrows 210a represent the mixture being sprayed, and the arrows 212a represent the synthetic beads 206 being sprayed towards one another in the flotation cell 201.

In operation, the collision technique causes vortices and collisions using enough energy to increase the probability of touching of the synthetic beads 206 and the valuable material in the mixture 202, but not too much energy to destroy bonds that form between the synthetic beads 206 and the valuable material in the mixture 202. Pumps, not shown, may be used to provide the mixture 202 and the synthetic beads 206 are the appropriate pressure in order to implement the collision technique.

By way of example, the first device 210 and the second device 212 may take the form of shower-head like devices having a perforated nozzle with a multiplicity of holes for spraying the mixture and the synthetic beads towards one another. As a result of the collision between the synthetic beads 206 and the mixture, enriched synthetic beads having the valuable material attached thereto will float to the top and form part of the froth in the flotation cell 201. The flotation cell 201 may include a top part or piping 214 configured to provide enriched synthetic beads 216 having the valuable material attached thereto, which may be further processed consistent with that set forth herein.

The alternative apparatus 200 may be used in place of the flotation columns or cells, and inserted into the apparatus or system shown in Figure 1, and may prove to be more efficient than using the flotation columns or cells.

According to the present invention, and by way of example, the apparatus 1000 (Fig. 19) may be implemented to process the crushed ore before the pulp slurry 202 is provided to the top part or piping 204 of the apparatus 200.

Figures 3-8

Various embodiments of the present invention are envisioned as examples to show that the valuable minerals can be mechanically, chemically, thermally, optically or electromagnetically removed or released from the enriched synthetic beads.

By way of example, the bead recovery process or processor 50 as shown in Figure 1 can be adapted for the removal of valuable minerals from the enriched synthetic beads in different ways. The releasing apparatus may include, or take the form of, a heater 150 (Figure 3) configured to provide thermal heat for the removal of the valuable minerals from the enriched synthetic beads; an ultrasonic wave producer 164 (Figure 4) configured to provide an ultrasonic wave for the removal of valuable minerals from the enriched synthetic beads, a container 168 (Figure 5) configured to provide an acid or acidic solution 170 for the removal of the valuable minerals from the enriched synthetic beads; a microwave source 172 (Figure 6) configured to provide microwaves for the removal of the valuable minerals from the enriched synthetic beads, a motor 186 and a stirrer 188 (Figure 7) configured to stir the enriched synthetic beads for the removal of the valuable minerals from the enriched synthetic beads; and multiple release or recovery processors (Figure 8) configured to use multiple release or recovery techniques for the removal of the valuable minerals from the enriched synthetic beads. The aforementioned releasing apparatus may be responsive to signaling, e.g., from a controller or control processor. In view of the aforementioned, and by way of example, the releasing techniques are set forth in detail below:

Sonically Releasing Valuable Material

When ultrasonic waves are applied in a solution or mixture containing the enriched synthetic beads, they can cause the attached mineral particles to move rapidly against the surface of the synthetic beads, thereby shaking the mineral particles loose from the surface. It is known that ultrasound is a cyclic sound pressure with a frequency greater than the upper limit of human hearing. Thus, in general, ultrasound goes from just above 20 kilohertz (KHz) all the way up to about 300KHz. In ultrasonic cleaners, low frequency ultrasonic cleaners have a tendency to remove larger particle sizes more effectively than higher operational frequencies. However, higher operational frequencies tend to produce a more penetrating scrubbing action and to remove particles of a smaller size more effectively. In mineral releasing applications involving mineral particles finer than 100μm to 1mm or larger, the ultrasonic wave frequencies range from 10Hz to 10MHz. By way of example, the bead recovery process or processor 50 as shown in Figure 1 can be adapted for removing the mineral particles in the enriched synthetic beads 18 by applying ultrasound to the solution in the flotation column 54. For example, as the reclaimed water from piping 64 is used to wash the enriched synthetic bubbles 18 inside the flotation column 54, it is possible to use an ultrasonic wave producer 164 to apply the ultrasound 166 in order to release the valuable material from the enriched synthetic beads 18. A diagram illustrating the ultrasonic application is shown in Figure 4.

Chemically Releasing Valuable Material

In physisorption, the valuable minerals are reversibly associated with the synthetic bubbles or beads, attaching due to electrostatic attraction, and/or van der Waals bonding, and/or hydrophobic attraction, and/or adhesive attachment. The physisorbed mineral particles can be desorbed or released from the surface of the synthetic beads if the pH value of the solution changes. Furthermore, the surface chemistry of the most minerals is affected by the pH. Some minerals develop a positive surface charge under acidic conditions and a negative charge under alkaline conditions. The effect of pH changes is generally dependent on the collector and the mineral collected. For example, chalcopyrite becomes desorbed at a higher pH value than galena, and galena becomes desorbed at a higher pH value than pyrite. If the valuable mineral is collected at a pH of 8 to 11, it is possible to weaken the bonding between the valuable mineral and the surface of the synthetic beads by lower the pH to 7 and lower. However, an acidic solution having a pH value of 5 or lower would be more effective in releasing the valuable mineral from the enriched synthetic beads. The bead recovery process or processor 50 as shown in Figure 1 can be adapted for removing the mineral particles in the enriched synthetic beads 18 by changing the pH of the solution in the flotation column 54. For example, as the reclaimed water from piping 64 is used to wash the enriched synthetic bubbles 18 inside the flotation column 54, it is possible to use a container 168 to release an acid or acidic solution 170 into the reclaimed water as shown in Figure 5. There are a number of acids easily available for changing the pH. For example, sulfuric acid (HCl), hydrochloric acid (H_2SO_4), nitric acid (HNO_3), perchloric acid ($HClO_4$), hydrobromic acid (HBr) and hydroiodic acid (HI) are among the strong acids that completely dissociate in water. However, sulfuric acid and hydrochloric acid can give the greater pH change at the lowest cost. The pH value used for mineral releasing ranges from 7 to 0. Using a very low pH may cause the synthetic beads to degrade. It should be noted that, however, when the valuable material is copper, for example, it is possible to provide a lower pH environment for the attachment of mineral particles and to provide a higher pH environment for the releasing of the mineral particles from the synthetic beads or bubbles.

In general, the pH value is chosen to facilitate the strongest attachment, and a different pH value is chosen to facilitate release. Thus, one pH value is chosen for mineral attachment, and a different pH value is chosen for mineral releasing. The different pH could be higher or lower, depending on the specific mineral and collector.

The physisorbed mineral particles can be desorbed or released from the surface of the synthetic beads if a surface active agent is introduced which interferes with the attachment of the mineral particles and the bead surface. In one embodiment, when the surface active agent is combined with mechanical energy, the particle easily detaches from the surface.

Electromagnetically Releasing Valuable Material

More than one way can be used to interrupt the attachment of the mineral particles to the synthetic beads electromagnetically. For example, it is possible to use microwaves to heat up the enriched synthetic beads and the water in the flotation column. Thus, it is possible to provide a microwave source where the enriched synthetic bubbles are processed. By way of example, the bead recovery process or processor 50 as shown in Figure 1 can be adapted for removing the mineral particles in the enriched synthetic bubbles 18 by using an electromagnetic source to provide electromagnetic waves to the solution or mixture in the flotation column 54. For example, as the reclaimed water from piping 64 is used to wash the enriched synthetic bubbles 18 inside the flotation column 54, it is possible to use a microwave source 172 to apply the microwave beam 174 in order to release the valuable material from the enriched synthetic beads 18. A diagram illustrating the ultrasonic application is shown in Figure 6.

Mechanically Releasing Valuable Material

When the enriched synthetic bubbles or beads are densely packed such that they are in a close proximity to each other, the rubbing action among adjacent synthetic bubbles or beads may cause the mineral particles attached to the enriched synthetic beads to be detached. By way of example, the bead recovery process or processor 50 as shown in Figure 1 can be adapted for removing the mineral particles in the enriched synthetic beads 18 mechanically. For example, a motor 186 and a stirrer 188 are used to move the enriched synthetic beads around, causing the enriched synthetic beads 18 inside the flotation column 54 to rub against each other. If the synthetic beads are magnetic, the stirrer 188 can be a magnetic stirrer. A diagram illustrating a mechanical release of valuable material is shown in Figure 7.

Other Types or Kinds of Release Techniques

A heater like element 150 (Figure 3), an ultrasonic wave producer like element 164 (Figure 4), a container like element 168 (Figure 5), a microwave source like element 172 (Figure 6), a motor and stirrer like elements 186 188 (Figure 7) are known in the art, and the scope of the invention is not intended to be limited to any particular type or kind thereof either now known or later developed in the future.

Multi-Stage Removal of Valuable Material

More than one of the methods for releasing the valuable material from the enriched synthetic beads can be used in the same bead recovery process or processor at the same time. For example, while the enriched synthetic beads 18 are subjected to ultrasonic agitation (see Figure 4), the reclaimed water can also be heated by a water heater, such as a heater 150 as depicted in Figure 3. Furthermore, an acidic solution can be also added to the water to lower the pH in the flotation column 54. In a different embodiment of the present invention, same or different releasing methods are used sequentially in different stages. By way of example, the enriched polymer bubbles 216 from the separation apparatus 200 (see Figure 2) can be processed in a multi-state processor 203 as shown in Figure 8. The apparatus 200 has a first recovery processor 218 where an acidic solution is used to release the valuable material at least partially from the enriched synthetic beads 216. A filter 219 is used to separate the released mineral 226 from the synthetic beads 220. At a second recovery processor 222, an ultrasound source is used to apply ultrasonic agitation to the synthetic beads 220 in order to release the remaining valuable material, if any, from the synthetic beads. A filter 223 is used to separate the released mineral 226 from the reclaimed synthetic beads 224. It is understood that more than two processing stages can be carried out and different combinations of releasing methods are possible.

Figure 9

The separation process can be carried out in a horizontal pipeline as shown in Figure 9. As shown in Figure 9, the synthetic beads 308 may be used in, or form part of, a size-based separation process using countercurrent flows with mixing implemented in apparatus such as a horizontal pipeline generally indicated as 300. In Figure 9, the horizontal pipeline 310 is configured with a screen 311 to separate the enriched synthetic beads 302 having the valuable material attached thereto from the mixture based at least partly on the difference in size. The horizontal pipeline 310 may be configured to separate the enriched synthetic beads 302 having the valuable material attached thereto from the mixture using countercurrent flows with mixing, so as to receive in the horizontal pipeline 310 slurry 304 flowing in a first direction A, receive in the horizontal pipeline 300 synthetic beads 308 flowing in a second direction B opposite to the first direction A, provide from the horizontal pipeline 308 the enriched synthetic beads 302 having the valuable material attached thereto and flowing in the second direction B, and provide from the horizontal pipeline 310 waste or tailings 306 that is separated from the mixture using the screen 311 and flowing in the second direction B. In a horizontal pipeline 310, it is not necessary that the synthetic beads 308 be lighter than the slurry 304. The density of the synthetic beads 308 can be substantially equal to the density of the slurry 304 so that the synthetic beads can be in a suspension state while they are mixed with slurry 304 in the horizontal pipeline 310.

According to the present invention, and by way of example, the apparatus 1000 (Fig. 19) may be implemented to process the crushed ore before the pulp slurry 304 is provided to the horizontal pipeline 310.

Figures 10a – 10d

As described below in conjunction with Figures 15a and 15b, the synthetic bead 70 can be a cube or sphere and has a hydrophobic surface layer made of the hydrophobic foam. The hydrophobic foam can take the form of a filter, a membrane or a conveyor belt as described in PCT application no. PCT/US12/39534 (Atty docket no. 712-002.359-1), entitled "Mineral separation using functionalized membranes;" filed 21 May 2012, which is hereby incorporated by reference in its entirety. Therefore, the synthetic beads described herein are generalized as engineered collection media. Likewise, the hydrophobic foam may be generalized as a material with three-dimensional open- cellular structure, an open-cell foam or reticulated foam. The synthetic bead may have a core made from soft polymers, hard plastics, ceramics, carbon fibers, glass and/or metals, but the surface layer is made of the hydrophobic foam.

Open-cell foam or reticulated foam offers an advantage over non-open cell materials by having higher surface area to volume ratio. When the foam is made of the reaction product of an isocyanate and polyol, it promotes attachment of mineral to the foam “network” enables higher mineral recovery rates and also improves recovery of less liberated mineral than conventional process. For example, the open cells in an engineered foam block allow passage of fluid and particles smaller than the cell size but captures mineral particles that come in contact with the open cells. This also allows the selection of cell size dependent upon slurry properties and application.

The engineered collection media take the form of an open-cell foam/ structure in a rectangular block or a cubic shape 70a as illustrated in Figure 10a. When the collection media are mixed with the slurry for mineral recovery, it is advantageous to use the tumbler cells as shown in Figures 13 and 14. These tumbler cells have been disclosed in PCT application serial no. PCT/US16US/68843 (Atty docket no. 712-002.427-1/CCS-0157), entitled "Tumbler cell form mineral recovery using engineered media," filed 28 December 2016, which claims benefit to Provisional Application No. 62/272,026, filed 28 December 2015, which are both incorporated by reference herein in their entirety.

