(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
15 June 2017 (15.06.2017)

(10) International Publication Number
WO 2017/096489 Al

(51) International Patent Classification:
G01D 21/00 (2006.01) *G08C 17/02* (2006.01)
E02D 17/00 (2006.01) *H01Q 13/12* (2006.01)
G01N 37/00 (2006.01)

(21) International Application Number:
PCT/CA20 16/05 1454

(22) International Filing Date:
9 December 2016 (09.12.2016)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/265,133 9 December 2015 (09. 12.2015) US

(71) Applicant: SCANIMETRICS INC. [CA/CA]; 9468 51 Avenue NW, Edmonton, Alberta T6E 5A6 (CA).

(72) Inventor: SLUPSKY, Steven; 21 Marlboro Road, Edmonton, Alberta T6J 2C7 (CA).

(74) Agent: WOODRUFF, Nathan; 200, 10328 81 Avenue NW, Edmonton, Alberta T6E 1X2 (CA).

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

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

(54) Title: MEASURING AND MONITORING A BODY OF GRANULAR MATERIAL

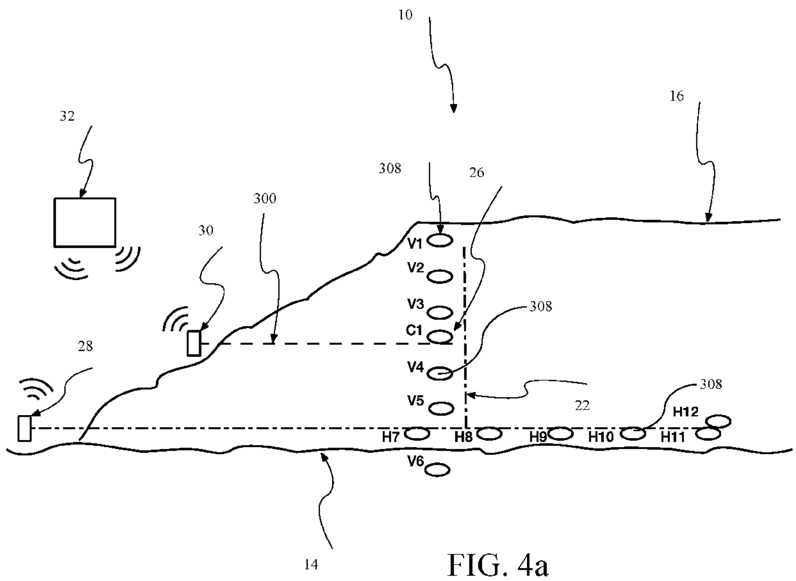

FIG. 4a

(57) Abstract: A method of monitoring a body of granular material includes the steps of: installing a plurality of wireless sensors in the body of granular material to measure one or more physical conditions of the granular material; installing one or more leaky cables in the body of granular material, each wireless sensor being sufficiently close to at least one leaky cable to communicate wirelessly with the at least one leaky cable; providing a data collection system that is communicatively connected to the one or more leaky cables; transmitting electronic data related to the one or more physical conditions from the wireless sensors to the data collection system via the one or more leaky cable; and characterizing the body of granular material based on the electronic data received by the data collection system.

WO 2017/096489 A1

MEASURING AND MONITORING A BODY OF GRANULAR MATERIAL

TECHNICAL FIELD

[0001] This relates to a system and method for monitoring a body of granular material, and in particular, a system and method that involves wireless sensors embedded in the granular material.

BACKGROUND

[0002] As the mining industry develops deposits of decreasing low-grade ores and mining processes increase in complexity, the heap leach mining process is increasingly more attractive for the industry because of its low capital and operating expense.

[0003] Geotechnical stability of a heap, which can be hundreds of feet in height, generally dictates that the flow of solutions through a heap is intended to occur under unsaturated conditions.

[0004] The key relationship for characterizing an unsaturated material is its soil water characteristic curve (SWCC), which is the relationship between the soil water content and total suction. Measurement of the SWCC is central to the design of any unsaturated system, such as a heap leach pile, because it describes the fundamental relationship between the energy state of the pore water, and the volume of water stored within the soil pores.

