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(54) **SYSTEMS AND METHODS FOR
SUBSURFACE METAL RECOVERY**

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(57) **ABSTRACT**

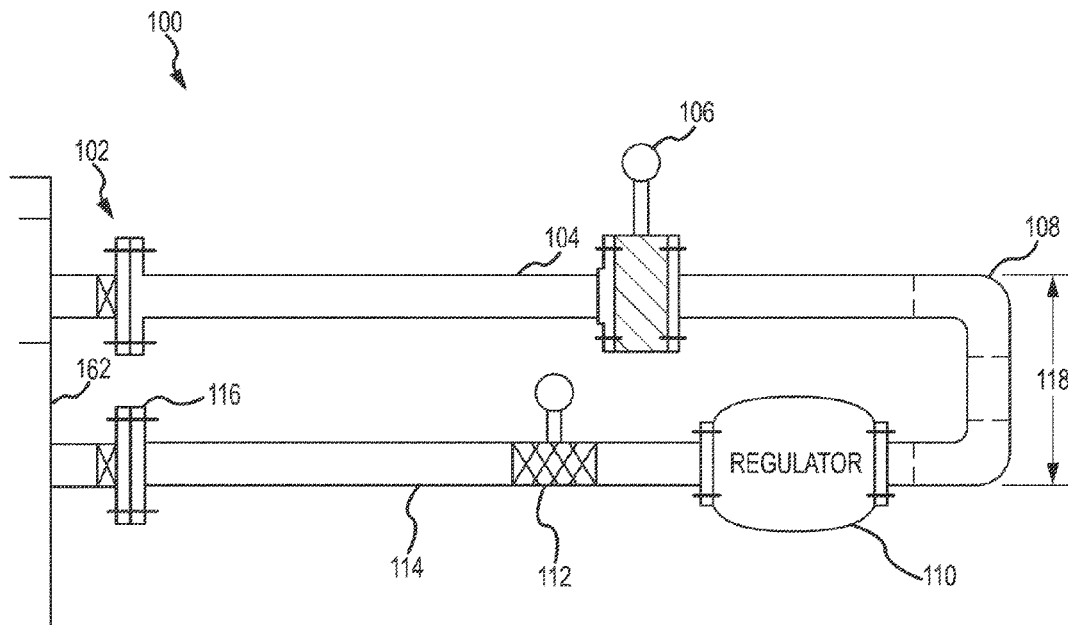
(21) Appl. No.: **18/480,354**

The present disclosure provides a method comprising determining an ore map for a heap to identify a location of a recoverable metal value in the heap, delivering a leaching solution from a leaching solution source to a leaching solution regulating system, regulating at least one of a pressure, a mass flow rate, or a volumetric flow rate of the leaching solution to achieve a first target operational condition, wherein the first target operational condition is selected to optimize a set of operational parameters to maximize recovery of the recoverable metal value, delivering the leaching solution at the first target operational condition from the leaching solution regulating system to a subsurface leaching distribution system, and delivering the leaching solution at the first target operational condition from the subsurface leaching distribution system to the location of the recoverable metal value under a surface of the heap to leach and recover at least one metal value.

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Related U.S. Application Data

(63) Continuation-in-part of application No. 18/124,333, filed on Mar. 21, 2023, which is a continuation of application No. 17/733,171, filed on Apr. 29, 2022, now Pat. No. 11,639,539, which is a continuation of application No. 17/223,404, filed on Apr. 6, 2021, now Pat. No. 11,332,808, which is a continuation of application No. 16/223,760, filed on Dec. 18, 2018, now Pat. No. 10,975,455, which is a continuation of application No. 15/989,614, filed on May 25, 2018, now Pat. No. 10,190,190, which is a continuation of application No. 15/539,328, filed on Jun. 23, 2017,



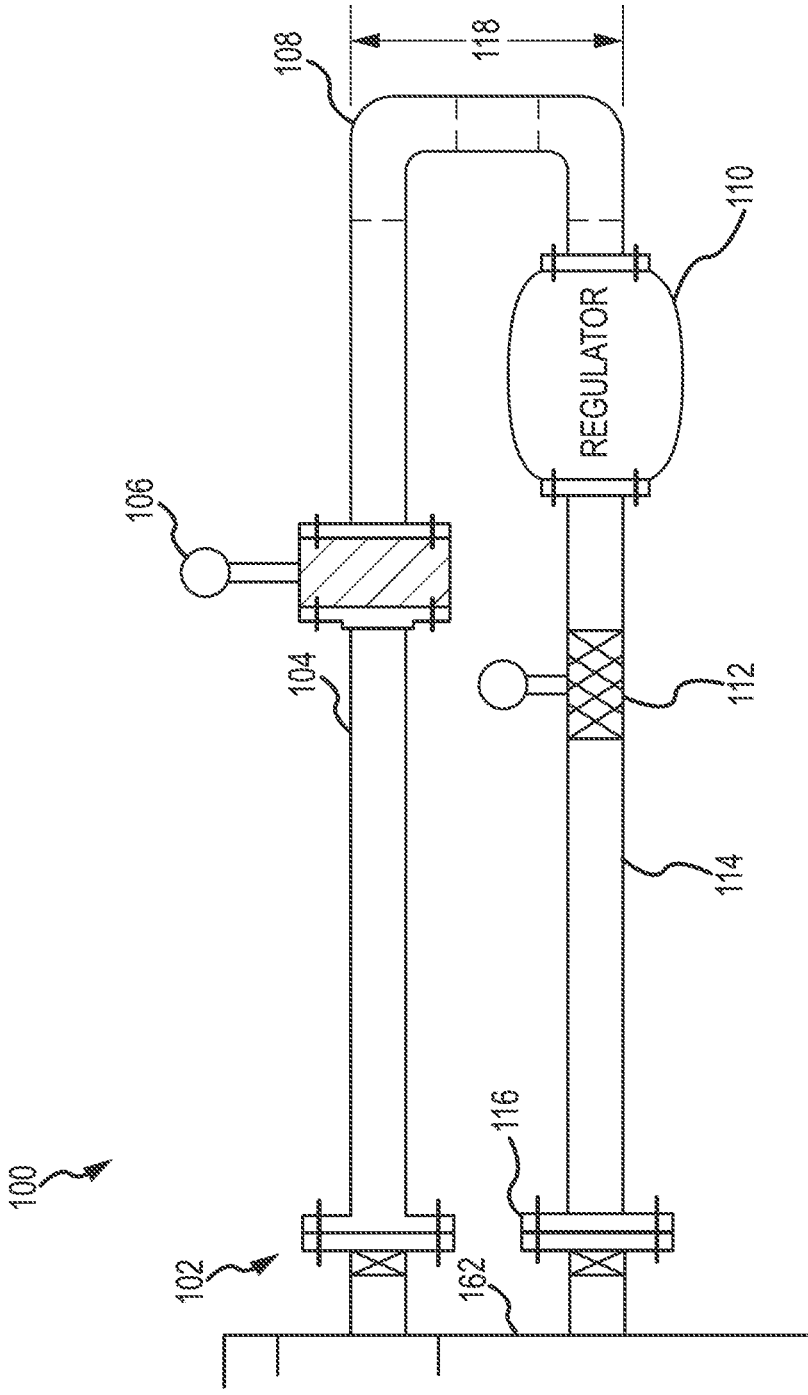
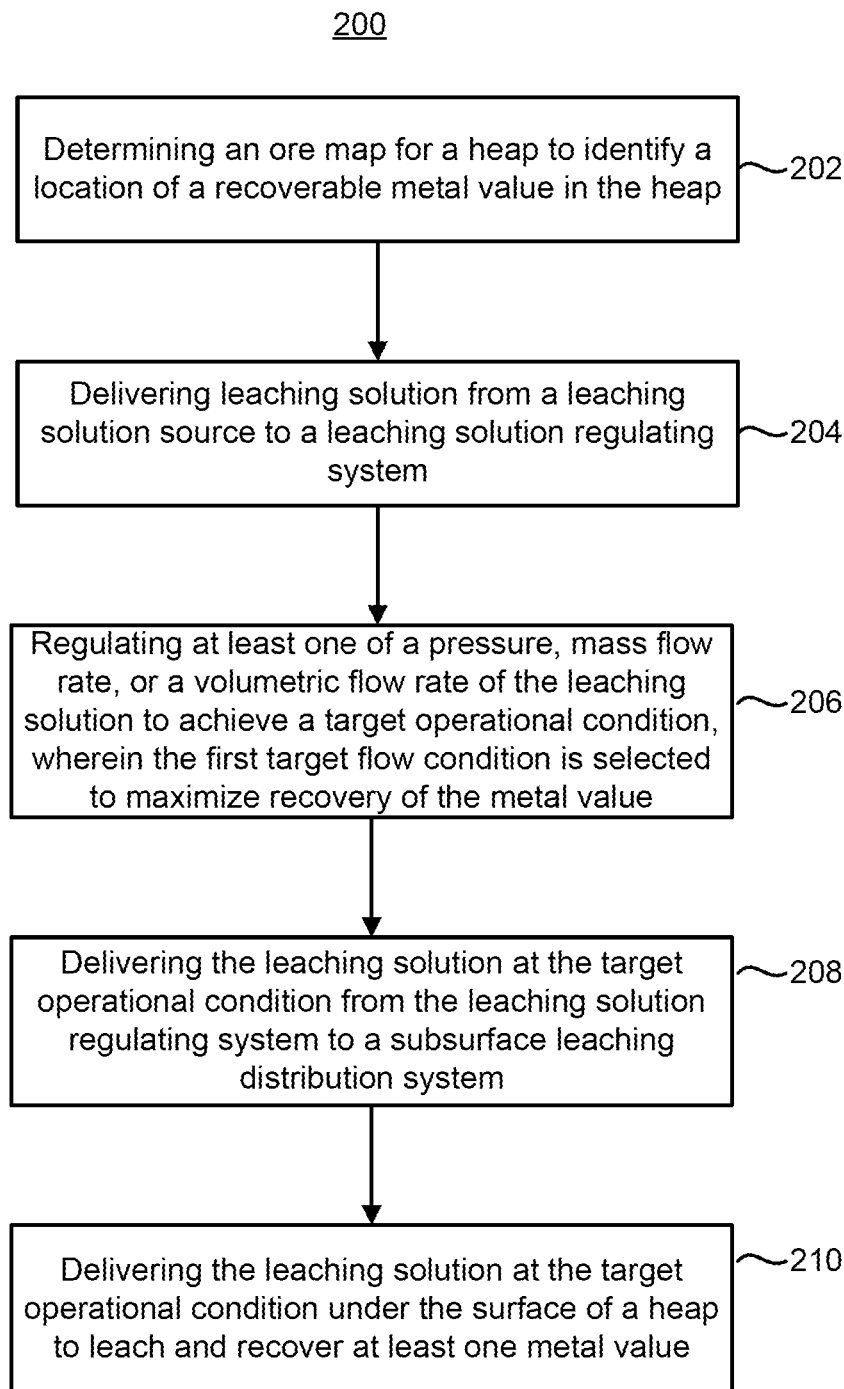