The engineered collection media may take the form of a filter 70b with a three-dimensional open-cell structure as shown in Figure 10b. The filter 70b can be used in a filtering assembly as shown in Figure 12, for example.

The engineered collection media may take the form of a membrane 70c, a section of which is shown in Figure 10c. As seen in Figure 10c, the membrane 70c can have an open-cell foam layer attached to a substrate or base. The substrate can be made from a material which is less porous than the open-cell foam layer. For example, the substrate can be a sheet of pliable polymer to enhance the durability of the membrane. The membrane 70c can be used as a conveyor belt as shown in Figure 11, for example.

The engineered collection media may take the form of a membrane 70d, a section of which is shown in Figure 10d. As seen in Figure 10d, the membrane 70d can have two open-cell foam layers attached to two sides of a substrate or base. The substrate can made of a material which is less porous than the open-cell foam layer. The membrane 70d can also be used as a conveyor belt as shown in Figure 11, for example.

The engineered collection media as shown in Figures 10a-10d may include, or take the form of, a solid-phase body configured with a three-dimensional open-cell structure to provide a plurality of collection surfaces for attracting one or more mineral particles in an aqueous mixture to the collection surfaces.

The solid phase body may have a core made from a material selected from, polyester urethane, polyether urethane, reinforced urethanes, PVC coated PV, silicone, polychloroprene, polyisocyanurate, polystyrene, polyolefin, polyvinylchloride, epoxy, latex, fluoropolymer, polypropylene, phenolic, EPDM, and nitrile. The solid-phase body has a hydrophobic surface layer made of the hydrophobic foam.

The solid phase body may be modified with tackifiers, plasticizers, crosslinking agents, chain transfer agents, chain extenders, adhesion promoters, aryl or alky copolymers, fluorinated copolymers, hexamethyldisilazane, silica or hydrophobic silica.

The solid phase body may include a core made of a material selected from acrylics, butyl rubber, ethylene vinyl acetate, natural rubber, nitriles; styrene block copolymers with ethylene, propylene, and isoprene, and polyvinyl ethers.

An adhesion agent may be provided between the solid phase body and the coating so as to promote adhesion between the core and the hydrophobic surface layer made of the hydrophobic foam.

The solid phase body may have a core made of plastic, ceramic, carbon fiber or metal, with a hydrophobic surface layer made of the hydrophobic foam.

The three-dimensional open-cell structure may include pores ranging from 10-200 pores per inch.

The engineered collection media may be encased in a cage structure that allows a mineral-containing slurry to pass through the cage structure so as to facilitate the contact between the mineral particles in slurry and the engineered collection media.

The cage structures or the filters carrying mineral particles may be removed from the processor so that they can be stripped of the mineral particles, cleaned and reused.

Figure 11

By way of example, Figure 11 shows the present invention in the form of a machine, device, system or apparatus 400, e.g., for separating valuable material from unwanted material in a mixture 401, such as a pulp slurry, using a first processor 402 and a second processor 404. The first processor 402 and the second processor 404 may be configured with a conveyor belt 420 that runs between the first processor 402and the second processor 404. The conveyor belt 420 can be entirely made of the hydrophobic foam or have a surface layer made of the hydrophobic foam. The arrows A1, A2, A3 indicate the movement of the conveyor belt 420. Techniques, including motors, gearing, etc., for running a conveyor belt like element 420 between two processors like elements 402 and 404 are known in the art, and the scope of the invention is not intended to be limited to any particular type or kind thereof either now know or later developed in the future. The conveyor belt 420 may include a layer structure as shown in Figures 10c or 10d.

The first processor 402 may take the form of a first chamber, tank, cell or column that contains an attachment rich environment generally indicated as 406. The first chamber, tank or column 402 may be configured to receive the mixture or pulp slurry 401 in the form of fluid (e.g., water), the valuable material and the unwanted material in the attachment rich environment 406, e.g., which has a high pH, conducive to attachment of the valuable material. The second processor 404 may take the form of a second chamber, tank, cell or column that contains a release rich environment generally indicated as 408. The second chamber, tank, cell or column 404 may be configured to receive, e.g., water 422 in the release rich environment 408, e.g., which may have a low pH or receive ultrasonic waves conducive to release of the valuable material. Alternatively, a surfactant may be used in the release rich environment 408 to detach the valuable material from the conveyor belt 420 under mechanical agitation or sonic agitation, for example. Sonic agitation can be achieved by a sonic source such as the ultrasonic wave producer 164 as shown in Figure 4. Mechanical agitation can be achieved by a stirring device such as the stirrer 188 as shown in Figure 17 or by a brush (not shown) caused to rub against the surface of the conveyor belt 420 while the conveyor belt 420 is moving through the release rich environment.

In operation, the first processor 402 may be configured to receive the mixture or pulp slurry 401 of water, valuable material and unwanted material and the conveyor belt 420 that may be configured to attach to the valuable material in the attachment rich environment 406. In Figure 11, the belt 420 is understood to be configured with a layer of the hydrophobic foam to attach to the valuable material in the attachment rich environment 406.

The first processor 402 may also be configured to provide drainage from piping 441 of, e.g., tailings 442 as shown in Figure 11. The second processor 404 may also be configured to provide the valuable material that is released from the enriched conveyor belt into the release rich environment 408. For example, in Figure 11 the second processor 404 is shown configured to provide via piping 461 drainage of the valuable material in the form of a concentrate 462.

According to the present invention, and by way of example, the apparatus 1000 (Fig. 19) may be implemented to process the crushed ore before the pulp slurry 401 is provided to the first processor 402.

Figure 12

By way of example, Figure 12 shows the present invention in the form of a machine, device, system or apparatus 500, e.g., for separating valuable material from unwanted material in a mixture 501, such as a pulp slurry, using a first processor 502, 502' and a second processor 504, 504'. The first processor 502 and the second processor 504 may be configured to process a hydrophobic member that is shown, e.g., as a filter 520 configured to be moved between the first processor 502 and the second processor 504' as shown in Figure 12 as part of a batch type process. In Figure 12, and by way of example, the batch type process is shown as having two first processor 502, 502' and second processor 504, 504, although the scope of the invention is not intended to be limited to the number of first or second processors. The collection filter 520 may take the form of an engineered collection media having an open-cell structure or made of a foam block as shown in Figure 10b. The arrow B1 indicates the movement of the collection filter 520 from the first processor 502, and the arrow B2 indicates the movement of the collection filter 520 into the second processor 502. Techniques, including motors, gearing, etc., for moving a filter like element 520 from one processor to another processor like elements 502 and 504 are known in the art, and the scope of the invention is not intended to be limited to any particular type or kind thereof either now know or later developed in the future. In the apparatus as shown in Figure 12, the collection filter has at least a layer of the hydrophobic foam.

The first processor 502 may take the form of a first chamber, tank, cell or column that contains an attachment rich environment which has a high pH, conducive to attachment of the valuable material. The second processor 504 may take the form of a second chamber, tank, cell or column that contains a release rich environment which may have a low pH or receive ultrasonic waves conducive to release of the valuable material. Alternatively, the second process 504 may be configured as a stripping tank where a surfactant is used to release the valuable material from the filter 522 under mechanical agitation or sonic agitation, for example.

The first processor 502 may also be configured to provide drainage from piping 541 of, e.g., tailings 542 as shown in Figure 12. The second processor 504 may be configured to receive the fluid 522 (e.g. water) and the enriched collection filter 520 to release the valuable material in the release rich environment. For example, in Figure 12 the second processor 504 is shown configured to provide via piping 561 drainage of the valuable material in the form of a concentrate 562.

The first processor 502' may also be configured with piping 580 and pumping 280 to recirculate the tailings 542 back into the first processor 502'. The scope of the invention is also intended to include the second processor 504' being configured with corresponding piping and pumping to recirculate the concentrate 562 back into the second processor 504'.

According to the present invention, and by way of example, the apparatus 1000 (Fig. 19) may be implemented to process the crushed ore before the pulp slurry 501 is provided to the first processor 502, 502'.

Figures 13-14

The engineered collection media as shown in Figures 10a, 15a and 15b can be used for mineral recovery in a co-current device as shown in Figure 13. Figure 13 illustrates a co-current tumbler cell configured to enhance the contact between the engineered collection media and the mineral particles in a slurry.

As seen in Figure 13, the tumbler cell 600 may include a container 602 configured to hold a mixture comprising engineered collection media 70a and a pulp slurry or slurry 677. The slurry 677 may contain mineral particles. The container 602 may include a first input 614 configured to receive the engineered collection media 70a and a second input 618 configured to receive the slurry 677. On the other side of the container 602, an output 620 may be provided for discharging at least part of the mixture 681 from the container 602 after the engineered collection media 70a are caused to interact with the mineral particles in slurry 677 in the container. The mixture 681 may contain mineral laden media or loaded media and ore residue or tailings 679. The arrangement of the inputs and output on the container 602 as shown in Figure 13 is known as a co-current configuration. The engineered collection media 70a may include collection surfaces made of the hydrophobic foam to attract the mineral particles to the collection surface so as to form mineral laden media. In general, if the specific gravity of the engineered collection media 70a is smaller than the slurry 677, then a substantial amount of the engineered collection media 70a in the container 602 may stay afloat on top the slurry 677. If the specific gravity of the collection media 70a is greater than the slurry 677, then a substantial amount of the engineered collection media 70a may sink to the bottom of the container 602. As such, the interaction between the engineered collection media 70a and the mineral particles in slurry 677 may not be efficient to form mineral laden media. In order to increase or enhance the contact between the engineered collection media 70a and the mineral particles in slurry 677, the container 602 may be caused to turn, e.g., such that at least some of the mixture in the upper part of the container may be caused to interact with at least some of mixture in the lower part of the container 602. After being discharged from the container 602, the mixture 681 having mineral laden media and ore residue may be processed through a separation device such as a screen so that the mineral laden media and the ore residue can be separated. The container 602 can be a horizontal pipe or cylindrical drum configured to be rotated, as indicated by numeral 610, along a horizontal axis, for example.

Figure 14 illustrates a cross-current tumbler cell configured to enhance the contact between the collection media and the mineral particles in a slurry. As seen in Figure 14, the container 602 of the tumbler cell 600' a first input 614, a second input 618, a first output 622 and a second output 624. The first input 614 may be arranged to receive engineered collection media 70a and the second output 624 is arranged to discharge ore residue 679. The second input 618 may be arranged to receive slurry 677 and the first output 622 is arranged to discharge mineral laden media 670. The arrangement of the inputs and outputs on the container 602 is known as a counter-current configuration. In the counter-current configuration, an internal separation device such as a screen may be used to prevent the medium laden media and the engineered collection media 70a in the container 602 from being discharged through the second output 624. As such, what is discharged through the second output 624 is ore residue or tailings 679. By rotating the container 602 along the rotation axis 691, at least some of the mixture in an upper part of the container 602 may be caused to interact with at least some of the mixture in a lower part of the container 602 so as to increase or enhance the contact between the engineered collection media 70a and the mineral particles in slurry 677.

According to the present invention, and by way of example, the apparatus 1000 (Fig. 19) may be implemented to process the crushed ore before the slurry input 618 is provided to the container 602.

Figures 15a-15b

Applicant's hydrophobic media may include, or take the form of, the engineered collection media that includes cubes or spheres used in mineral separation are referred herein as synthetic beads. As shown in Figure 15a, each of the synthetic beads 70 has a solid body 82 made of the hydrophobic foam. As shown in Figure 15b, each of the synthetic beads 70 has a core 86 and a surface layer 84. While the surface layer 84 is made of the hydrophobic foam, the core 86 can be made of a different material such as a different polymer or polymer-based material, or a silica or silica-based, or a glass or glass-based material, ceramic, metal or a magnetic material.

The term “polymer bubbles or beads”, and the term “synthetic bubbles” are used interchangeably.

Three Dimensional Functionalized Open-Network Structure

Applicant's hydrophobic media may include, or take the form of, hydrophobic foam, e.g., as shown in Figure 16.

Surface area is an important property in the mineral recovery process because it defines the amount of mass that can be captured and recovered. High surface area to volume ratios allows higher recovery per unit volume of media added to a cell. As illustrated in Figures 10a to 10d, the engineered collection media are shown as having an open-cell structure. Open cell or reticulated foam offers an advantage over other media shapes such as the sphere by having higher surface area to volume ratio. When the open-cell structure or reticulate foam is made of the hydrophobic foam, it promotes attachment of mineral to the foam “network “ enables higher recovery rates and improved recovery of less liberated mineral when compared to the conventional process. For example, open cells allow passage of fluid and unattracted particles smaller than the cell size but capture mineral bearing particles that come in contact with the hydrophobic foam. Selection of cell size is dependent upon slurry properties and application.

The hydrophobic foam may be cut in a variety of shapes and forms. For example, a hydrophobic foam belt can be moved through the slurry to collect the desired minerals and then cleaned to remove the collected desired minerals. The cleaned foam belt can be reintroduced into the slurry. Strips, blocks, and/or sheets of foam of varying size can also be used where they are randomly mixed along with the slurry in a mixing cell. The thickness and cell size of a foam can be dimensioned to be used as a cartridge-like filter which can be removed, cleaned of recovered mineral, and reused.