[0005] The finer textured material has the ability to retain moisture under higher suction values as compared to the coarse material because of the former's smaller pore sizes. Hence, the coarser textured material starts to "drain" first as suction is increased from saturated conditions, and loses moisture as suction continues to increase. In contrast, the finer textured material remains at the saturated volumetric water content (i.e. porosity) for the same suction condition. This phenomenon is referred to as "tension saturated" conditions. Ultimately the finer textured material will also begin to drain as the suction is increased. The rate at which the water content decreases with increasing suction is a function of the particle size distribution of the material. A uniform material will tend to drain "rapidly" over a small range of suction values because the pore sizes are generally the same size. Well graded materials will have a gentler slope to the SWCC once drainage conditions are initiated because they possess a wide range of pore sizes. A well graded material will drain under higher and higher suction values starting with the larger pore sizes first as the negative pore-water pressures overcome the water tension conditions within the pores.

[0006] The relationship between hydraulic conductivity and matric suction, commonly referred to as the soil's K function, is the second key relationship for the characterization of unsaturated soils. Under saturated conditions the coarse material has a greater ability to conduct water than the fine material (ksat coarse > ksat fine). As suction increases however, the hydraulic conductivity of the coarse material decreases more rapidly than the hydraulic conductivity of the fine material, and eventually the fine material becomes a better conductor of water. This occurs because at higher suctions the larger pores of the coarse material drain rapidly and no longer have the ability to conduct water, while the smaller pores of the fine material have not yet drained at these suction conditions and continue to conduct water. For this reason in soil profiles containing layers of coarse and fine textured material the preferred flow path may be the fine textured material layer.

[0007] Heap and dump leach piles are unsaturated environments and therefore heap leach management requires addressing all the complex flow conditions inherent to unsaturated zone hydrology. The two key hydrological concerns are adequate flow and even or uniform flow of solution through the heap. Adequate flow is necessary for the heap to be leached in an economical time, while uniform flow is needed to allow all the ore to be thoroughly leached.

[0008] The process requires a relatively permeable and a uniformly structured material that will not promote solution channeling or short-circuiting. Portions of the heap do not receive sufficient contact with the solution and remain unleached if solution does not flow evenly throughout the heap and instead flows preferentially through distinct paths.

[0009] Compaction is the process in which a stress applied to a granular material causes densification as air is displaced from the pores between the grains. When stress is applied that causes densification due to water (or other liquid) being displaced from between the grains, then consolidation has occurred. For example, compaction may be the result of heavy machinery compressing the granular material. Consolidation may occur as a result of the application of irrigation. Moreover, affected granular materials may become less able to absorb moisture, thus increasing runoff and erosion. Furthermore, affected granular materials may loose the ability to maintain their form and begin to flow.

[0010] Referring to FIG. 5, a heap and dump leach pile 10 is a body of dense broken or crushed material that is subject to settlement of the course and fine particles in the material as the material is stacked and a solvent formulation is applied using an irrigation system 11 to leach the chemical of economic interest. The type of irrigation system, the types of which are well known in the industry, will generally be selected by the operator, although the method and system described herein may suggest the use of a different irrigation system. The density of the pile increases with application of the solvent formulation since the solvent is absorbed by the surface of the material particles and displaces the air occupying the voids between the ore particles either partially or completely. Compaction of the material occurs as the finer material particles fill the voids between the larger material particles due to settlement during stacking and application of the solvent formulation. Moreover, within the pile, pressure from the stacked material and solvent generate compressive and sheer forces.

[0011] Heap leach and dump processes are dependent on chemical and biological processes that are affected by temperature. Chemical rates of reaction, chemical solubility, solution viscosity and surface tension, microbial activity, and the development of ice wedges are all temperature dependent. Spatial differences in temperatures occur in heap leach and dump piles. The propagation of temperature within the subsurface depends on both the physical and thermal properties of the material, as well as highly non-linear heat transfer processes taking place at the interface between the material and the atmosphere. The addition of biological processes introduces further non-linear processes that can affect the distribution of temperature in a heap.

[0012] Existing means of measuring temperature within a heap leach and dump pile involve the use of a continuous optical fibres. Said optical fibres are problematic because of forces within the heap acting on the optical fibre to sheer, pull, puncture or otherwise damage the optical fibre.