FIG.1



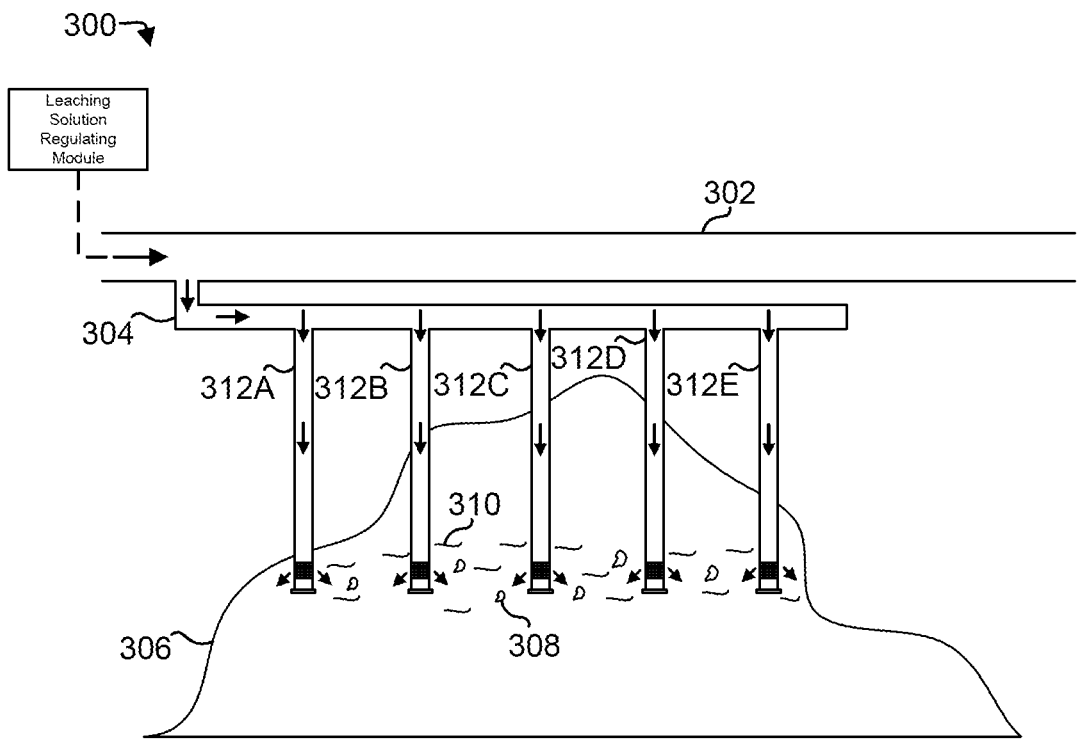


FIG. 3

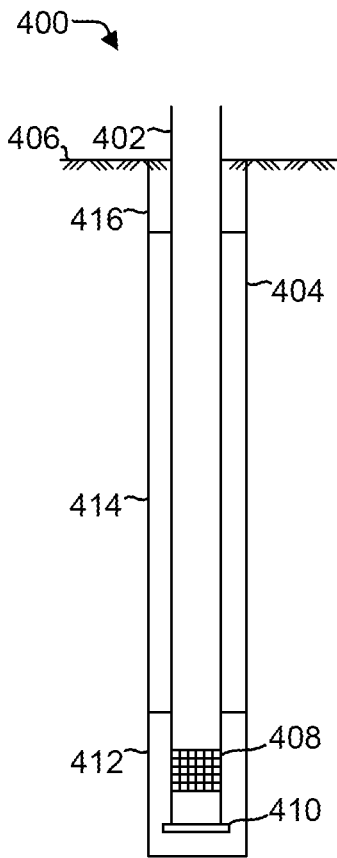


FIG. 4A

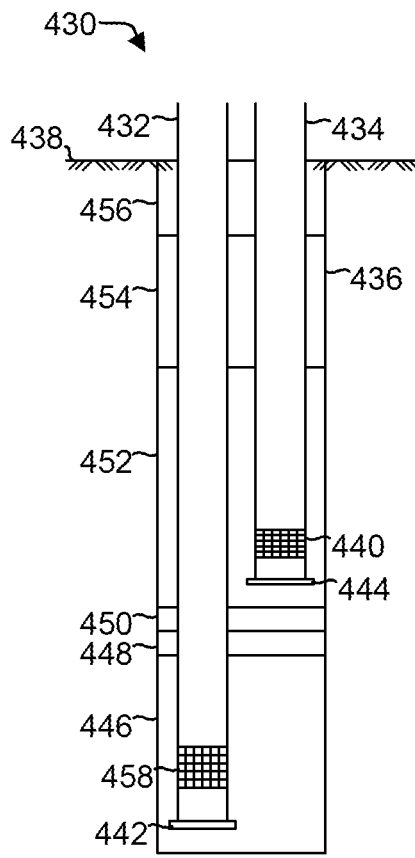


FIG. 4B

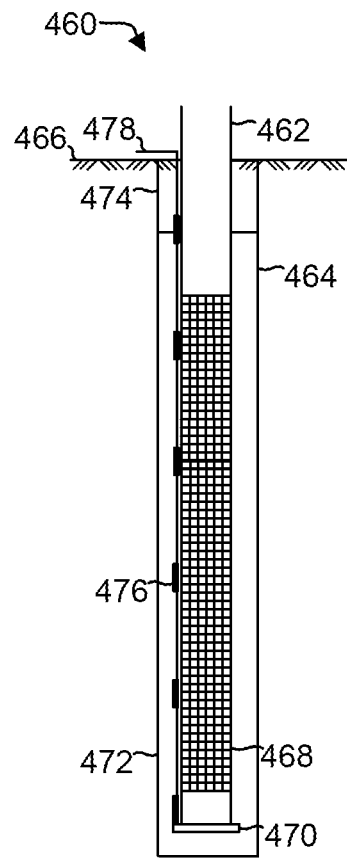


FIG. 4C

SYSTEMS AND METHODS FOR SUBSURFACE METAL RECOVERY

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation-in-part of and claims priority to U.S. patent application Ser. No. 18/124,333, entitled “SYSTEMS AND METHODS FOR MONITORING METAL RECOVERY SYSTEMS,” which was filed on Mar. 21, 2023 (the “’333 Application”). The ’333 Application is a continuation of and claims priority to U.S. patent application Ser. No. 17/733,171, entitled “SYSTEMS AND METHODS FOR MONITORING METAL RECOVERY SYSTEMS,” which was filed on Apr. 29, 2022, now U.S. Pat. No. 11,639,539, issued on May 2, 2023 (the “’171 Application”). The ’171 Application is a continuation of and claims priority to U.S. patent application Ser. No. 17/223,404, entitled “SYSTEMS AND METHODS FOR MONITORING METAL RECOVERY SYSTEMS,” which was filed on Apr. 6, 2021, now U.S. Pat. No. 11,332,808, issued on May 17, 2022 (the “’404 Application”). The ’404 Application is a continuation of and claims priority to U.S. patent application Ser. No. 16/223,760, entitled “SYSTEMS AND METHODS FOR MONITORING METAL RECOVERY SYSTEMS,” which was filed on Dec. 18, 2018, now U.S. Pat. No. 10,975,455, issued on Apr. 13, 2021 (the “’760 Application”). The ’760 Application is a continuation of and claims priority to U.S. patent application Ser. No. 15/989,614, entitled “SYSTEMS AND METHODS FOR MONITORING METAL RECOVERY SYSTEMS,” which was filed on May 25, 2018, now U.S. Pat. No. 10,190,190, issued on Jan. 29, 2019 (the “’614 Application”). The ’614 Application is a continuation of and claims priority to U.S. patent application Ser. No. 15/539,328, entitled “SYSTEMS AND METHODS FOR MONITORING METAL RECOVERY SYSTEMS,” which was filed on Jun. 23, 2017, now U.S. Pat. No. 9,982,321, issued on May 29, 2018 (the “’328 Application”). The ’328 Application is a U.S. National Phase filing under 35 U.S.C § 371 of and claims priority to PCT/US2015/050015, filed on Sep. 14, 2015, which claims priority to U.S. Provisional Patent Application Ser. No. 62/097,458, filed on Dec. 29, 2014.

FIELD OF THE DISCLOSURE

[0002] The present disclosure relates, generally, to systems and methods for monitoring and/or regulating subsurface metal recovery systems, and more specifically, to systems and methods for introducing leaching solution under the surface of a heap at a target operational condition to target areas of residual copper.

BACKGROUND OF THE DISCLOSURE

[0003] Hydrometallurgical treatment of metal bearing materials, such as copper ores, copper concentrates, and other metal bearing ores and concentrates, has been well established for many years. Typically, conventional hydrometallurgical processes for copper recovery involve leaching metal bearing materials with an acidic solution, for example, either atmospherically or under conditions of elevated temperature and pressure. The resultant process stream—the pregnant leach solution—is recovered, and a processing step such as solution extraction is used to form a highly concentrated and relatively pure metal value contain-

ing aqueous phase. One or more metal values may then be electrowon from this aqueous phase.