As mentioned earlier, the open cell or reticulated foam made with the hydrophobic foam offers an advantage over other media shapes such as sphere by having higher surface area to volume ratio. Surface area is an important property in the mineral recovery process because it defines the amount of mass that can be captured and recovered. High surface area to volume ratios allows higher recovery per unit volume of media added to a cell.

The open cell or reticulated foam provides three-dimensional open network structures having high surface area with extensive interior surfaces and tortuous paths protected from abrasion and premature release of attached mineral particles. This provides for enhanced collection and increased functional durability. Without a coating, the hydrophobic foam conveyor belts or filters could last longer.

The use of the reaction product of an isocyanate and polyol promotes attachment of mineral to the foam “network” enables higher recovery rates and improved recovery of less liberated mineral when compared to the conventional process. This foam is open-cell structure so it allows passage of fluid and unattracted particles smaller than the cell size but captures mineral bearing particles the come in contact with the collection surfaces. Selection of cell size is dependent upon slurry properties and application.

A three-dimensional open cellular structure optimized to provide a compliant, tacky surface of low energy enhances collection of hydrophobic or hydrophobized mineral particles ranging widely in particle size. This structure may include, or take the form of, open-cell foam with a compliant, tacky surface of low surface energy.

The structure may be in the form of sheets, cubes, spheres, or other shapes as well as densities (described by pores per inch and pore size distribution), and levels of tortuosity that optimize surface access, surface area, mineral attachment/ detachment kinetics, and durability. These structures may be additionally optimized to target certain mineral particle size ranges, with denser structures acquiring smaller particle sizes. In general, cellular densities may range from 10 – 200 pores per inch, more preferably 10 – 90 pores per inch, and most preferably 20 – 60 pores per inch.

The specific shape or form of the structure may be selected for optimum performance for a specific application. For example, the structure may be cut in a variety of shapes and forms. For example, a hydrophobic foam belt could be moved through the slurry removing the desired mineral whereby it is cleaned and reintroduced into the slurry. Strips, blocks, and/or sheets of hydrophobic foam of varying size could also be used where they are randomly mixed along with the slurry in a mixing cell. Alternatively, a conveyor structure may be formed where the foam is encased in a cage structure that allows a mineral-containing slurry to pass through the cage structure to be introduced to the underlying foam structure where the mineral can react with the foam and thereafter be further processed in accordance with the present invention. The thickness and cell size could be changed to a form cartridge like filter whereby the filter is removed, cleaned of recovered mineral, and reused. Figure 16 is an example a section of hydrophobic reticulated foam that was used to recovery Chalcopyrite mineral. Mineral particles captured from copper ore slurry can be seen throughout the foam network.

There are numerous characteristics of the foam that may be important and should also be considered, as follows:

Mechanical durability: Ideally, the foam will be durable in the mineral separation process. For example, a life of over 30,000 cycles in a plant system would be beneficial. Without a coating, a conveyor belt, synthetic bead or a filter may have a significant advantage in medium durability and lifetime.

Surface area: Higher surface area provides more sites for the mineral to the surface of the foam substrate. There is a tradeoff between larger surface area (for example using small pore cell foam) and ability of the hydrophobic foam structure to capture mineral while allowing gangue material to pass through and not be capture, for example due to a small cell size that would effectively entrap gangue material. The foam size is selected to optimize capture of the desired mineral and minimize mechanical entrainment of undesired gangue material.

Cell size distribution: Cell diameter needs to be large enough to allow gangue and mineral to be removed but small enough to provide high surface area. There should be an optimal cell diameter distribution for the capture and removal of specific mineral particle sizes.

Tortuosity: Cells that are perfectly straight cylinders have very low tortuosity. Cells that twist and turn throughout the foam have “tortuous paths” and yield foam of high tortuosity. The degree of tortuosity may be selected to optimize the potential interaction of a mineral particle with the foam substrate, while not be too tortuous that undesirable gangue material in entrapped by the foam substrate.

The pore size (pores per inch (PPI)) of the foam is an important characteristic which can be leveraged to improved mineral recovery and/or target a specific size range of mineral. As the PPI increases the specific surface area (SSA) of the foam also increases. A high SSA presented to the process increases the probability of particle contact which results in a decrease in required residence time. This in turn, can lead to smaller size reactors. At the same time, higher PPI foam acts as a filter due to the smaller pore size and allows only particles smaller than the pores to enter into its core. This enables the ability to target, for example, mineral fines over coarse particles or opens the possibility of blending a combination of different PPI foam to optimize recovery performance across a specific size distribution.

Applications

The scope of the invention is described in relation to mineral separation, including the separation of copper from ore. It should be understood that the synthetic beads are also configured for use in oilsands separation – to separate bitumen from sand and water in the recovery of bitumen in an oilsands mining operation.

The Related Family

By way of example, this application is also related to a family of nine PCT applications, which were all concurrently filed on 25 May 2012, as follows:

PCT application no. PCT/US12/39528 (Atty docket no. 712-002.356-1), entitled "Flotation separation using lightweight synthetic bubbles and beads;"

PCT application no. PCT/US12/39524 (Atty docket no. 712-002.359-1), entitled "Mineral separation using functionalized polymer membranes;"

PCT application no. PCT/US12/39540 (Atty docket no. 712-002.359-2), entitled "Mineral separation using sized, weighted and magnetized beads;"

PCT application no. PCT/US12/39576 (Atty docket no. 712-002.382), entitled "Synthetic bubbles/beads functionalized with molecules for attracting or attaching to mineral particles of interest," which corresponds to U.S. Patent No. 9,352,335, which discloses solid beads, belts and filters, but not open-network structures;

PCT application serial no. PCT/US12/39591 (712-2.383-1/CCS-0090), entitled "Method and system for releasing mineral from synthetic bubbles and beads," filed 25 May 2012, which itself claims the benefit of U.S. Provisional Patent Application No. 61/489,893, filed 25 May 2011, and U.S. Provisional Patent Application No. 61/533,544, filed 12 September 2011, which corresponds to co-pending U.S. Patent Application No. 14/117,912, filed 15 November 2013;

PCT application no. PCT/US/39596 (Atty docket no. 712-002.384), entitled "Synthetic bubbles and beads having hydrophobic surface;"

PCT application no. PCT/US/39631 (Atty docket no. 712-002.385), entitled "Mineral separation using functionalized filters and membranes," which corresponds to U.S. Patent No. 9,302,270;"

PCT application no. PCT/US12/39655 (Atty docket no. 712-002.386), entitled "Mineral recovery in tailings using functionalized polymers;" and

PCT application no. PCT/US12/39658 (Atty docket no. 712-002.387), entitled "Techniques for transporting synthetic beads or bubbles In a flotation cell or column," all of which are incorporated by reference in their entirety.

This application also related to PCT application no. PCT/US2013/042202 (Atty docket no. 712-002.389-1/CCS-0086), filed 22 May 2013, entitled "Charged engineered polymer beads/bubbles functionalized with molecules for attracting and attaching to mineral particles of interest for flotation separation," which claims the benefit of U.S. Provisional Patent Application No. 61/650,210, filed 22 May 2012, which is incorporated by reference herein in its entirety.

This application is also related to PCT/US2014/037823, filed 13 May 2014, entitled "Polymer surfaces having a siloxane functional group," which claims benefit to U.S. Provisional Patent Application No. 61/822,679 (Atty docket no. 712-002.395/CCS-0123), filed 13 May 2013, as well as U.S. Patent Application No. 14/118,984 (Atty docket no. 712-002.385/CCS-0092), filed 27 January 2014, and is a continuation-in-part to PCT application no. PCT/US12/39631 (712-2.385//CCS-0092), filed 25 May 2012, which are all hereby incorporated by reference in their entirety.

This application also related to PCT application no. PCT/US13/28303 (Atty docket no. 712-002.377-1/CCS-0081/82), filed 28 February 2013, entitled "Method and system for flotation separation in a magnetically controllable and steerable foam," which is also hereby incorporated by reference in its entirety.

This application also related to PCT application no. PCT/US16/57334 (Atty docket no. 712-002.424-1/CCS-0151), filed 17 October 2016, entitled "Opportunities for recovery augmentation process as applied to molybdenum production," which is also hereby incorporated by reference in its entirety.

This application also related to PCT application no. PCT/US16/37322 (Atty docket no. 712-002.425-1/CCS-0152), filed 17 October 2016, entitled "Mineral beneficiation utilizing engineered materials for mineral separation and coarse particle recovery," which is also hereby incorporated by reference in its entirety.

This application also related to PCT application no. PCT/US16/62242 (Atty docket no. 712-002.426-1/CCS-0154), filed 16 November 2016, entitled "Utilizing engineered media for recovery of minerals in tailings stream at the end of a flotation separation process," which is also hereby incorporated by reference in its entirety.

This application is related to PCT application serial no. PCT/US16US/68843 (Atty docket no. 712-002.427-1/CCS-0157), entitled "Tumbler cell form mineral recovery using engineered media," filed 28 December 2016, which claims benefit to Provisional Application No. 62/272,026, entitled “Tumbler Cell Design for Mineral Recovery Using Engineered Media”, filed 28 December 2015, which are both incorporated by reference herein in their entirety.

The Scope of the Invention

It should be further appreciated that any of the features, characteristics, alternatives or modifications described regarding a particular embodiment herein may also be applied, used, or incorporated with any other embodiment described herein. It should be noted that the engineered collection media having the open-cell structure as shown in Figure 17a, for example, can be made of a material that has a specific gravity smaller than, equal to or greater than that of the slurry. The engineered collection media can be made from a magnetic polymer or have a magnetic core so that the para-, ferri-, ferro-magnetism of the engineered collection media is greater than the para-, ferri-, ferro-magnetism of the unwanted ground ore particles in the slurry. Thus, although the invention has been described and illustrated with respect to exemplary embodiments thereof, the foregoing and various other additions and omissions may be made therein and thereto without departing from the spirit and scope of the present invention.

WHAT IS CLAIMED IS:

1. Apparatus for recovering mineral particles of interest from a pulp having crushed ore in a mining process, comprising:

a conditioner configured to receive and condition a pulp having crushed ore with mineral particles of interest using a hydrophobic conditioner so as to form hydrophobic conditioned crushed ore having a hydrophobicity; and

a further conditioner configured to receive and further condition the hydrophobic conditioned crushed ore using a promoter having a hydrophobic polymer or surfactant and provide enhanced hydrophobic further conditioned crushed ore having an enhanced hydrophobicity that is greater than the hydrophobicity of the hydrophobic conditioned crushed ore.

2. Apparatus according to claim 1, wherein the hydrophobic polymer or surfactant comprises a liquid PDMS polymer, a glycerol monooleate surfactant or an MQ Resin powder polymer.

3. Apparatus according to claim 1, wherein the further conditioner further conditions the pulp using a concentration of the hydrophobic polymer or surfactant in a range of about 15-50 ppm w/w.

4. Apparatus according to claim 1, wherein the conditioner is configured to condition the pulp using potassium amyl xanthate (PAX).

5. Apparatus according to claim 4, wherein the conditioner conditions the pulp using the potassium amyl xanthate (PAX) in a concentration of about 50 ppm w/w, including conditioning for about 5 minutes.

6. Apparatus according to claim 1, wherein the apparatus comprises a grinding stage that crushed the crushed ore to a P80 of about 370 um.

7. Apparatus according to claim 1, wherein the hydrophobic polymer or surfactant comprises a hydrophobic silica polymer, a polyglycol polymer, or a Br Sec Alc EtO polymer.

8. Apparatus according to claim 1, wherein the mineral particles of interest is copper or molybdenum.

9. Apparatus according to claim 1, wherein the apparatus comprises hydrophobic media, including either hydrophobic coated reticulated foam or hydrophobic bubbles or beads, for processing the enhanced hydrophobic further conditioned crushed ore.

10. Apparatus according to claim 1, wherein the apparatus comprises a mineral flotation processor for processing the further conditioned crushed ore.

11. A method for recovering mineral particles of interest from a pulp having crushed ore in a mining process, comprising:

receiving and conditioning a pulp having crushed ore with mineral particles of interest using a hydrophobic conditioner and providing hydrophobic conditioned crushed ore having a hydrophobicity; and

further conditioning the hydrophobic conditioned crushed ore using a promoter having a hydrophobic polymer or surfactant and providing enhanced hydrophobic further conditioned crushed ore having an enhanced hydrophobicity that is greater than the hydrophobicity of the hydrophobic conditioned crushed ore.

12. A method according to claim 11, wherein the method comprises using a liquid PDMS polymer, a glycerol monooleate surfactant or an MQ Resin powder polymer as the hydrophobic polymer or surfactant.

13. A method according to claim 11, wherein the method comprises further conditioning the pulp using a concentration of the hydrophobic polymer or surfactant in a range of about 15-50 ppm w/w.

14. A method according to claim 11, wherein the method comprises using potassium amyl xanthate (PAX) as the conditioner.

15. A method according to claim 14, wherein the method further comprises conditioning the pulp using the potassium amyl xanthate (PAX) in a concentration of about 50 ppm w/w, including conditioning for about 5 minutes.

16. A method according to claim 11, wherein the method further comprises grinding the crushed ore to a P80 of about 370 um.

17. A method according to claim 11, wherein the method comprises using a hydrophobic silica polymer, a polyglycol polymer, or a Br Sec Alc EtO polymer as the hydrophobic polymer or surfactant.

18. A method according to claim 11, wherein the mineral particles of interest is copper or molybdenum.

19. A method according to claim 11, wherein the method comprises processing the further enhanced hydrophobic further conditioned crushed ore using hydrophobic media, including using either hydrophobic coated reticulated foam or hydrophobic bubbles or beads.

20. A method according to claim 11, wherein the method comprises processing the enhanced hydrophobic further conditioned crushed ore using a mineral flotation processing technique.

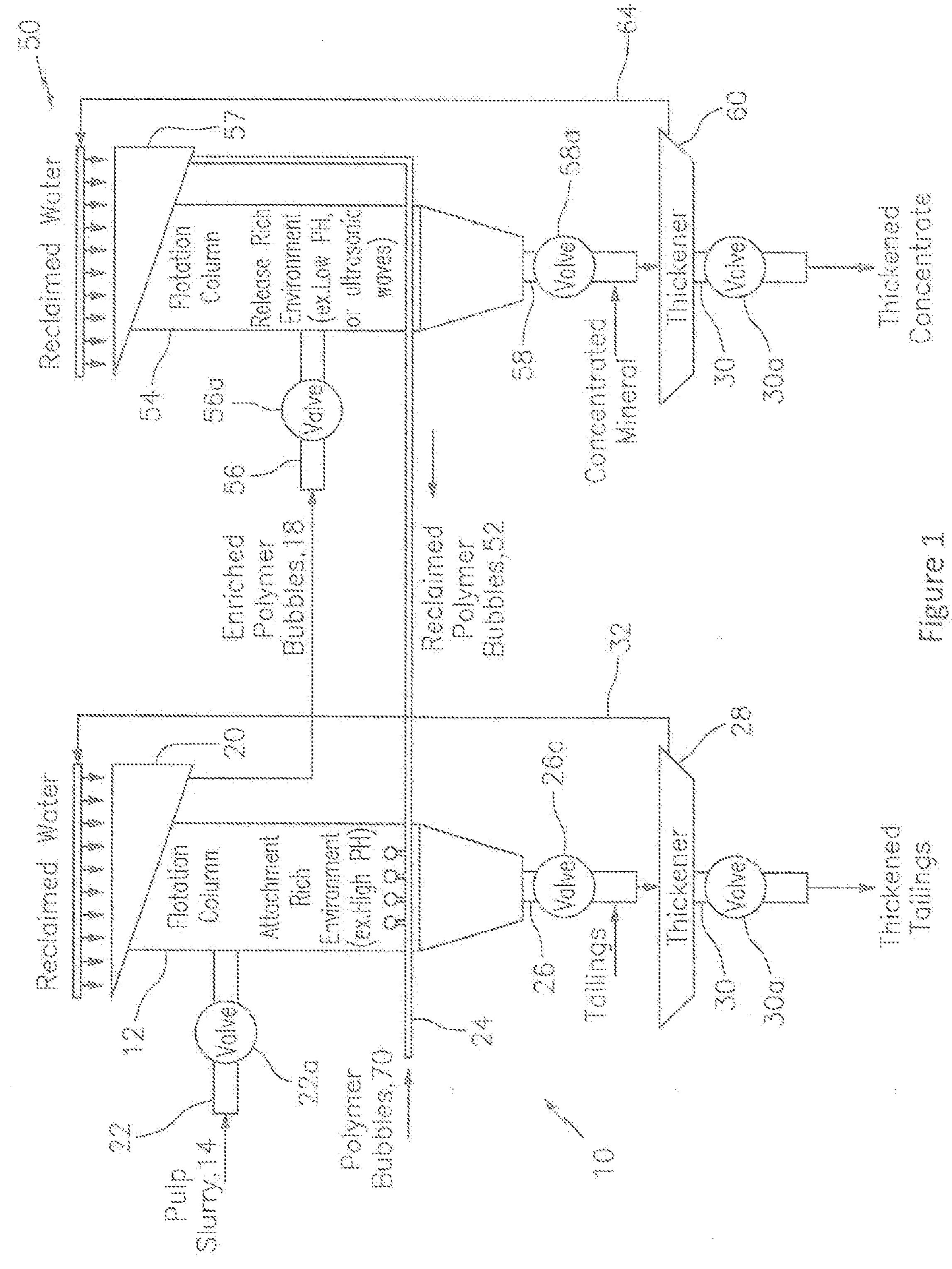

50
Reclaimed Water
57
Flotation Column
Release Rich Environment (ex.Low PH, or ultrasonic waves)
54
64
60
58a
Valve
58
Concentrated Mineral
Thickener
Valve
30
30a
Thickened Concentrate
Valve
56a
56
Enriched Polymer Bubbles,18
Reclaimed Polymer Bubbles,52
32
Reclaimed Water
20
Flotation Column
Attachment Rich Environment (ex.High PH)
12
28
26a
Valve
26
Tailings
Thickener
Valve
30
30a
Thickened Tailings
Valve
22a
22
Pulp Slurry,14
Polymer Bubbles,70
24
10

Figure 1

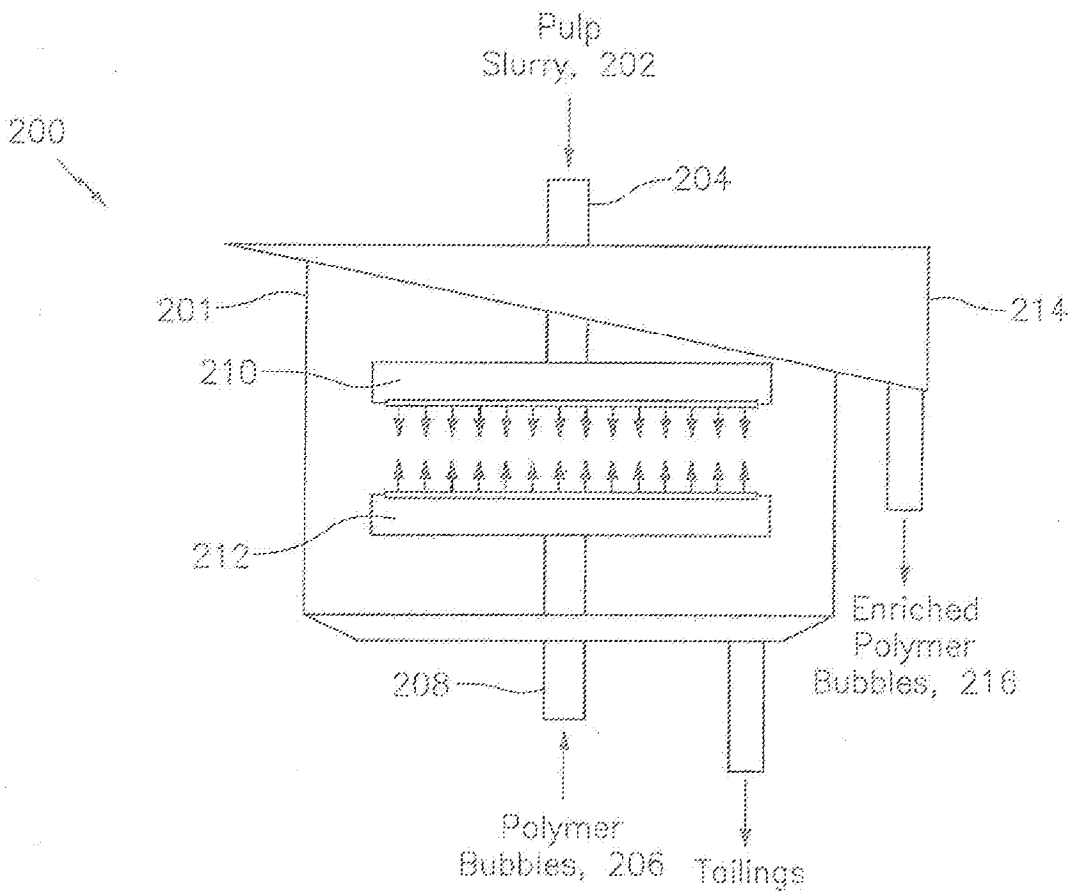

Pulp
Slurry, 202
200
204
201
214
210
212
Enriched
Polymer
Bubbles, 216
208
Polymer
Bubbles, 206
Tailings

Figure 2

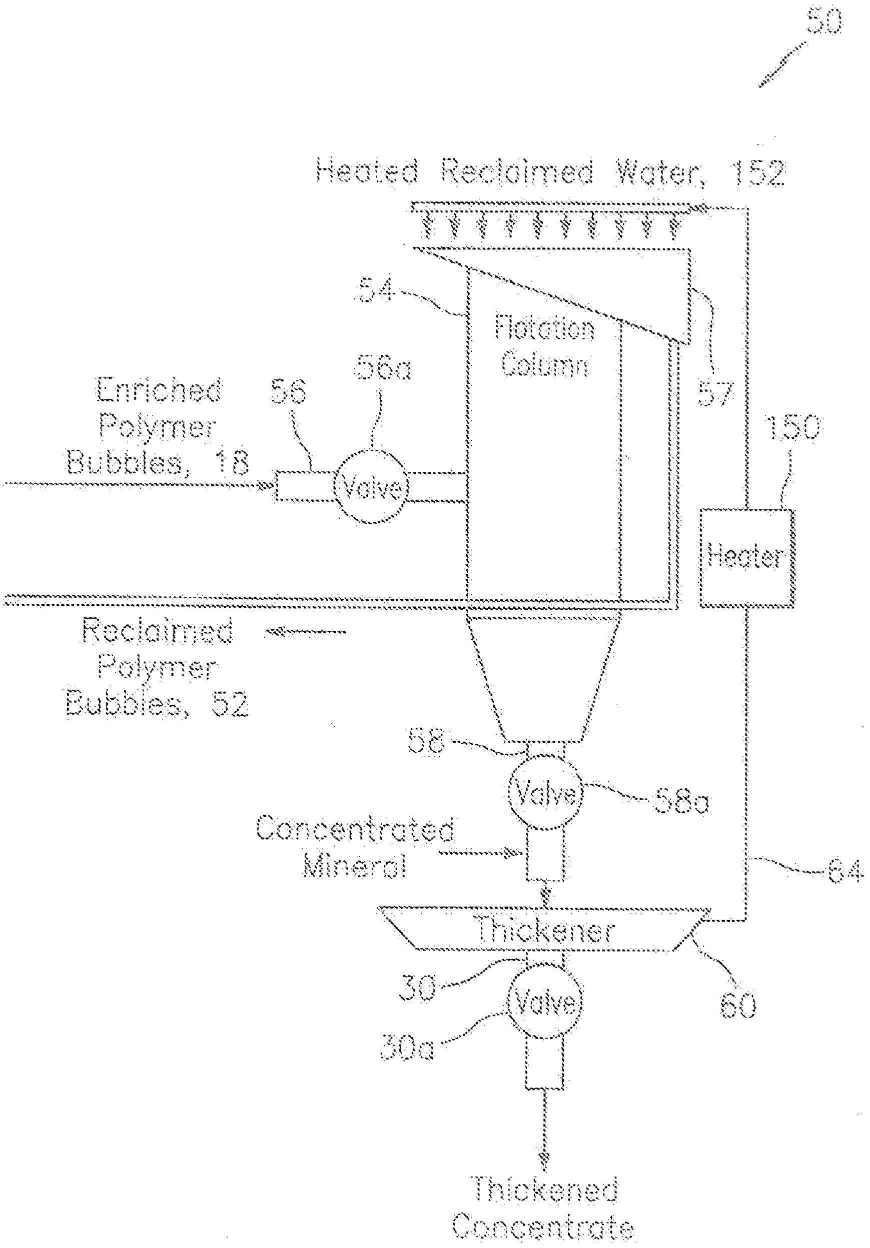

50
Heated Reclaimed Water, 152
54
Flotation Column
57
150
Heater
Enriched Polymer Bubbles, 18
56
56a
Valve
Reclaimed Polymer Bubbles, 52
58
Valve
58a
Concentrated Mineral
64
Thickener
60
30
Valve
30a
Thickened Concentrate