[0004] Leaching under atmospheric conditions in a conventional heap leaching operation may comprise placing an acidic leaching solution onto the surface of a collection of ore referred to as a heap to liberate metal values from the ore. Heap leaching may thus involve the use of a leaching solution distribution system, which is typically a large network of pipes or other conduits. The pipes or other conduits may have nozzles or other orifices that are designed to emit leaching solution at a particular flow condition.

[0005] Typically, leaching solution is distributed on top of the heap and, by force of gravity, travels down towards the pad. The pad may be sloped toward a collection pipe or conduit for recovering the pregnant leach solution. Leaching solution may comprise any liquid capable of liberating a metal value from ore. In various embodiments, leaching solution may be acidic and may comprise sulfuric acid. However, in various embodiments, leaching solution may be basic and may comprise ammonia or ammonium ions. Leaching solution may also be enhanced with heat, bacteria, oxygen or oxidizers, and other additives or physical modifications that enhance leaching via one or more mechanisms.

[0006] The leaching solution may be sourced from a variety of locations. Fresh acid and/or water may be used as well as acid and/or water that is recycled or reclaimed from other metal value recovery processes. Accordingly, particulates or other solid phase impurities and/or liquid organic phase containments (also referred to as “crud”) may be introduced from the recycled/reclaimed acid and/or water and thus contained within the leaching solution. Over time, a build-up of crud may occlude or otherwise obstruct the nozzles and/or orifices of the leaching solution distribution system. Such obstruction restricts leaching solution flow from its ideal flow conditions, resulting in improper leaching solution flow that is detrimental to metal value recovery processes. For example, deviation from an ideal flow condition may adversely affect the efficiency and effectiveness of leaching operations, specifically subsurface leaching operations, including the ability to leach and/or recover metal values from the heap.

[0007] Conventional surface heap leaching operations may be unable to liberate certain metal values from the ore as a result of low permeable materials such as high clay content materials present in the heap. Such low permeable materials may prevent percolation of the leaching solution through portions of the heap, thereby preventing contact of the ore with the leaching solution in these portions, ultimately resulting in metal values remaining unliberated in the heap.

[0008] Further, existing subsurface systems may lack the ability to regulate flow conditions of the leaching solution, for example, pressure, mass flow rate, and volumetric flow rate, which may be important factors in determining subsurface leaching efficiency and effectiveness. Targeted and controlled subsurface delivery of leaching solutions is important in order to optimize the economics of subsurface leaching. For example, leach heaps are non-homogenous due to the fact that the ore comes from multiple locations in the ore body. This results in a wide variation in mineralogy and leaching characteristics throughout the heap. Thus, when the ore was originally leached via surface leaching, the copper placed in some locations may have leached to near completion, while the copper placed in other locations did

not leach well due to a variety of factors, including mineralogy, heap permeability, and lixiviant chemistry.

[0009] Subsurface leaching, as currently practiced, involves drilling vertical holes into the leach heap and injecting leaching solution into the holes so that the raffinate contacts the ore at depth. This method, while effective, requires large quantities of leaching solution as it is pumped at a standardized flow rate across the leach pad. Further, current operations generally apply solution to the length of the vertical hole, dosing sections of the pad that may have already been sufficiently leached, resulting in wasted solution. Inefficient solution application is particularly non-economic when the leach solution is enhanced with various costly additives. Similarly, as the process of pumping solutions to the leach pad is energy intensive, applying solution to unnecessary areas of the heap is not economically efficient. As such, there is a need to improve sub-surface leaching by implementing additional controls so that inputs such as energy and leaching solution are used in the most economically advantageous manner to optimize metal recovery.

[0010] A further limitation of currently known methods of subsurface leaching is the preference of maintaining a consistent solution flow through the entirety of the leaching cycle. The ability to change the solution flow as leaching cycle data is received and evaluated to address issues that arise through the leaching process, such as, for example, the “locking up” of leach solution in the heap or the occlusion of solution distribution lines, would be beneficial and allow for a more effective leaching process.

[0011] Various attempts have been made to improve the process, such as, for example, in Guzman et al., “Hybrid Integration System”, U.S. Pat. No. 8,186,607. This patent proposed using a combined surface and subsurface leaching system to improve surface ponding and heap stability through the use of solution delivered at a set operating pressure based on the heap’s hydraulic properties. However, by primarily focusing on maintaining heap stability and improving safety through hydraulic controls, several other pertinent operational factors are not taken into account when determining optimal leaching conditions. Therefore, it is not possible to maximize recovery using this process.

[0012] This invention utilizes pressure, flow, and volume control through a subsurface leaching distribution system combined with residual metal mapping to identify ore targets and apply solutions of targeted chemistry to exact locations and depths within leach heaps at a target operational condition to maximize recovery.

SUMMARY OF THE DISCLOSURE

[0013] A method may comprise determining an ore map for a heap to identify a location of a recoverable metal value in the heap, delivering a leaching solution from a leaching solution source to a leaching solution regulating system, regulating at least one of a pressure, a mass flow rate, or a volumetric flow rate of the leaching solution to achieve a first target operational condition, wherein the first target operational condition is selected to optimize a set of operational parameters to maximize recovery of the recoverable metal value, delivering the leaching solution at the first target operational condition from the leaching solution regulating system to a subsurface leaching distribution system, and delivering the leaching solution at the first target operational condition from the subsurface leaching distribution

system to the location of the recoverable metal value under a surface of the heap to leach and recover at least one metal value.

[0014] In various embodiments, the leaching solution regulating system may comprise a plurality of leaching solution regulating modules. Each leaching solution regulating module may comprise a meter configured to detect a pressure or flow rate of the leaching solution. Each leaching solution regulating module may comprise a regulator configured to set a pressure or flow rate of the leaching solution to the target operational condition. In an exemplary embodiment, the regulator may comprise a 3-way valve comprising a vent configured to prevent a pressure drop of the leaching solution. Each leaching solution regulating module may comprise a transmitter configured to transmit a pressure or flow rate of the leaching solution. In various embodiments, the set of operational parameters comprises at least one of mineralogy, chemistry, permeability, and remaining recoverable metal values.

[0015] In various embodiments, determining the ore map may comprise adding flow data, irrigation data, and a remaining mineral prediction from a machine learning model to obtain information by section and by date for the heap. In various embodiments, the method may further comprise determining x, y, z coordinates for the location of recoverable metal value in the heap.

[0016] An exemplary system may comprise a recoverable metal value in a heap, a leaching solution regulating system configured to regulate a leaching solution to a target operational condition, wherein the target operational condition is selected to optimize a set of operational parameters to maximize recovery of the recoverable metal value, and a subsurface leaching solution distribution system fluidly coupled to the leaching solution regulating system, the subsurface leaching solution distribution system comprising a subsurface injector configured to deliver leaching solution under a surface of a heap to leach one or more metal values.

[0017] The subsurface injector may comprise a metal or thermoplastic material. The subsurface leaching solution distribution system may comprise a first subsurface injector and a second subsurface injector, the first subsurface injector extending into the heap a greater distance than the second subsurface injector. The subsurface injector may comprise a slotted portion comprising at least one slot configured to deliver leach solution to the heap. The subsurface injector may be fluidly coupled to a primary pipe and a secondary pipe, the primary pipe fluidly coupled to the leaching solution distribution system. The subsurface injector may be inserted into a bore formed in the heap, the bore filled with at least one material configured to provide stability and sealing for the subsurface injector. The bore may be filled with a gravel material, a cushion material, and a grout-based material. The system may further comprise a plurality of sensors distributed along a length of the subsurface injector.

[0018] In various embodiments, the system may further comprise an ore map determined by adding flow data, irrigation data and a remaining mineral prediction from a machine learning model to obtain information by section and by date for the heap. In various embodiments, the set of operational parameters comprises at least one of mineralogy, chemistry, permeability, and remaining recoverable metal values.

[0019] In accordance with an exemplary embodiment, a subsurface leaching distribution system may comprise a

primary pipe, a secondary pipe fluidly coupled to the primary pipe, and a subsurface injector fluidly coupled to the primary pipe or the secondary pipe, the subsurface injector configured to be inserted under a surface of a heap to deliver leaching solution to a targeted location within the heap at a target operational condition set by a leaching solution regulating system coupled to the subsurface leaching distribution system.

[0020] In various embodiments, the subsurface injector may comprise a slotted portion comprising at least one slot configured to deliver leaching solution to the targeted location within the heap. The slotted portion may extend approximately 0 to 40 feet along a length of the subsurface injector. The subsurface injector may comprise PVC pipe approximately 3 to 5 inches in diameter, or otherwise sufficiently large enough to facilitate the target operational condition of the leaching solution. The subsurface leaching distribution system may further comprise a plurality of sensors coupled to and distributed along a sensor wire, the plurality of sensors configured to monitor a flow condition of the leaching solution from the subsurface injector.

[0021] The foregoing features and elements may be combined in various combinations without exclusivity, unless expressly indicated otherwise. These features and elements as well as the operation thereof will become more apparent in light of the following description and the accompanying drawings. It should be understood, however, the following description and drawings are intended to be exemplary in nature and non-limiting.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] The subject matter of the present invention is particularly pointed out and distinctly claimed in the concluding portion of this specification. A more complete understanding of the present invention, however, may best be obtained by referring to the detailed description and claims when considered in connection with the drawing figures, wherein like numerals denote like elements and wherein:

[0023] FIG. 1 is a diagram illustrating a leaching solution regulating system in accordance with various embodiments of the present disclosure;

[0024] FIG. 2 is a diagram illustrating a method for identifying areas of recoverable ore, regulating leaching solution flow, and delivering leaching solution beneath the surface of a heap in accordance with various embodiments of the present disclosure;

[0025] FIG. 3 is a diagram illustrating a subsurface leaching solution distribution system in accordance with various embodiments of the present disclosure;

[0026] FIG. 4A is a diagram illustrating a single injection well design of a subsurface leaching solution distribution system in accordance with various embodiments of the present disclosure;

[0027] FIG. 4B is a diagram illustrating a nested injection well design of a subsurface leaching solution distribution system in accordance with various embodiments of the present disclosure; and

[0028] FIG. 4C is a diagram illustrating an injection well design of a subsurface leaching solution distribution system including one or more monitoring electrodes in accordance with various embodiments of the present disclosure.