Figure 3

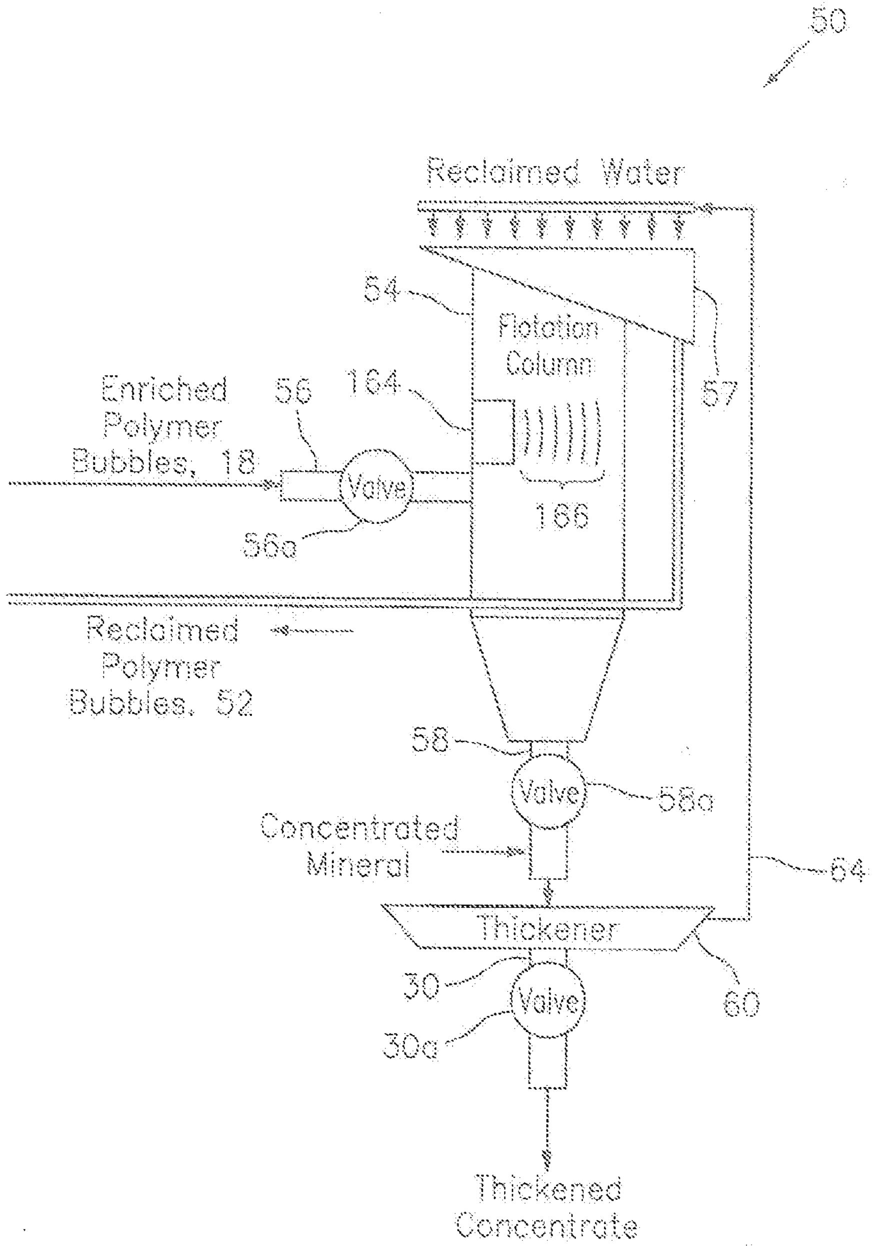

50
Reclaimed Water
54
Flotation Column
57
164
Enriched Polymer Bubbles, 18
56
Valve
56a
166
Reclaimed Polymer Bubbles, 52
58
Valve
58a
Concentrated Mineral
64
Thickener
60
30
Valve
30a
Thickened Concentrate

Figure 4

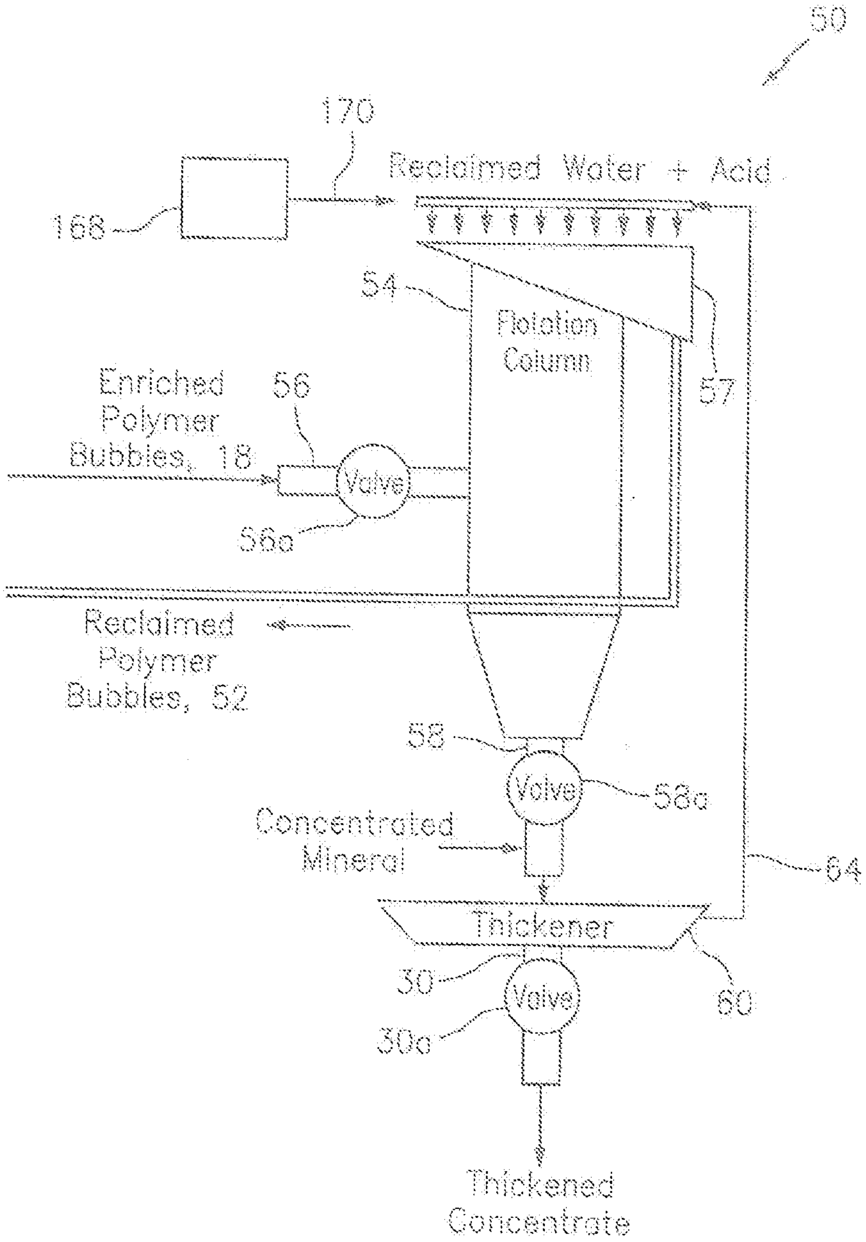

50
170
Reclaimed Water + Acid
168
54
Flotation Column
57
Enriched Polymer Bubbles, 18
56
Valve
56a
Reclaimed Polymer Bubbles, 52
58
Valve
58a
Concentrated Mineral
64
Thickener
60
30
Valve
30a
Thickened Concentrate

Figure 5

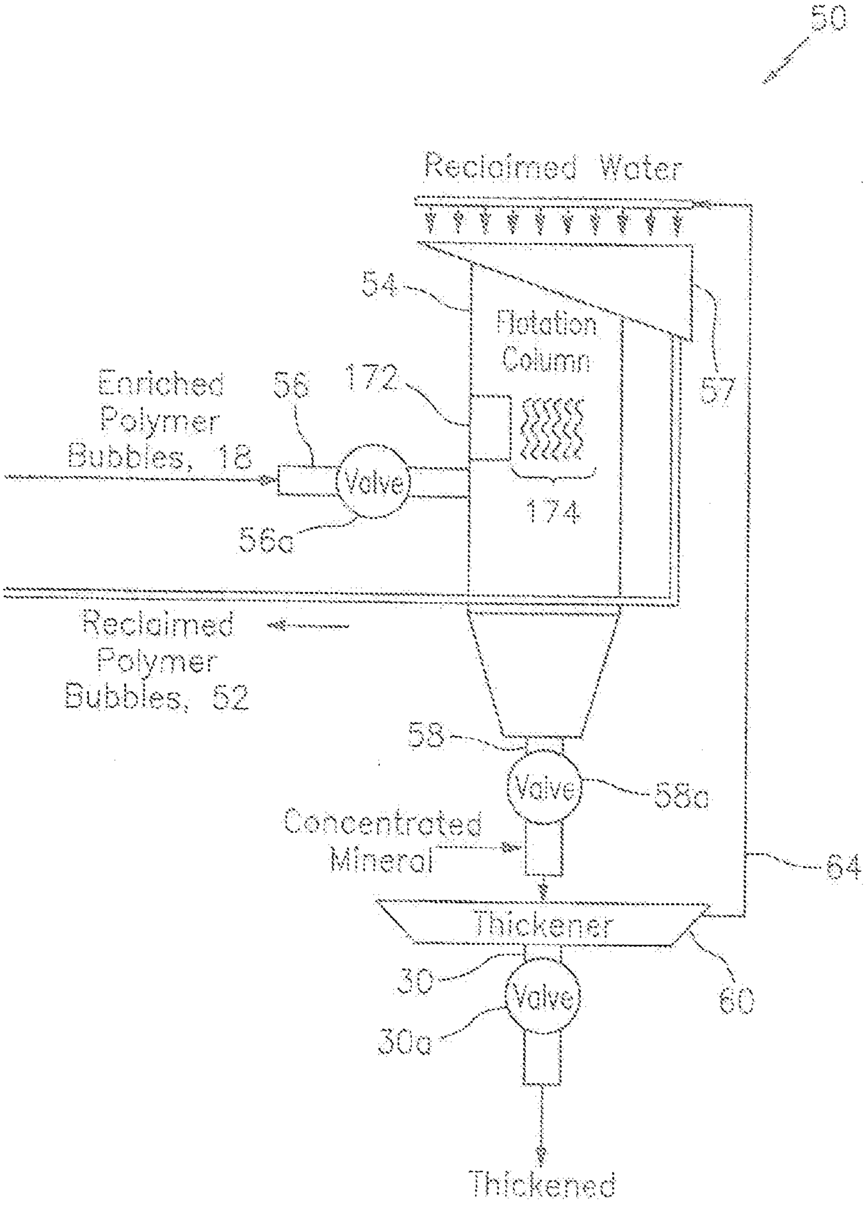

50
Reclaimed Water
54
Flotation Column
57
Enriched Polymer Bubbles, 18
56
172
Valve
56a
174
Reclaimed Polymer Bubbles, 52
58
Valve
58a
Concentrated Mineral
64
Thickener
30
Valve
60
30a
Thickened Concentrate

Figure 6

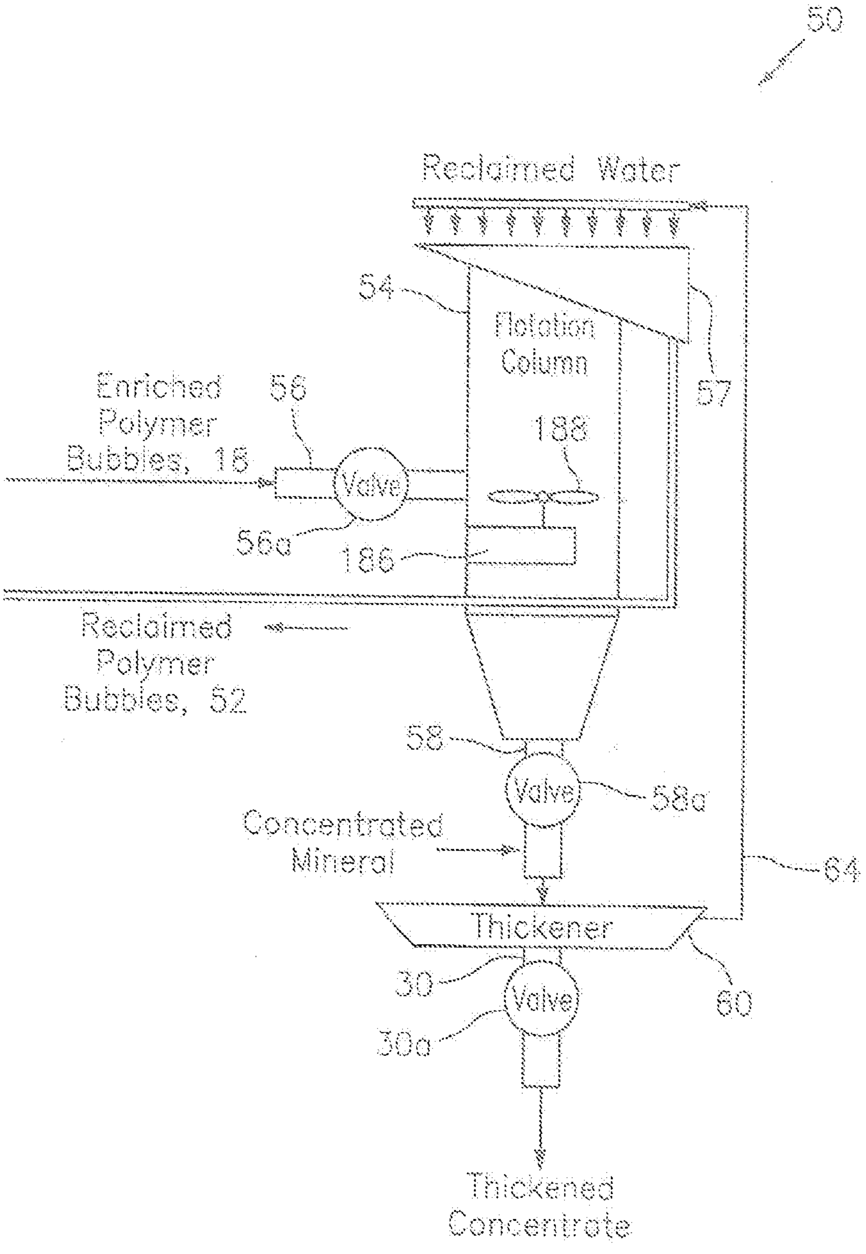

50
Reclaimed Water
54
Flotation Column
57
Enriched Polymer Bubbles, 18
56
188
Valve
56a
186
Reclaimed Polymer Bubbles, 52
58
Valve
58a
Concentrated Mineral
64
Thickener
30
Valve
60
30a
Thickened Concentrate