DETAILED DESCRIPTION

[0029] The following description is merely exemplary in nature and is not intended to limit the present invention, its applications, or its uses. It should be understood that throughout the drawings, corresponding reference numerals indicate like or corresponding parts and features. The description of specific examples indicated in various embodiments of the present invention are intended for purposes of illustration only and are not intended to limit the scope of the invention disclosed herein. Moreover, recitation of multiple embodiments having stated features is not intended to exclude other embodiments having additional features or other embodiments incorporating different combinations of the stated features.

[0030] Furthermore, the detailed description of various embodiments herein makes reference to the accompanying drawing figures, which show various embodiments by way of illustration. While the embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, it should be understood that other embodiments may be realized, and that logical and mechanical changes may be made without departing from the spirit and scope of the present invention. Thus, the detailed description herein is presented for purposes of illustration only and not of limitation. For example, steps or functions recited in descriptions any method, system, or process, may be executed in any order and are not limited to the order presented. Moreover, any of the step or functions thereof may be outsourced to or performed by one or more third parties. Furthermore, any reference to singular includes plural embodiments, and any reference to more than one component may include a singular embodiment.

[0031] The present disclosure relates, generally, to systems and methods for metal recovery and, more specifically, to systems and methods for subsurface metal recovery and systems for regulating leaching solution flow to subsurface metal recovery systems.

[0032] Conventional heap leaching processes may comprise forming a mass of ore, known as a heap, over a base or pad. Ore, for example, crushed ore, is typically processed to a desired particle size and uniformity. However, ore, referred to as run-of-mine ore, may be placed on the heap without any post-fragmentation processing. Ore may comprise any metal bearing material, such as an ore, a combination of ores, a concentrate, a process residue, a flotation tailings product, an impure metal salt, combinations thereof, or any other material from which metal values may be recovered. Metal values such as, for example, copper, gold, silver, zinc, platinum group metals, nickel, cobalt, molybdenum, rhenium, uranium, rare earth metals, and the like may be recovered from ore in accordance with various embodiments. In various embodiments, ore comprises copper and copper containing minerals and may comprise chalcopyrite, chalcocite, covellite, bornite, tetrahedrite, digenite, malachite, azurite, cuprite, chrysocolla, tennantite, and/or diopside, for example.

[0033] Conventional heap leaching may comprise distributing a leaching solution over the surface of a heap of ore via a leaching solution distribution system. A leaching solution distribution system may generally comprise one or more pipes arranged to deposit leaching solution to the heap. The leaching solution distribution system may be configured in a network arrangement to receive leaching solution from one or more sources and conduct the leaching solution to the

heap. The leaching solution may be sourced from a variety of locations. Fresh acid and/or water may be used as well as acid and/or water that is recycled or reclaimed from other metal value recovery processes, such as raffinate from a solvent extraction/electrowinning (“SXEW”) process. In various embodiments, fresh basic medium and/or water may be used as well as basic medium and/or water that is recycled or reclaimed from other metal value recovery processes. In various embodiments the leach solution may be enhanced with specific strains of bacteria, air, enriched air, oxygen, chemical oxidants, and/or leach enhancing chemicals. In various embodiments, the leach solution may be heated. Accordingly, the leaching solution distribution system may be provided these sources of leaching solution and distribute them to the heap.

[0034] The leaching solution distribution system may comprise one or more primary pipes that are fluidly coupled to smaller pipes or branches. The smaller pipes may comprise one or more orifices at predetermined distances. In that regard, the orifices are configured to allow leaching solution to drip or otherwise flow from the smaller pipes and onto the heap. The leaching solution distribution system may be configured to distribute leaching solution at predetermined flow conditions, for example, within a predetermined range of pressures and/or flow rates. For example, a flow rate that is above a predetermined flow rate range may have a cooling effect on the leach pad and negate the effect of any exothermic reactions or heating efforts. Additionally, a high flowrate may exacerbate pad permeability issues by flooding flow channels within the heap beyond their capacity to carry solution. This may result in structural problems with the earthen heap. A flow rate that is below a predetermined flow rate range may not deliver enough of the reagents that drive the leach reaction, so that the reaction either does not result in an optimum economic metal recovery or takes much longer to do so. In that regard, maintaining leaching solution flow conditions within a predetermined range is beneficial.

[0035] Such conventional surface heap leaching operations may be suitable for some portions of the heap, however, may be ineffective for other portions of the heap depending on the properties of the heap and materials present in the heap. For example, some materials, such as high clay content materials, or other dense or high content materials, may prevent effective leaching of the target ore material by preventing leaching solution from percolating through these impenetrable areas. Other known problems, such as large amounts of scaling and a high degree of saturation, may present further problems for conventional surface heap leaching operations.

[0036] Additionally non-uniform percolation of solution throughout the heap may be caused by the presence of fines, elevated bulk densities and zones of secondary precipitation and mineralization. These less-than-optimal conditions resulting in non-uniform percolation occur to some extent with all heap-leachable ores. Non-uniform percolation may also result from elevated heap bulk densities that, due to elevated density, result in reduced porosity negatively impacting fluid communication pathways within the heap matrix and thereby inhibiting optimum percolation rates and metal recovery. Elevated heap bulk densities and reduced porosity within the heap can be attributable to material compaction that occurs during heap construction or operation, insular laminated zones can exhibit elevated bulk density and lower porosity and fluid communication path-

ways and thereby reduce percolation rates, whether such conditions are attributable to secondary mineralization or precipitation reactions associated with the percolated lixiviant and contact with gangue and mineralized heap constituents, percolation reduction attributable to sorting of lenticular clays and fines stratified within the heaped material or percolation reduction due to elevated bulk density within the heap resulting from triaxial pressures and structural loading conditions of the heap pad as constructed, operated and maintained, including instances where the heap exhibits elevated triaxial pressures and geotechnical loading upon the heap matrix derivative from heap depth, such heap conditions impacting and reducing percolation flow rates and corresponding physical and chemical transport of metals within the heap.

[0037] It is well understood that the leaching reagents must percolate throughout the heap matrix so as to diffuse into the ore particles and react with the metal bearing minerals in the ore, and then the resultant metallic complexes have to diffuse back into the solution. The transport of the solute is influenced by the way the solute interacts with the solid-liquid matrices in the porous medium. The rate-limiting mass transfer between stagnant and mobile liquids leads to the physical non-equilibrium of solute. The leaching solution will choose the path of least resistance, commonly called channeling. If enough fine material has built up within the heap materials, there is a chance the solution may not be able to flow at all; this is referred to as blinding. These particles clog the spaces between the larger ore particles and result in an uneven distribution of the leaching solution. This leads to poor interaction between the ore and leach solution, producing inadequate metal recoveries, or the need to extend the leach time. Accordingly, a subsurface metal recovery system may attempt to increase metal recovery by targeting areas of low permeability or areas comprising certain identified chemical properties and injecting leach solution directly adjacent to or within these areas. Such an application may be more effective at recovering metal values than conventional surface heap leaching operations. Further, some surface heap leaching operations may be effective at leaching metal values, but ineffective at recovering the metal values from the heap, as the metal-rich solution may get locked up in the heap due to permeability issues. Accordingly, a subsurface metal recovery system may seek to increase recovery of metal values from the heap in addition to more effective leaching.

[0038] When designing a subsurface metal recovery system, the mineral forms and quantities of the remaining metal values in the heap are factors to take into account so raffinate can be injected only at targeted locations and depths within the heap in order to minimize application costs and achieve the most effective recovery. It would thus be beneficial to determine an ore map of the heap, wherein areas of recoverable metal value in the heap are identified, before implementing a subsurface application system to target locations that would provide optimum economic return. Determining such an ore map may be accomplished in accordance with various embodiments, such as, for example, analysis of data from geographic information system (“GIS”) programs combined with historical leach recovery data. In accordance with various embodiments, determining an ore map before implementing a subsurface application system may help maximize recovery.

[0039] Particulates or other solid phase impurities and/or organic phase contaminants (together, referred to as “crud” as mentioned above) may be contained within the leaching solution. Over time, crud may occlude or otherwise obstruct the orifices of the leaching solution distribution system. Such obstruction restricts leaching solution flow. As discussed above, improper leaching solution flow is detrimental to metal value leaching and/or recovery processes. The pressure and/or flow rate of leaching solution in a leaching solution distribution system may change in response to one or more orifices becoming plugged. Identifying these changes in pressure and/or flow rate may be accomplished in accordance with various embodiments.

[0040] In accordance with various embodiments, a subsurface leaching system and solution regulating system is disclosed that may comprise one or more leaching solution regulating modules. The leaching solution regulating module may comprise a system configured to monitor pressure and/or flow rate across a portion of a subsurface leaching solution distribution system and/or regulate the pressure and/or flow rate to a target operational condition. A change in pressure and/or flow rate may allow for identification and amelioration of one or more plugged orifices and allow a target operational condition to be more readily achieved.

[0041] A target operational condition is an operational control that is selected by leaching operators to allow the leach heap to run most efficiently and ultimately maximize recovery. In various embodiments, a target operational condition is controlled by multiple factors, such as pressure, mass flow rate, or volumetric flow rate. To determine a target operational condition, operators must make an assessment of the various operational parameters of the specific heap, such as, for example, minerology, chemistry, permeability, and remaining recoverable metal values, any of which may be more important than another based on the unique properties of the assessed heap. In various embodiments, a target operational condition may be selected to achieve a desired outcome, such as maximizing recovery, preventing plugging of a leaching solution distribution system, and/or minimizing the “locking up” of solution in the heap. In various embodiments, a target operational condition is variable and may be adjusted throughout the leach cycle to shift from one desired outcome to another in response to evaluating the data of a leach cycle and determining changes in the heap.

[0042] For example, the target operational condition may have originally been selected to reduce zones of impermeability in the heap but, after leaching commenced, the impacted zones’ permeability improved. In such a scenario, an operator may choose to adjust the target operational condition to achieve a second, different, outcome, such as maximizing recovery. In accordance with various embodiments, when the desired outcome is to maximize recovery, preferably, all, or most of the physical and chemical factors of the heap will be taken into account for determining target operational condition. Each of these factors, such as, for example, minerology, chemistry of the heap and/or lixiviant, permeability, and areas of under-leached material contribute to the overall recovery of a metal value. To consider only a single factor when selecting a target operational condition may not maximize recovery, as the unconsidered factors may react in such a way that leaching efficiency decreases. For example, if only permeability is considered to maximize recovery, under-leached areas of the heap that have poor permeability due to blinding or channeling will be neglected

in favor of areas with better permeability, even if those areas have been more effectively leached than others. As such, preferably a considerable number of factors should be taken into consideration when determining a target operational condition to maximize recovery. In accordance with various embodiments, the operational flexibility of the subsurface leaching system and solution regulating system maximizes leaching efficiency. In accordance with various embodiments, a implementing a leaching solution regulating module with a subsurface delivery system may help maximize recovery.

[0043] In accordance with various embodiments, a leaching solution regulating module may comprise one or more pipes or conduits configured to fluidly couple to a portion of a subsurface leaching solution distribution system, receive leaching solution from the subsurface leaching solution distribution system, detect at least one of a pressure and/or flow rate, and allow the leaching solution to be distributed back to the subsurface leaching solution distribution system at a target operational condition. In various embodiments, a leaching solution regulating module may comprise a U-shaped geometry or other similar shape to allow for a compact design. A compact design may allow for easy installation into existing leaching solution distribution systems.

[0044] In accordance with various embodiments, a leaching solution regulating module may comprise an electronic regulating module that may receive data regarding at least one of a pressure or flow rate. Data may then be sent, in real time and/or a batch process, through a data network to a monitoring module. The monitoring module may communicate via a data network, for example, a wireless data network, to one or more leaching solution regulating modules. In that regard, status of the leaching solution regulating modules may be centralized. Alerts regarding detected issues to be addressed may then be distributed to the appropriate resource for further investigation and/or amelioration. Centralized monitoring may provide enhanced logistics, especially when used in connection with large area heap leaching operations.

[0045] In accordance with various embodiments, across a leaching solution distribution system, which may comprise a subsurface leaching solution distribution system, multiple leaching solution regulating modules may be installed to monitor and/or regulate various local areas of the leaching solution distribution system. For example, a centralized monitoring system may comprise a plurality of measurement transmitters in a measurement network. A meter and/or transmitter as described herein may comprise an electronic module that implements a data transmission protocol such as the HART network. In that regard, the plurality of measurement transmitters may transmit data to a gateway. In various embodiments, a leaching solution distribution system may cover large areas, such as many acres or square miles. In that regard, the plurality of measurement transmitters may function as repeaters. The measurement transmitters may transmit their own data to the gateway. However, in various embodiments, a remote measurement transmitter (i.e., a measurement transmitter far from the gateway) may transmit data to a measurement transmitter that is closer to the gateway. The measurement transmitter may then relay or repeat the data transmission to the gateway.

[0046] In various embodiments, the gateway may be configured to receive data from the plurality of measurement

transmitters. The gateway may implement one or more communications interfaces such as a data transmission protocol (e.g., a HART protocol or a Delta V interface). The gateway may perform preprocessing functions, for example, by aggregating data by measurement transmitter. The gateway may aggregate these data and transmit them via a network to a processor. The network may comprise a wired and/or wireless Ethernet network, as referenced above. The processor may process data from a gateway and perform various analytical routines. The processor may implement a Delta V interface to process data to and from the gateway. The Delta V interface may exist on a Delta V area control network that is able to interface with an Ethernet data network. The processor may process data from the gateway using a variety of suitable methods. For example, the processor may perform graphical analysis and/or may implement a Human Machine Interface (HMI), which may allow a human user to analyze data provided by the processor and make decisions with regards to a status of leaching solution distribution system.

[0047] With reference to FIG. 1, in accordance with various embodiments, an exemplary leaching solution regulating module 100 is shown. In various embodiments, leaching solution regulating module 100 may be configured to monitor flow conditions of leaching solution, regulate the flow of leaching solution to achieve a target operational condition, and deliver the leaching solution at the target operational condition to a subsurface leaching distribution system. An interface 102 may comprise a joint that fluidly couples a pipe 104 to leaching solution distribution system 162, which in various embodiment may comprise a subsurface leaching solution distribution system. The term “fluidly couples” or “fluidly coupled” may refer to a configuration allowing a fluid to be communicated from one component to another, for example, from a pipe of leaching solution distribution system 162 to pipe 104. Stated another way, by way of example, a pipe of leaching solution distribution system 162 may be in fluid communication with pipe 104 such that fluid may pass between them. Interface 102 may comprise a pair of mating flanges secured by one or more fasteners. In this manner, leaching solution may be conducted through interface 102 without material loss, if any, of leaching solution across interface 102.

[0048] In various embodiments, pipe 104 and pipe 114 may comprise any suitable pipe. For example, pipe 104 may comprise any material suited to conduct leaching solution, for example, any metal such as steel and/or any suitable thermoplastic material, provided the thermoplastic material is configured to resist corrosion due to exposure to leaching solution. In various embodiments, pipe 104 and pipe 114 comprise approximately 3" and/or 4" schedule 80 CPVC piping. Further, while described herein as a “pipe,” pipe 104 and pipe 114 are not limited in this regard and may comprise any suitable structure for delivery of leaching solution to and/or beneath a surface of a heap, for example, a hose, conduit, or other suitable structure.

[0049] In accordance with various embodiments, pipe 104 may comprise a length that is at least twice its diameter. Such sizing improves the accuracy of leaching solution regulating module 100. In various embodiments, as described herein, meter 106 may benefit from having a length of at least two pipe diameters or more both upstream and downstream of meter 106.

[0050] In accordance with various embodiments, pipe 104 may fluidly couple to meter 106. Meter 106 may be any device capable of measuring a fluid pressure and/or flow rate. “Flow rate” may refer to volume of fluid per unit time or mass of fluid per unit time within a pipe, while “mass flow rate” may refer to mass of fluid per unit time within a pipe and “volumetric flow rate” may refer to volume of fluid per unit time within a pipe. Meter 106 may comprise any suitable technology for detecting a pressure and/or flow rate. In accordance with various embodiments, meter 106 may comprise a differential pressure flow meter, for example, one having an orifice plate with one or more apertures. An orifice plate with two or more apertures has particular advantages as it is associated with a shorter length of pipe both downstream and upstream from the orifice plate. Stated another way, a more compact leaching solution regulating module 100 may be achieved using a differential pressure flow meter having an orifice plate with two or more apertures. By introducing an orifice plate into the flow and assessing differential pressure, flow rate after may be determined. For example, meter 106 may comprise a compact orifice meter such as a compact orifice meter manufactured by Emerson Electric Company, 8000 West Florissant Avenue, P.O. Box 4100, St. Louis, MO, USA 63136. More specifically, meter 106 may comprise a compact orifice meter sold by Emerson Electric Company under the model number 3051S or other functionally equivalent meters. In accordance with various embodiments, meter 106 may comprise an apparatus configured to measure a pressure and/or flow rate that is in electrical communication with an electronic module to store, process, and/or report the detected pressure and/or flow rate.

[0051] An electronic module of meter 106 may include a communications interface. Communications interfaces allow data to be transferred between an electronic module and external devices. Examples of communications interface may include a wired Ethernet network, a wireless Ethernet network (e.g., an ad hoc network utilizing IEEE 802.11a/b/g/n/ac), a wireless communications protocol using short wavelength UHF radio waves and defined at least in part by IEEE 802.15.1 (e.g., the BLUETOOTH protocol maintained by Bluetooth Special Interest Group), a low power wireless protocol such as Bluetooth Smart, inductive coupling, near field communication (NFC), or other protocol having a physical link comprising radio frequency (RF) signals. Communications interfaces may also include data transmission protocols such as Highway Addressable Remote Transducer (“HART”) protocol, transmission control protocol (“TCP”) and Internet Protocol (“IP”).

[0052] For example, in accordance with various embodiments, meter 106 may comprise a HART protocol interface. The HART protocol is a digital automation protocol that may convey data over a wired or wireless data network. The HART protocol defines a HART packet data structure wherein data may be encapsulated and transmitted. In that regard, the electronic module of the meter 106 may be configured to periodically determine the pressure and/or flow rate of the leaching solution passing through the meter 106, encode the pressure and/or flow rate into a HART packet data structure and transmit the HART packet data structure to another HART-compliant module, as discussed herein. Meter 106 may record pressure and/or flow rate at any suitable period, from about 120 Hz to 1 Hz, and, in

various embodiments, once a minute, once every ten minutes, and once every hour or over potentially longer intervals.

[0053] In accordance with various embodiments, leaching solution may flow from meter **106** into U-shaped section **108**. U-shaped section **108** may comprise one or more pipes configured in a U shape. U-shaped section **108** may be configured to turn the flow of leaching solution on the order of one hundred eighty (180) degrees. Distance **118** is the distance within which the flow of leaching solution is turned. U-shaped section **108** is configured to mate with regulator **110** to conduct leaching solution into regulator **110**. While described with reference to a U-shape, U-shaped section **108** is not limited in this regard and may comprise any suitable shape, for example, a “C” or “V” shape, such that leaching solution may flow through leaching solution regulating module **100** in a compact and efficient manner and be returned to a leaching solution distribution system.