Figure 7

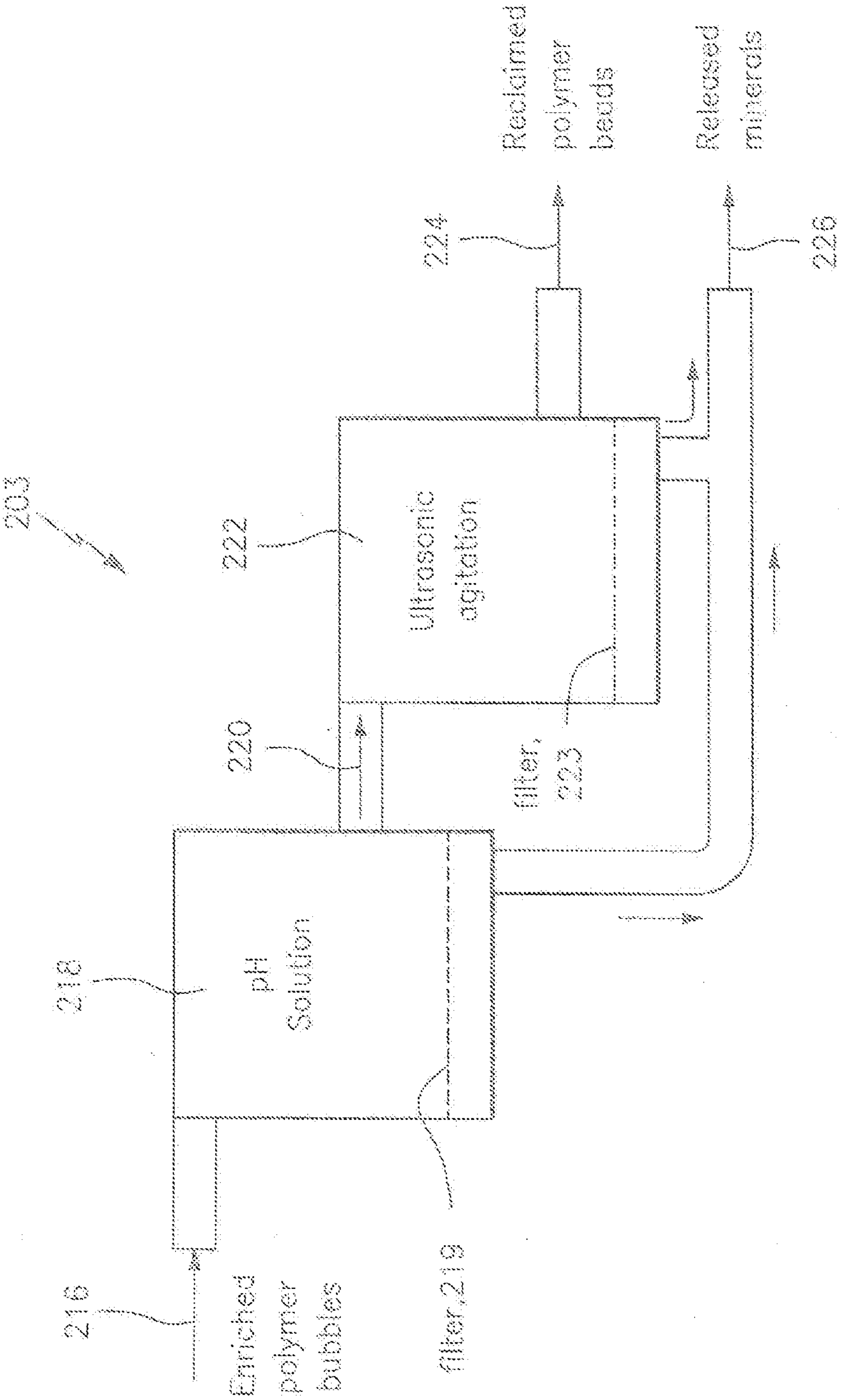

203
Enriched polymer bubbles
216
filter,219
218
pH Solution
220
filter, 223
222
Ultrasonic agitation
224
Reclaimed polymer beads
226
Released minerals

Figure 8

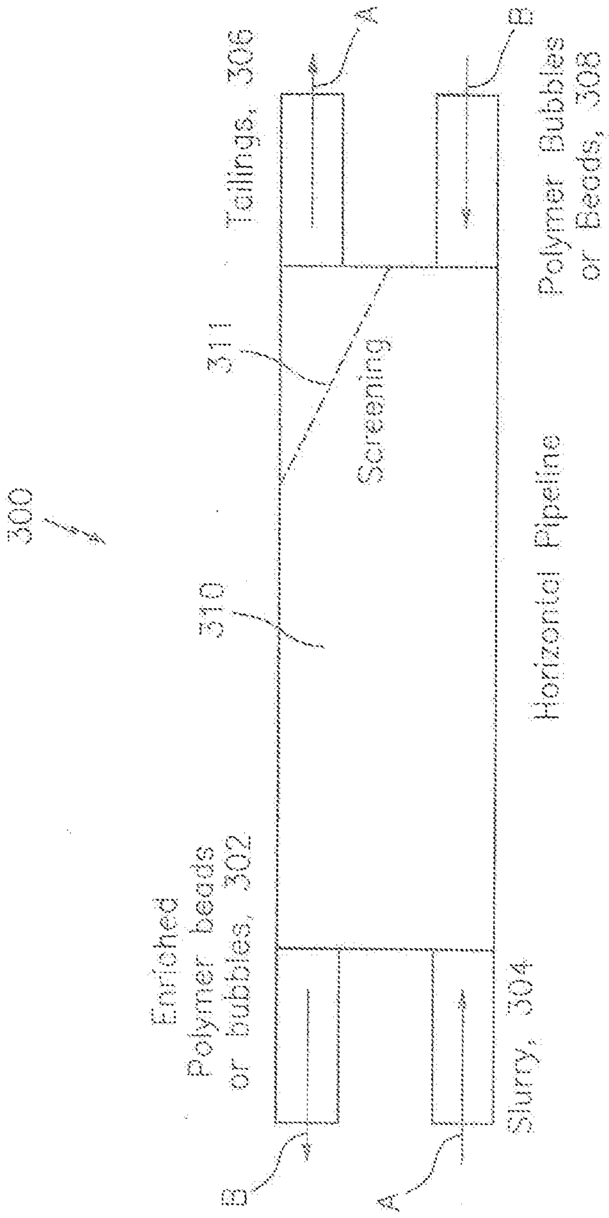
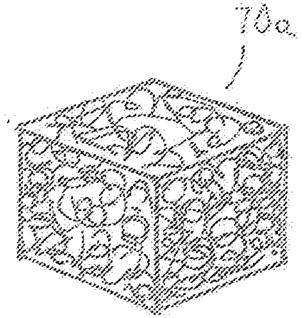

300
Enriched Polymer beads or bubbles, 302
Slurry, 304
Tailings, 306
Polymer Bubbles or Beads, 308
310
311
Screening
Horizontal Pipeline
A
B
A
B

Figure 9

Figure 10a



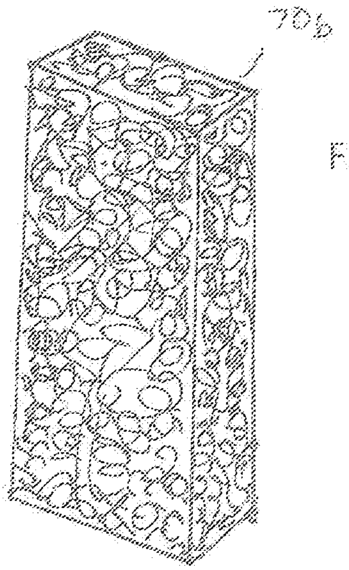


Figure 10b

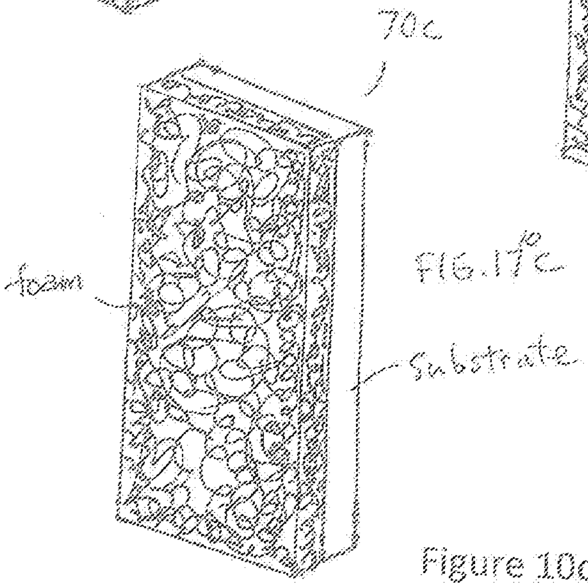


Figure 10c

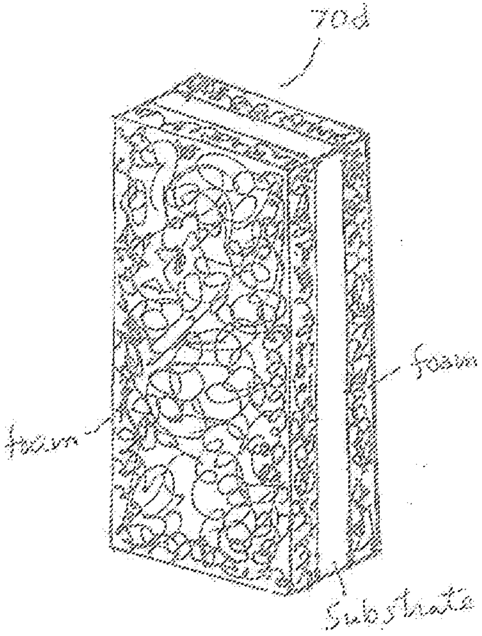


Figure 10d

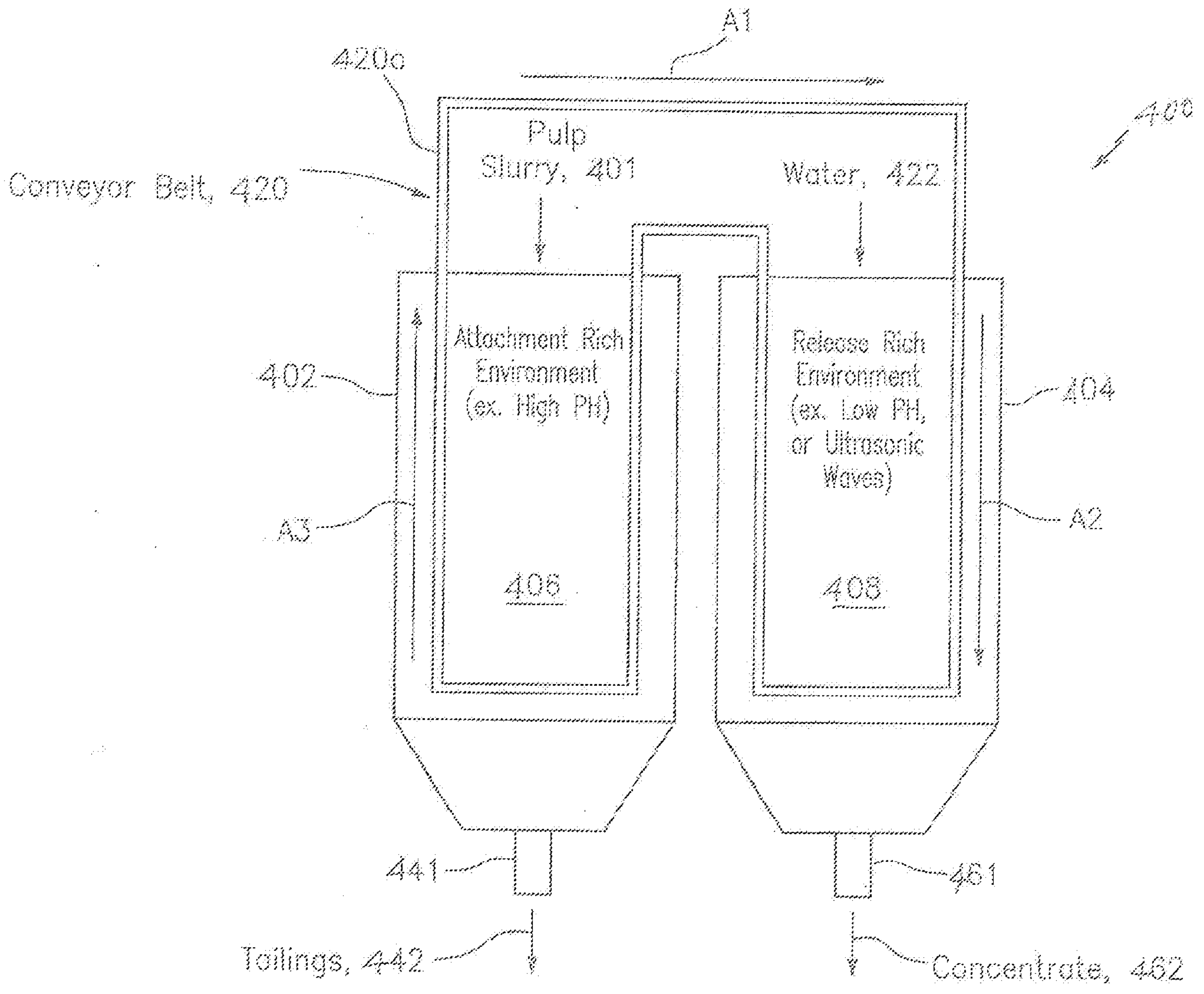

A1
420a
400
Pulp Slurry, 401
Water, 422
Conveyor Belt, 420
Attachment Rich Environment (ex. High PH)
Release Rich Environment (ex. Low PH, or Ultrasonic Waves)
402
404
A3
A2
406
408
441
461
Tailings, 442
Concentrate, 462