[0054] In accordance with various embodiments, regulator **110** may comprise any suitable pressure regulator or flow rate regulator, such as a control valve. For example, regulator **110** may be any device suitable for regulating pressure and/or flow rate of fluid within a pipe or other suitable structure. Regulator **110** may comprise any device capable of altering the pressure and/or flow rate of a fluid in a pipe. For example, regulator **110** may be a pressure and/or flow rate sustaining valve and/or a pressure and/or flow rate reducing valve and/or a pressure and/or flow rate increasing valve. In various embodiments, regulator **110** may further comprise a pressure and/or flow rate reducing valve that reduces higher upstream pressure and/or flow rate to a lower, constant downstream pressure and/or flow rate, regardless of fluctuating demand or varying upstream pressure and/or flow rate. In various embodiments, regulator **110** may comprise a pressure and/or flow rate sustaining valve configured to sustain (i.e., maintain constant) pressure and/or flow rate in response to a pressure and/or flow rate drop to a pressure and/or flow rate below a target value. The regulator **110** may comprise a 3-way valve configured with a vent to prevent a pressure and/or flow rate drop (referred to as a “3-way regulator”). In that regard, regulator **110** prevents a pressure and/or flow rate drop across leaching solution regulating module **100**. Regulator **110** may comprise a pressure and/or flow rate adjustment control feature that is configured to adjust the target pressure and/or flow rate. In that regard, the target pressure and/or flow rate is the pressure and/or flow rate below which regulator **110** will act on the leaching solution to increase pressure and/or flow rate in order sustain the target pressure and/or flow rate. The pressure and/or flow rate adjustment control feature may be adjusted manually or via an electronic interface. Regulator **110** may further comprise a filter to capture and remove crud from the leaching solution.

[0055] In accordance with various embodiments, transmitter **112** may be configured to periodically report the pressure and/or flow rate of leaching solution across leaching solution regulating module **100** and/or a binary status of whether the pressure and/or flow rate of the leaching solution across leaching solution regulating module **100** is below and/or above the target pressure and/or flow rate of regulator **110**. Transmitter **112** may comprise an electronic module configured to implement the HART protocol, as described above with reference to meter **106**. Transmitter **112** may measure pressure data from leaching solution regulating module **100**,

for example, by measuring the pressure and/or flow rate at a point within or across leaching solution regulating module **100**. In various embodiments, transmitter **112** may package pressure and/or flow rate data and transmit the data using the HART protocol. Transmitter **112** may record pressure and/or flow rate at any suitable period, from about 120 Hz to 1 Hz, and, in various embodiments, once a minute, once every ten minutes, and once every hour or over potentially longer intervals. In various embodiments, transmitter **112** may be configured to provide status regarding the pressure and/or flow rate of leaching solution to the electronic module associated with meter **106**. In various embodiments, transmitter **112** is housed separately from regulator **110** and meter **106** and collects data for broadcast using the HART protocol.

[0056] Regulator **110** may be configured to interface with pipe **114** and conduct leaching solution to pipe **114**. Pipe **114** returns leaching solution to leaching solution distribution system **162**, such as a subsurface leaching solution distribution system, through interface **116**. In that regard, interfaces **116** and **102** may be referred to as leaching solution distribution system interfaces. While discussed in relation to FIG. 1 as comprising a meter **106**, a regulator **110**, and a transmitter **112**, leaching solution regulating module **100** is not limited in this regard and may comprise any combination of components capable of monitoring flow conditions associated with leaching solution and setting such flow conditions to a target operational condition.

[0057] With reference to FIG. 2, in accordance with various embodiments, a method **200** of regulating and delivering leaching solution beneath the surface of a heap is shown. In various embodiments, method **200** may comprise determining a location of recoverable metal value in a heap based on determining an ore map for the heap (step **202**). The ore map is used to determine areas suitable for further leaching and may help target remaining economic pockets of residual copper for recovery initiatives, such as targeting these areas with leaching solution under the surface of a heap. In various embodiments, determining an ore map helps maximize recovery of a subsurface leaching system. In various embodiments, the ore map comprises a variety of data inputs from the mine and leaching process, such as, for example, ore placement targeting via dispatch data, truck sensor data, GIS polygon data and/or mineralogy data (e.g., from a block model).

[0058] The ore map may also be configured to communicate with Mine Material Tracking (“MMT”) systems and receive further data inputs from such systems. In various embodiments, the ore map may include a determination of the total mineralogy per heap through data obtained from MMT, section mapping, irrigation, and polygons. In various embodiments, the ore map may also include the addition of flow data, irrigation data and remaining copper prediction from a machine learning model (e.g., multi-layer perceptron (“MLP”)) to obtain information by section and by date for a heap. The ore map uses data about where the copper is from, where the copper is placed and where the copper is remaining. The ore map may merge on the date and heap at the date level and section level by combining the PLS grade and flow and/or chemistry (e.g., acid) concentration at the date level and heap level with the raffinate irrigation on a heap at the date level and section level. The ore map merges the date and heap, so the ore map can provide raffinate chemistry data

and irrigation data at the date level and understand the impact on the section on that date.

[0059] In various embodiments, the ore map may also provide a visualization of where the heap includes recoverable amounts of copper remaining, based on historical leaching processes for the heap. The ore map may also include 4D visualization, including x, y, z and time information. The ore map may provide interactive visualization of all (or any subset) heap, section mineralogy populated on the map of each heap, filtering of sections by lift, heap or mineralogy composition and/or displaying aggregated values for selected sections. Ore Map 4D visualization (aka "ore finder") may include determining x, y, z locations of the remaining copper and time-series layering. The ore map may define heap and section boundaries based on polygons recorded in GIS. Dump locations of haul trucks may be mapped into these polygons based on combined signals from MMT location information (which obtains information from a beaconing system), GPS coordinates pulled from sensors and other systems on haul trucks and mapping section identifiers and sub-piles to specific leach heaps. After the dump locations of trucks are known, the MMT data (associated with all trucks matched to a given section) are aggregated and averaged to estimate section-level characterizations of mineralogy and P80. Recovery from these sections may be estimated based on the column test model, and the remaining copper may be calculated at the section-level by deducting estimated recovered copper from initial placements. Finally, the ore map may determine which sections are economically viable for recovery via drip, wobbler or injection irrigation based on a number of contiguous high-remaining sections and the proximity of the high-remaining sections to a top lift.

[0060] With continued reference to FIG. 2, the method may further comprise delivering leaching solution from a leaching solution source to a leaching solution regulating system, which may comprise a leaching solution regulating module similar to leaching solution regulation module described with reference to FIG. 1 (step 204). The method may further comprise regulating at least one of a pressure, a mass flow rate, or a volumetric flow rate to achieve a target operational condition (step 206). In accordance with various embodiments, implementing a leaching solution regulating module helps maximize recovery through its ability to achieve the target operational condition and vary the target operational condition in response to changes in the operational characteristics of the heap, such as, for example, mineralogy, chemistry, and permeability. In accordance with various embodiments, the method may further comprise delivering the leaching solution at the target operational condition from the leaching solution regulating system to a subsurface leaching solution distribution system (step 208). The method may further comprise delivering the leaching solution at the target operational condition under the surface of a heap to leach and recover at least one metal value (step 210).

[0061] The method as illustrated in FIG. 2 has improvements over historical subsurface leaching methods as it has the flexibility to set and adjust the target operational condition based on the optimization of one or more of a selection of different operational parameters in order to maximize recovery. Operational parameters that may be selected for optimization, as discussed above, can include a heap's unique mineralogy, chemistry, permeability, and remaining

recoverable metal values. Unlike the prior art, wherein the operating pressure is selected in response to the hydraulic properties of the heap in order to maintain heap stability, the instant invention is primarily directed towards maximizing recovery through an assessment of a variety of operational controls, any of which may be more important based on the various specific characteristics of the heap. That significant difference notwithstanding, all operational controls are reviewed before implementation to ensure they will not compromise the integrity of the heap.

[0062] In various embodiments, maximizing recovery comprises an assessment of a variety of operational controls and setting the target operational condition to optimize one or more based on the various specific characteristics of the heap. In accordance with various embodiments, maximizing recovery comprises regulating pressure through a leaching solution regulating system to achieve a target operational condition. In accordance with various embodiments, maximizing recovery comprising regulating flow rate through a leaching solution regulating system to achieve a target operational condition. In accordance with various embodiments, maximizing recovery comprises determining an ore map of the heap to identify areas of recoverable metal value before deploying a subsurface leaching solution.

[0063] With reference to FIG. 3, in accordance with various embodiments, an exemplary subsurface leaching solution distribution system 300 is shown fluidly coupled to a leaching solution regulating module, which may be similar to that discussed with reference to FIG. 1 and may be configured to regulate flow of leaching solution to a target operational condition. Subsurface leaching solution distribution system 300 may comprise a primary pipe 302 which may fluidly communicate leaching solution to secondary pipe 304, for distribution of leaching solution within heap 306. Heap 306 may comprise one or more metal deposits 308 and one or more low permeable materials 310. One or more metal deposits 308 may be enclosed within one or more low permeable materials 310 such that traditional surface leaching techniques may be ineffective in leaching and/or recovering the one or more metal deposits 308.

[0064] In accordance with various embodiments, subsurface leaching solution distribution system 300 may comprise one or more subsurface injectors 312. Subsurface injectors 312 may comprise any suitable structure configured to deliver leaching solution at a target operational condition beneath the surface of a heap. In various embodiments, subsurface leaching solution distribution system 300 may comprise a first subsurface injector 312A, a second subsurface injector 312B, a third subsurface injector 312C, a fourth subsurface injector 312D, and a fifth subsurface injector 312E. Subsurface leaching solution distribution system 300 may also suitably comprise more or less than five subsurface injectors 312, in various embodiments. Subsurface injectors 312 may be fluidly coupled to primary pipe 302 and/or secondary pipe 304 to receive leaching solution and distribute the leaching solution to desired locations within heap 306.

[0065] The leaching solution regulating module, which may, in various embodiments, be a leaching solution regulating module similar to leaching solution regulating module 100 described with reference to FIG. 1, may be configured to condition the flow of leaching solution to a target operational condition and deliver the leaching solution to subsurface leaching solution distribution system 300. Specifically,

a leaching solution regulating module, e.g. regulating module 100, which may be coupled to primary pipe 302 and/or secondary pipe 304 may be configured to set one of a pressure, a mass flow rate, or a volumetric flow rate and/or other parameter associated leaching solution within subsurface leaching solution distribution system 300. Such a parameter may be preselected, and leaching solution may be introduced in areas of low permeability within heap 306. The leaching solution regulating module may ensure that the target operational condition associated with the leaching solution is maintained throughout the subsurface heap leaching operation.

[0066] In accordance with various embodiments, the leaching solution may comprise a raffinate solution salvaged from a previous leaching operation. For example, the leaching solution may comprise raffinate, acidified water, fresh acid and/or water or acid and/or water that is recycled or reclaimed from other metal value recovery processes. The leaching solution may include an oxidant, such as, for example, ferric iron, hydrogen peroxide, other peroxides, chlorate, perchlorates, nitrates, and permanganates. Leaching solutions may also be oxidized by contact with air, enriched air, oxygen, or a stoichiometric air/SO₂ mixture. In various embodiments, the leaching solution may contain one or more leaching aids targeted toward the mineralogy of the material to be leached. In various embodiments, the leaching solution may be heated prior to subsurface application. In various embodiments, the leaching solution may be sourced from a different location than leaching solution utilized in above surface leaching application systems.

[0067] In various embodiments, one or more flow conditions associated with the leaching solution may be selected and/or varied. For example, a flow rate associated with the leaching solution may be “pulsed” between a relatively low flow rate and a relatively high flow rate. Further, the composition of the leaching solution may be selected based on the chemical properties of the areas of the heap to be leached. Accordingly, the content and/or flow conditions of the leaching solution may be selected in order to increase the quantity of metal values leached and/or recovered from the heap.

[0068] With reference to FIG. 4A, an exemplary embodiment of a single injection well design 400 of a subsurface heap leaching operation is shown, in accordance with various embodiments. Single injection well design 400 may comprise a subsurface injector 402 inserted into a bore 404 formed into a heap and protruding at least partially from a surface 406 of the heap. In various embodiments, bore 404 may be formed through the surface 406 of the heap utilizing various techniques, including, for example, sonic drilling, rotary drilling, auger drilling, or direct push. Bore 404 may extend a predetermined depth into the heap such that subsurface injector 402 may deliver subsurface leaching solution adjacent to targeted areas to be leached. Bore 404 may extend any suitable depth into the heap and may comprise any suitable diameter. In various embodiments, bore 504 may extend between approximately 0 and 250 feet or more into the heap and comprise a diameter between about 0 and 12 inches, preferably approximately 8 inches.

[0069] In accordance with various embodiments, subsurface injector 402 may comprise any material suited to conduct leaching solution, for example, any metal such as steel or other alloys and/or any suitable thermoplastic material, provided the thermoplastic material is configured to

resist corrosion due to exposure to leaching solution. In various embodiments, subsurface injector 402 may comprise 4-inch schedule 40 PVC piping. Subsurface injector 402 may further comprise a slotted portion 408 positioned near a distal end of subsurface injector 402. For example, slotted portion 408 of subsurface injector 402 may comprise a 4-inch schedule 40 PCV screen comprising any suitable slot size and shape, for example, approximately 0.04 to 0.08-inch slots, e.g., 0.06-inch slots, comprising a circular-like or square-like geometry. Leaching solution may be configured to flow through subsurface injector 402 and out of slotted portion 408 into the heap. In various embodiments, slotted portion 408 may extend any length of subsurface injector 402, for example, between approximately 0 and 40 feet, such as approximately 20 feet. An end cap 410 may prevent leaching solution from flowing out of a distal end of subsurface injector 402.

[0070] In various accordance with embodiments, bore 404 may be filled with one or more layers of material configured to provide stability and sealing for subsurface injector 402. Bore 404 may be filled with a first layer of material 412 around a distal end of subsurface injector 402, a second layer of material 414 around a middle portion of subsurface injector 402, and a third layer of material 416 around subsurface injector 402 near surface 406 of the heap. First layer of material 412 may comprise gravel such as pea gravel or similar sized gravel, second layer of material 414 may comprise a cushion material such as a clay material (e.g. bentonite), and third layer of material 416 may comprise a grout-based material such as a mixture of water, cement, and sand. However, first layer of material 412, second layer of material 414, and third layer of material 416 are not limited in this regard and may comprise any combination of materials capable of providing stability and sealing for subsurface injector 402.

[0071] In accordance with various embodiments and with reference to FIG. 4B, a nested well design 430 of a subsurface heap leaching operation is shown. Nested well design 430 may comprise a first subsurface injector 432 and a second subsurface injector 434 adjacent to first subsurface injector 432. First subsurface injector 432 and second subsurface injector 434 may be inserted into a bore 436 formed into a heap and protrude at least partially from a surface 438 of the heap. First subsurface injector 432 may be inserted into the heap a first depth, while second subsurface injector 434 may be inserted into the heap a second depth less than the first depth. In various embodiments, bore 436 may be formed through the surface 438 of the heap utilizing various techniques, including, for example, sonic drilling, rotary drilling, auger drilling, or direct push. Bore 436 may extend a predetermined depth into the heap such that first subsurface injector 432 and second subsurface injector 434 may deliver subsurface leaching solution adjacent to targeted areas to be leached. Bore 436 may extend any suitable depth into the heap and may comprise any suitable diameter. In various embodiments, bore 436 may extend between approximately 0 and 250 feet or more into the heap and comprise a diameter between about 0 and 12 inches, preferably approximately 9 inches.

[0072] In accordance with various embodiments, first subsurface injector 432 and second subsurface injector 434 may comprise any material suited to conduct leaching solution, for example, any metal such as steel or other alloy and/or any suitable thermoplastic material, provided the thermo-

plastic material is configured to resist corrosion due to exposure to leaching solution. In various embodiments, first subsurface injector **432** and second subsurface injector **434** may comprise about 3-inch schedule 40 PVC piping. First subsurface injector **432** and second subsurface injector **434** may further comprise one or more slotted portions **458** and **440** positioned near a distal end of first subsurface injector **432** and second subsurface injector **434**, respectively. For example, slotted portion **458** of first subsurface injector **432** and slotted portion **440** of second subsurface injector **434** may each comprise a 3-inch schedule 40 PCV screen comprising any suitable slot size and shape, for example, about 0.04 to 0.08-inch slots, e.g., 0.06-inch slots, comprising a circular-like or square-like geometry. Leaching solution may be configured to flow through first subsurface injector **432** and second subsurface injector **434** and out of slotted portions **458**, **440** into the heap. In various embodiments, slotted portions **458** and **440** may extend any length of first subsurface injector **432** and second subsurface injector **434**, for example between approximately 0 and 20 feet or approximately 10 feet. First subsurface injector **432** and second subsurface injector **434** may each comprise an end cap **442**, **444** which may prevent leaching solution from flowing out of a distal end of the first subsurface injector **432** and the second subsurface injector **434**, respectively.

[0073] In accordance with various embodiments, bore **436** may be filled with one or more layers of material configured to provide stability and sealing for first subsurface injector **432** and second subsurface injector **434**. Bore **436** may be filled with a first layer of material **446** around a distal end of first subsurface injector **432**, a second layer of material **448** above (toward surface **438**) first layer of material **446**, a third layer of material **450** above second layer of material **448**, a fourth layer of material **452** above third layer of material **450** and around a distal end of second subsurface injector **434**, a fifth layer of material **454** above fourth layer of material **452**, and a sixth layer of material **456** above fifth layer of material **454** and near surface **438** of the heap.

[0074] First layer of material **446** may comprise a gravel material such as pea gravel or other like gravel for filtering, second layer of material **448** may comprise a seal material such as a bentonite seal or clay material, third layer of material **450** may comprise a cushion material such as a clay material (e.g. bentonite), fourth layer of material **452** may comprise a gravel material such as pea gravel or other like gravel, fifth layer of material **454** may comprise a cushion material such as a clay material (e.g. bentonite), and fifth layer of material **456** may comprise a grout-based material such as a mixture of water, cement, and sand. However, first layer of material **446**, second layer of material **450**, third layer of material **452**, fourth layer of material **454**, and fifth layer of material **456** are not limited in this regard and may comprise any combination of materials capable of providing stability and sealing for first subsurface injector **432**.

[0075] In accordance with various embodiments and with reference to FIG. 4C, a well monitoring design **460** of a subsurface heap leaching operation is shown. Well monitoring design **460** may comprise a subsurface injector **462** inserted into a bore **464** formed into a heap and protruding at least partially from a surface **466** of the heap. In various embodiments, bore **464** may be formed through the surface **466** of the heap utilizing various techniques, including sonic drilling, rotary drilling, auger drilling, or direct push. Bore **464** may extend a predetermined depth into the heap such

that subsurface injector **462** may deliver subsurface leaching solution adjacent to targeted areas to be leached. Bore **464** may extend any suitable depth into the heap and may comprise any suitable diameter. In various embodiments, bore **404** may extend between about 0 and 250 or more feet into the heap and comprise a diameter between about 0 and 12 inches, preferably approximately 8 inches.