Figure 11

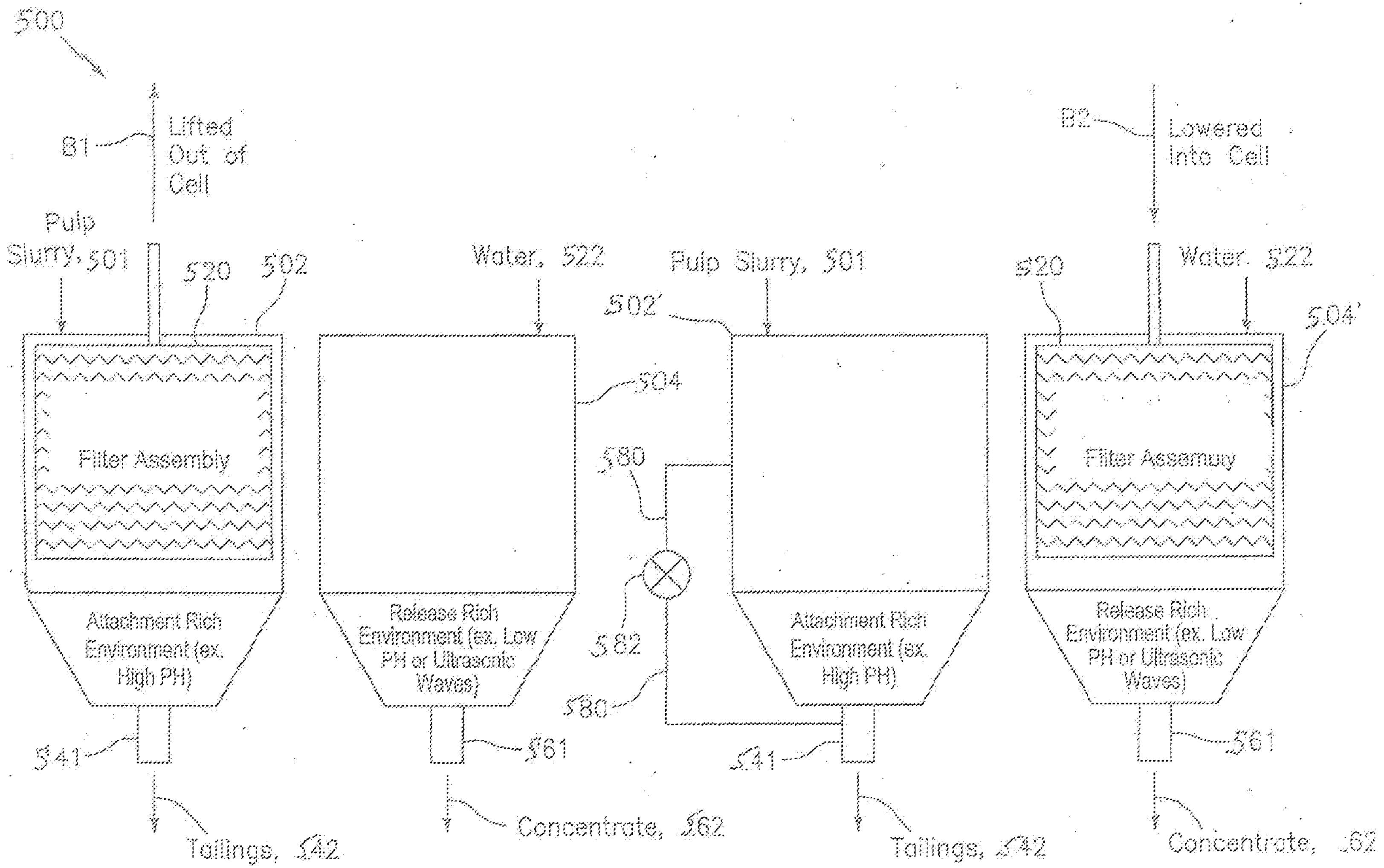

500
81
Lifted Out of Cell
Pulp Slurry, 501
520
502
Filter Assembly
Attachment Rich Environment (ex. High PH)
541
Tailings, 542
Water, 522
504
Release Rich Environment (ex. Low PH or Ultrasonic Waves)
561
Concentrate, 562
580
582
580
Pulp Slurry, 501
502'
Attachment Rich Environment (ex. High PH)
541
Tailings, 542
B2
Lowered Into Cell
520
Water, 522
504'
Filter Assembly
Release Rich Environment (ex. Low PH or Ultrasonic Waves)
561
Concentrate, 62

Figure 12

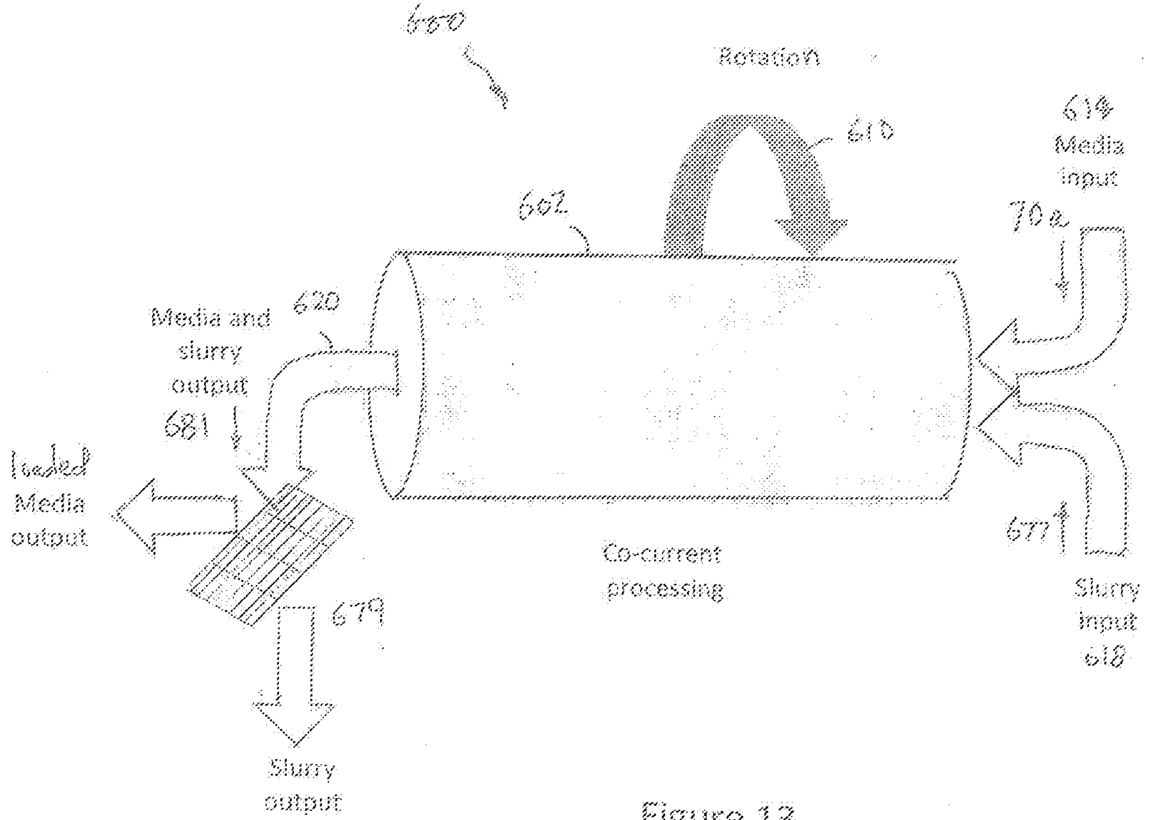

600
Rotation
610
602
614
Media
input
70a
620
Media and
slurry
output
681
loaded
Media
output
679
Slurry
output
Co-current
processing
677
Slurry
input
618

Figure 13

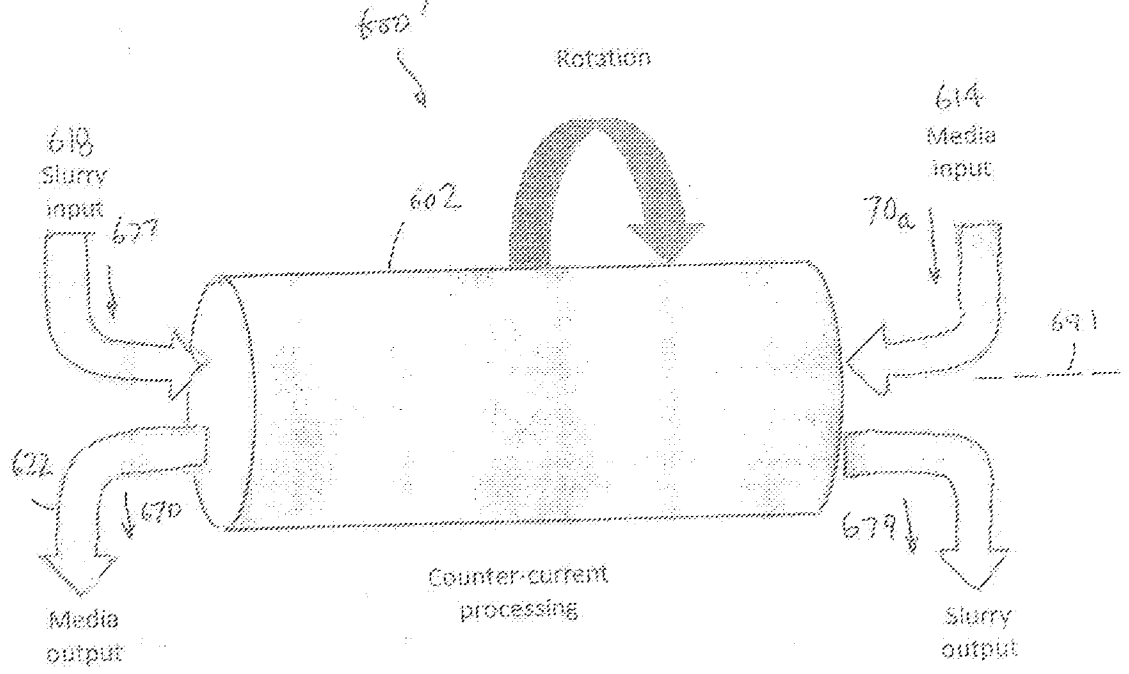

600'
Rotation
618
Slurry
input
677
602
614
Media
input
70a
691
622
670
679
Media
output
Counter-current
processing
Slurry
output

Figure 14

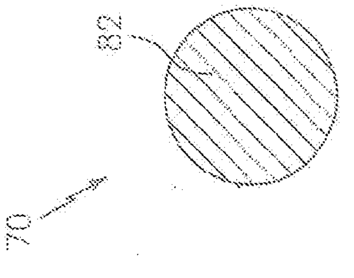


Figure 15a

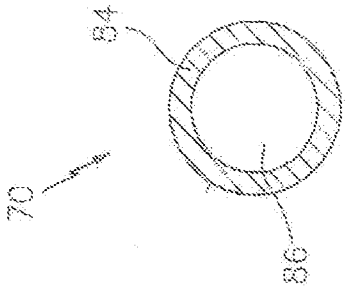
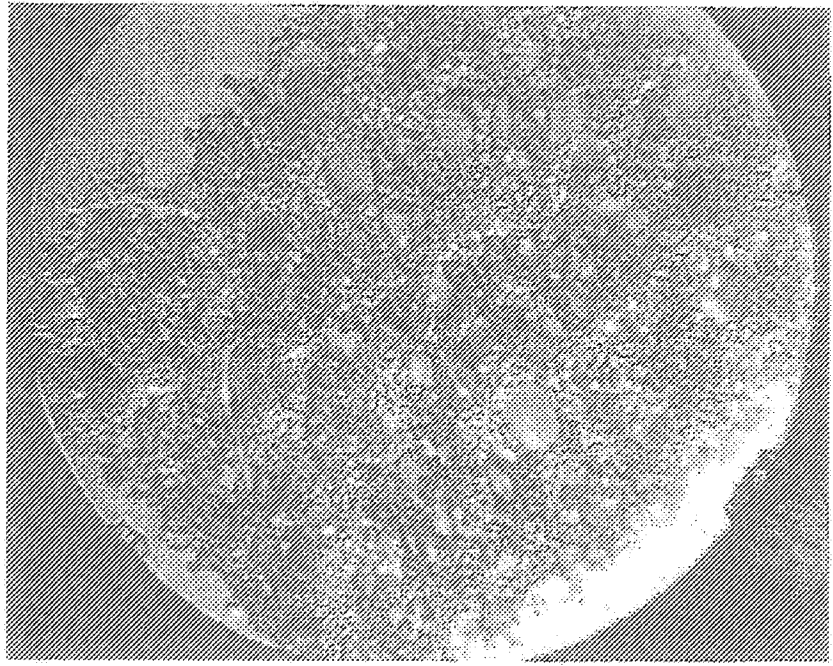