[0076] In accordance with various embodiments, subsurface injector **462** may comprise any material suited to conduct leaching solution, for example, any metal such as steel or other alloy and/or any suitable thermoplastic material, provided the thermoplastic material is configured to resist corrosion due to exposure to leaching solution. In various embodiments, subsurface injector **462** may comprise 4-inch schedule 40 PVC piping. Subsurface injector **462** may further comprise a slotted portion **468** positioned near a distal end of subsurface injector **462**. For example, slotted portion **468** of subsurface injector **462** may comprise a 4-inch schedule 40 PCV screen comprising any suitable slot size and shape; in an exemplary embodiment, for example, 0.02-inch slots comprising a circular or square geometry may be utilized. Leaching solution may be configured to flow through subsurface injector **462** and out of slotted portion **468** into the heap. In various embodiments, slotted portion **468** may extend any length of subsurface injector **462**, for example between approximately 0 and 150 feet or approximately 70 feet. An end cap **470** may prevent leaching solution from flowing out of a distal end of subsurface injector **462**.

[0077] In accordance with various embodiments, bore **464** may be filled with one or more layers of material configured to provide stability and sealing for subsurface injector **462**. Bore **464** may be filled with a first layer of material **472** around a distal end of subsurface injector **462** and a second layer of material **474** around a middle portion and extending to surface **466** of the heap. First layer of material **472** may comprise sand, while second layer of material **474** may comprise a cushion material such as a clay material (e.g. bentonite). However, first layer of material **472** and second layer of material **474** are not limited in this regard and may comprise any combination of materials capable of providing stability and sealing for subsurface injector **462**.

[0078] Well monitoring design **460** may further comprise one or more sensors **476** distributed along a length of subsurface injector **462**, in various embodiments. Sensors **476** may be any suitable device capable of measuring and communicating a pressure and/or flow rate of the leaching solution. Specifically, well monitoring design **460** may comprise one or more sensors **476** configured to monitor flow through slotted portion **468** and into the heap. One or more sensors **476** may be configured to monitor various flow conditions associated with the leaching solution through subsurface injector **462** to ensure that the target operational condition of the leaching solution is achieved and communicate a status of flow through subsurface injector **462**. One or more sensors **476** may further be configured to monitor other characteristics of the solution, such as, for example, oxygen content. One or more sensors **476** may be distributed equally or unequally along a length of subsurface injector **462**. For example, in various embodiments, the one or more sensors **476** may be spaced in approximately 5-foot, 10-foot, 15-foot, or 20-foot increments, however, the spacing is not limited in this regard and may be distributed in any manner along subsurface injector **462**. Further, one or more sensors

476 may extend along any length of subsurface injector 462 such as an entire length of subsurface injector 462. The one or more sensors 476 may be coupled to a signal wire 478 which may extend along subsurface injector 462 and out of surface 466. Signal wire 478 may transmit information acquired by the one or more sensors 476 to the one or more leaching solution regulating systems. However, well monitoring design 460 is not limited in this regard and may wirelessly communicate information obtained by one or more sensors 476 to the one or more leaching solution regulating systems.

[0079] While described above in various embodiments as comprising a subsurface injector, the subsurface leaching solution distribution systems disclosed herein are not limited in this regard. For example, the subsurface leaching solution distribution systems disclosed herein may comprise any suitable structure and orientation configured to deliver leaching solution at a target operational condition beneath the surface of the heap. As such, the disclosed embodiments herein are not intended to be limiting to the structure and/or orientation of such subsurface leaching solution distribution systems. Further, while discussed herein with reference to subsurface systems, the present disclosure is not limited in this regard and may comprise above surface leaching solution distribution systems in addition to or instead of the subsurface leaching solution systems disclosed herein. For example, in various embodiments, above surface leaching techniques may be utilized followed by the subsurface leaching techniques in order to maximize metal value leaching and/or recovery.

[0080] In operation, in accordance with various embodiments, a leaching solution regulating module, such as leaching solution regulating module 100, may observe a pressure and/or flow rate change. A pressure and/or flow change may be indicative of plugging of an orifice in the subsurface leaching solution distribution system. Data indicative of a pressure and/or flow rate change may be sent via a measurement transmitter to a gateway. The processor may receive the data indicative of a pressure and/or flow rate from the gateway and initiate a response. The processor may provide an alert in response to receiving data indicative of at least one of an abnormal pressure and/or flow rate and a low pressure and/or flow rate. An abnormal pressure and/or flow rate may be a pressure and/or flow rate that is outside a predetermined pressure and/or flow rate target value, which in various embodiments may be a range of pressures or flow rates. For example, the processor may send an email, an SMS message, and or other communication in response to the data that is indicative of a pressure and/or flow rate. For example, one may be dispatched to the particular area of the leaching solution distribution system to fix the plugged orifice. Upon correction, the leaching solution regulating module will continue to report a target pressure and/or flow rate.

[0081] Further, the leaching solution regulating module may regulate the flow of the leaching solution to achieve a desired flow condition best suited for a given leaching application, such as a leaching application for high-clay content or other impenetrable materials and deliver the leaching solution directly adjacent to deposits of desired metal values. Accordingly, the present disclosure may provide benefits over traditional surface leaching operations by delivering leaching solution directly adjacent to areas to be

leached and provide benefits over existing subsurface leaching systems by maintaining target operational conditions.

[0082] It is believed that the disclosure set forth above encompasses at least one distinct invention with independent utility. While the invention has been disclosed in the exemplary forms, the specific embodiments thereof as disclosed and illustrated herein are not to be considered in a limiting sense as numerous variations are possible. Equivalent changes, modifications and variations of various embodiments, materials, compositions and methods may be made within the scope of the present invention, with substantially similar results. The subject matter of the inventions includes all novel and non-obvious combinations and subcombinations of the various elements, features, functions and/or properties disclosed herein.

[0083] Benefits, other advantages, and solutions to problems have been described herein with regard to specific embodiments. However, the benefits, advantages, solutions to problems, and any element or combination of elements that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as critical, required, or essential features or elements of any or all the claims of the invention. Many changes and modifications within the scope of the instant invention may be made without departing from the spirit thereof, and the invention includes all such modifications. Corresponding structures, materials, acts, and equivalents of all elements in the claims below are intended to include any structure, material, or acts for performing the functions in combination with other claim elements as specifically claimed. The scope of the invention should be determined by the appended claims and their legal equivalents, rather than by the examples given above.

1. A method, comprising:

determining an ore map for a heap to identify a location of a recoverable metal value in the heap;
delivering a leaching solution from a leaching solution source to a leaching solution regulating system;
regulating at least one of a pressure, a mass flow rate, or a volumetric flow rate of the leaching solution to achieve a first target operational condition, wherein the first target operational condition is selected to optimize a set of operational parameters to maximize recovery of the recoverable metal value;
delivering the leaching solution at the first target operational condition from the leaching solution regulating system to a subsurface leaching distribution system; and
delivering the leaching solution at the first target operational condition from the subsurface leaching distribution system to the location of the recoverable metal value under a surface of the heap to leach and recover at least one metal value.

2. The method of claim 1, wherein the leaching solution regulating system comprises a plurality of leaching solution regulating modules.

3. The method of claim 2, wherein each leaching solution regulating module comprises a meter configured to detect a pressure or flow rate of the leaching solution.

4. The method of claim 2, wherein each leaching solution regulating module comprises a regulator configured to set a pressure or flow rate of the leaching solution to the target operational condition.

5. The method of claim 4, wherein the regulator comprises a 3-way valve comprising a vent configured to prevent a pressure drop of the leaching solution.

6. The method of claim 1, wherein the set of operational parameters comprises at least one of minerology, chemistry, permeability, and remaining recoverable metal values.

7. The method of claim 1, wherein the determining the ore map comprises adding flow data, irrigation data, and a remaining mineral prediction from a machine learning model to obtain information by section and by date for the heap.

8. The method of claim 1, further comprising determining x, y, z coordinates for the location of the recoverable metal value in the heap.

9. The method of claim 1, further comprising regulating at least one of a pressure, a mass flow rate, or a volumetric flow rate of the leaching solution to achieve a second target operational condition, wherein the second target operational condition is selected to maximize recovery of the recoverable metal value in accordance with variations in at least one of the location's physical and chemical characteristics in response to evaluating a leach cycle data.

10. A system, comprising:

a recoverable metal value in a heap;

a leaching solution regulating system configured to regulate a leaching solution to a target operational condition, wherein the target operational condition is selected to optimize a set of operational parameters to maximize recovery of the recoverable metal value; and

a subsurface leaching solution distribution system fluidly coupled to the leaching solution regulating system, the subsurface leaching solution distribution system comprising a subsurface injector configured to deliver leaching solution to the recoverable metal value under the surface of the heap to leach and recover at least one metal value.

11. The system of claim 10, wherein the set of operational parameters comprises at least one of minerology, chemistry, permeability, and remaining recoverable metal values.

12. The system of claim 10, wherein the subsurface injector comprises a metal or thermoplastic material.

13. The system of claim 10, wherein the subsurface leaching solution distribution system comprises a first subsurface injector and a second subsurface injector, the first subsurface injector extending into the heap a greater distance than the second subsurface injector.

14. The system of claim 10, wherein the subsurface injector comprises a slotted portion comprising at least one slot configured to deliver leach solution to the heap.

15. The system of claim 10, wherein the subsurface injector is fluidly coupled to a primary pipe and a secondary pipe, the primary pipe fluidly coupled to the leaching solution distribution system.

16. The system of claim 10, wherein the subsurface injector is inserted into a bore formed in the heap, the bore filled with at least one material configured to provide stability and sealing for the subsurface injector.

17. The system of claim 10, further comprising a plurality of sensors distributed along a length of the subsurface injector.

18. The system of claim 17, wherein the plurality of sensors are configured to monitor a flow condition of the leaching solution from the subsurface injector.

19. The system of claim 10, further comprising an ore map determined by adding flow data, irrigation data and a remaining mineral prediction from a machine learning model to obtain information by section and by data for the heap.

20. The system of claim 10, wherein the at least one location of the recoverable metal value in the heap is in x, y, z coordinates of the heap.

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