Figure 15b



Reticulated Foam with Cu Mineral entrained throughout the structure

Figure 16

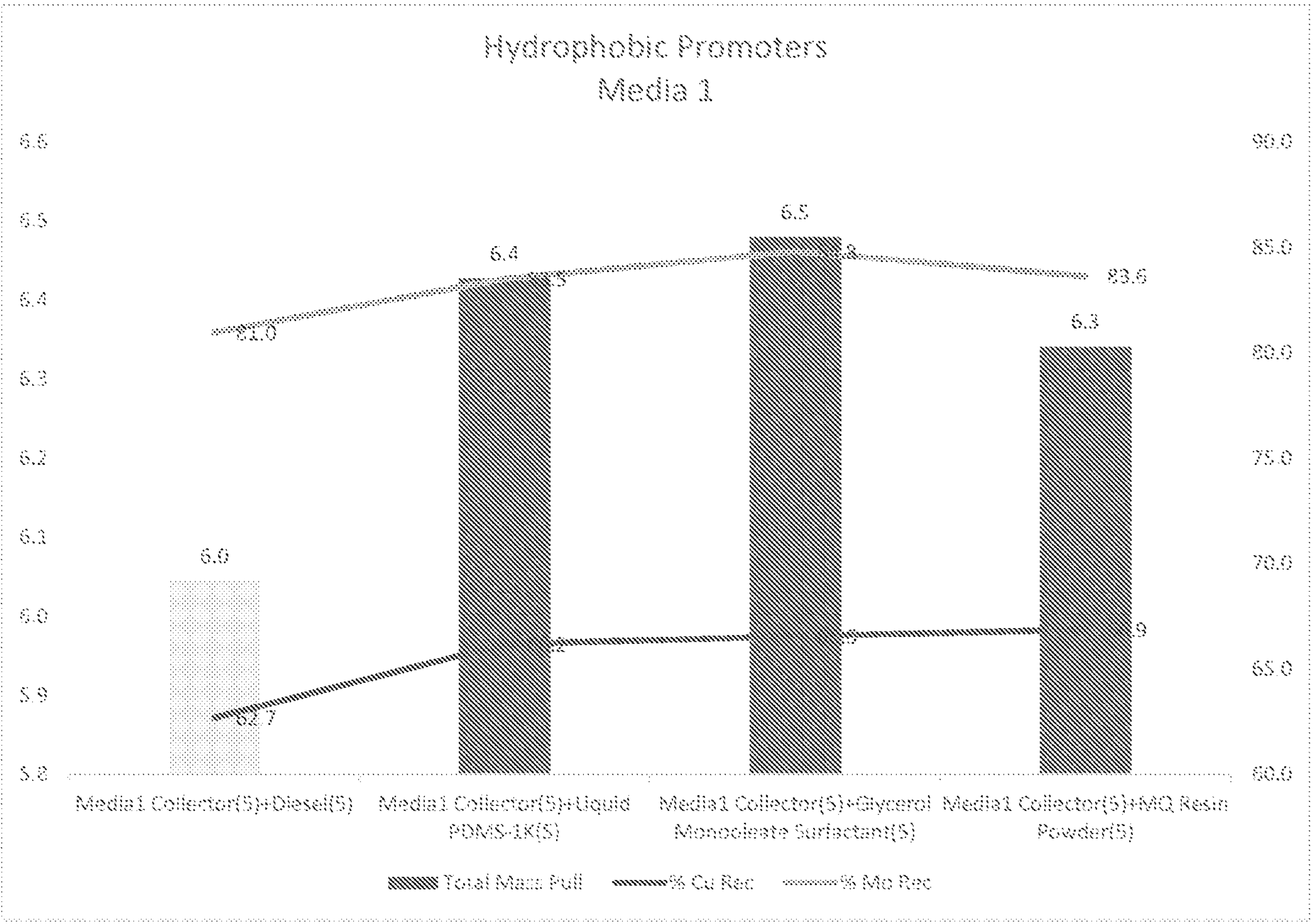

Hydrophobic Promoters
Media 1
6.6
6.5
6.4
6.3
6.2
6.1
6.0
5.9
5.8
90.0
85.0
80.0
75.0
70.0
65.0
60.0
6.0
6.4
6.5
6.3
81.0
.5
.8
83.6
62.7
.2
.9
Media1 Collector(5)+Diesel(5)
Media1 Collector(5)+Liquid PDMS-1K(5)
Media1 Collector(5)+Glycerol Monooleate Surfactant(5)
Media1 Collector(5)+MQ Resin Powder(5)
▨ Total Mass Pull
% Cu Rec
% Mo Rec

Figure 17

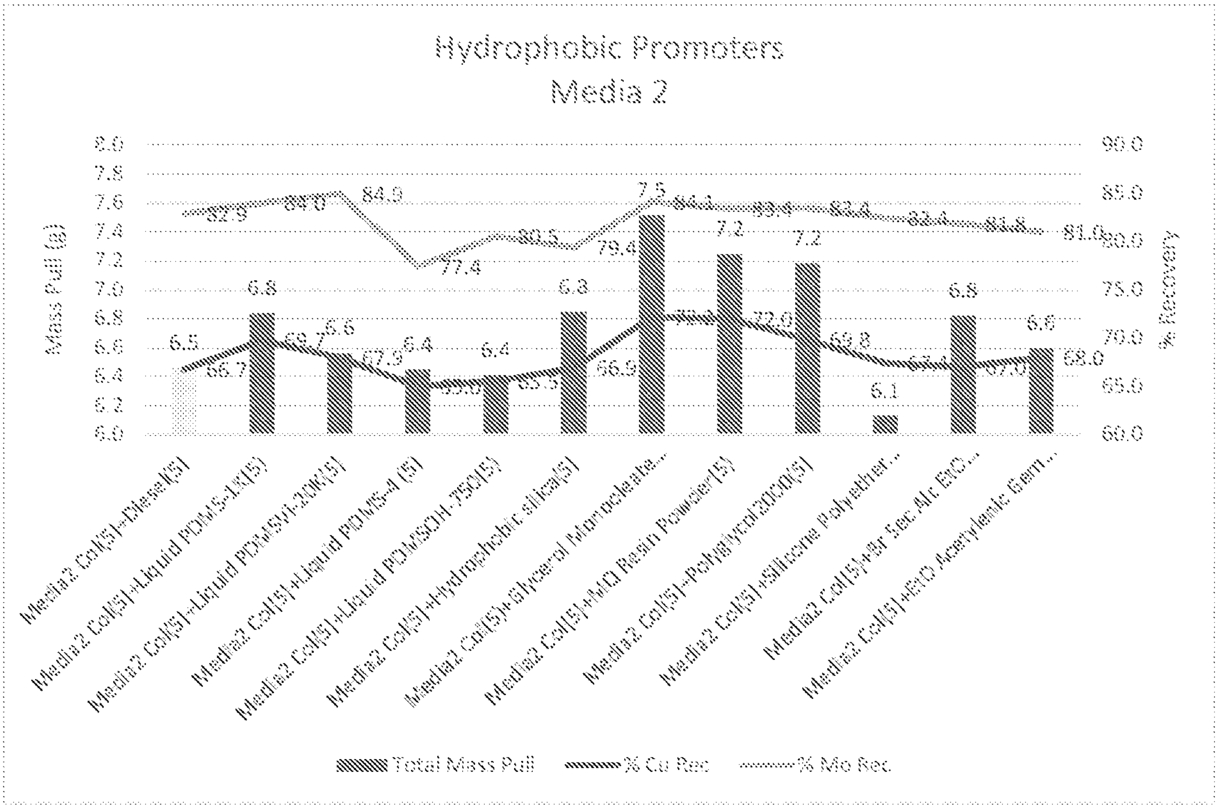
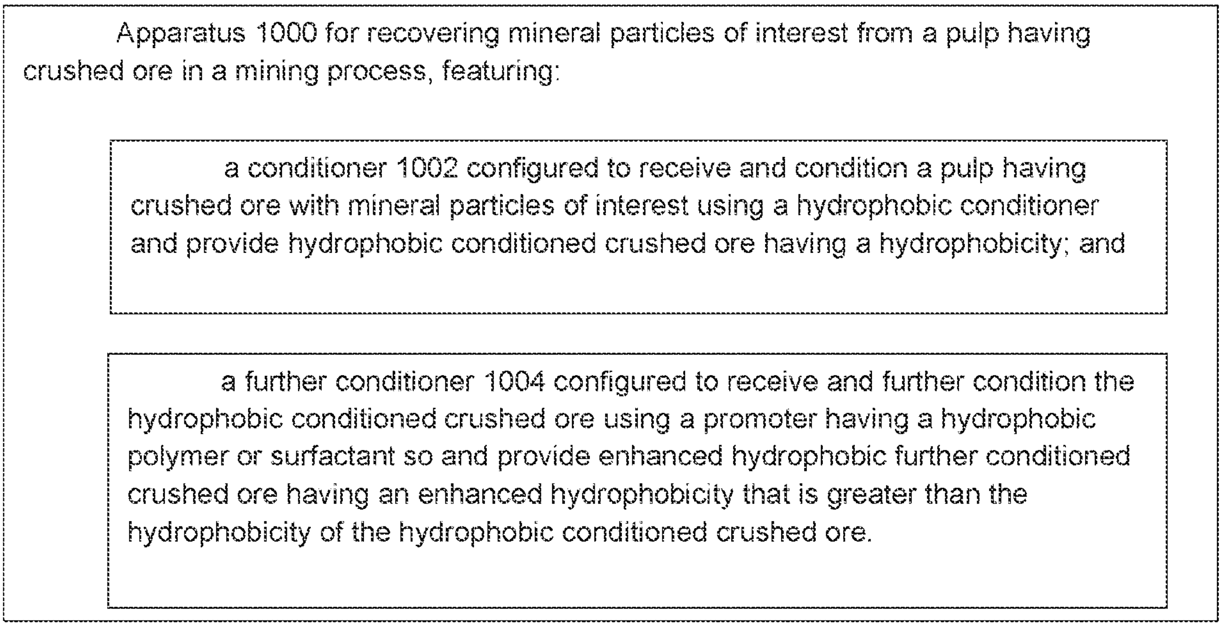

Hydrophobic Promoters
Media 2
Mass Pull (g)
% Recovery
8.0
7.8
7.6
7.4
7.2
7.0
6.8
6.6
6.4
6.2
6.0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
6.5
6.8
6.6
6.4
6.4
6.8
7.5
7.2
7.2
6.1
6.8
6.6
66.7
69.7
67.9
65.0
65.5
66.9
72.0
69.8
67.4
67.0
68.0
82.9
84.0
84.9
77.4
80.5
79.4
84.1
83.4
82.4
82.4
81.8
81.0
Media2 Col(5)+Diesel(5)
Media2 Col(5)+Liquid PDMS-1K(5)
Media2 Col(5)+Liquid PDMSVI-20K(5)
Media2 Col(5)+Liquid PDMS-4 (5)
Media2 Col(5)+Liquid PDMSOH-750(5)
Media2 Col(5)+Hydrophobic silica(5)
Media2 Col(5)+Glycerol Monooleate...
Media2 Col(5)+MQ Resin Powder(5)
Media2 Col(5)+Polyglycol2000(5)
Media2 Col(5)+Silicone Polyether...
Media2 Col(5)+Br Sec Alc EtO...
Media2 Col(5)+EtO Acetylenic Gem...
Total Mass Pull
% Cu Rec
% Mo Rec

Figure 18



Apparatus 1000 for recovering mineral particles of interest from a pulp having crushed ore in a mining process, featuring:

a conditioner 1002 configured to receive and condition a pulp having crushed ore with mineral particles of interest using a hydrophobic conditioner and provide hydrophobic conditioned crushed ore having a hydrophobicity; and

a further conditioner 1004 configured to receive and further condition the hydrophobic conditioned crushed ore using a promoter having a hydrophobic polymer or surfactant so and provide enhanced hydrophobic further conditioned crushed ore having an enhanced hydrophobicity that is greater than the hydrophobicity of the hydrophobic conditioned crushed ore.

Figure 19