SUMMARY

[0013] According to an aspect, there is provided a method of monitoring a body of granular material. The method comprises the steps of: installing a plurality of wireless sensors in a body of granular material to be monitored, each wireless sensor being adapted to measure one or more physical conditions of the granular material; installing one or more leaky cables in the body of granular material, the one or more leaky cables and the wireless sensors being embedded within the body of granular material, each wireless sensor being sufficiently close to at least one leaky cable to communicate wirelessly with the at least one leaky cable; providing a data collection system that is communicatively connected to the one or more leaky cables; transmitting electronic data related to the one or more physical conditions from the wireless sensors to the data collection system via the one or more leaky cable; and characterizing the body of granular material based on the electronic data received by the data collection system.

[0014] According to another aspect, there is provided a system for monitoring a body of granular material, the system comprising: a plurality of wireless sensors in the body of granular material to be monitored, each wireless sensor being adapted to measure one or more physical conditions of the granular material; one or more leaky cables installed in the body of granular material, the one or more leaky cables and the wireless sensors being embedded within the body of granular material, each wireless sensor being sufficiently close to at least one leaky cable to communicate wirelessly with the at least one leaky cable; and a data collection system that is communicatively connected to the one or more leaky cables; wherein the wireless sensors are adapted to transmit electronic data related to the one or more physical conditions from the wireless sensors to the data collection system via the one or more leaky cable, the data collection system comprising instructions to characterize the body of granular material based on the electronic data received by the data collection system. The system is preferably provided in combination with a body of granular material.

[0015] According to other aspects, the method and the system, alone or in combination with the body of granular material, may comprise one or more of the aspects

listed below, alone or in combination, where appropriate and where not mutually exclusive.

[0016] The wireless sensors may be selected from a group consisting of moisture sensors, soil compaction sensors, force sensors, pressure sensors, temperature sensors, ion specific sensors, pH sensors, or combinations thereof; the wireless sensors may be distributed horizontally and vertically within the body of granular material to form an array of sensors.

[0017] The body of granular material may be a heap leach, and there may be a treatment step applied to the heap leach, or a treatment step being applied may be adjusted, and the wireless sensors may monitor changes to the heap leach in response to the treatment step. The treatment step that is applied to the heap leach may be determined by the characterization of the heap leach based on the electronic data from the wireless sensors. The characterization of the heap leach may comprise comparing the electronic data to a predetermined model of the heap leach to identify one or more deficiency relative to the predetermined model. The one or more deficiency may comprise an excess of moisture, a lack of moisture, over compaction, under compaction, consolidation, or combination thereof.

[0018] One or more transmission cables may be electrically connected to one or more leaky cables, each leaky cable having a portion of its shielding removed to permit radio frequency signals to escape or be received.

[0019] Each of the wireless sensors may comprise a fully enclosing housing that houses a wireless transceiver, a processor, and a power supply, and a sensor element that is external to the fully enclosed housing and electrically connected to the processor. Each of the wireless sensors may be electrically insulated from the leaky cables and the data collection system. One or more wireless sensors may be mechanically attached to one or more leaky cables.

[0020] The body of granular material may comprise a tailings dam or an earthen bank adjacent to a buried pipeline, and the one or more physical conditions comprise compaction levels and moisture levels of the granular material.

[0021] One or more wireless sensors may be positioned within a flexible, permeable enclosure filled with reference granular material. The one or more wireless sensors may comprise at least one of a compaction sensor element and a moisture sensor element, and wherein the compaction sensor element may be positioned outside the enclosure. The wireless sensors may be calibrated based on the reference granular material in the flexible, permeable enclosure prior to embedding the sensor in the body of granular material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] These and other features will become more apparent from the following description in which reference is made to the appended drawings, the drawings are for the purpose of illustration only and are not intended to be in any way limiting, wherein:

FIG. 1 is a graph of moisture sensor response versus time during a column experiment.

FIG. 2 is a graph of moisture sensor data versus time of column CI with a flow rate of 8 $1/hr/m^2$) for sensors located at 115 cm from the top and at 15 cm from the top of the heap.

FIG. 3 is a graph of moisture sensor data versus time of column C2 with a flow rate of 17.6 $1/hr/m^2$) for sensors located at 115 cm from the top and at 15 cm from the top of the heap.

FIG. 4a is an illustration of a sensor placement in a heap leach pile.

FIG. 4b is an illustration of a sensor placement in a tailings dam.

FIG. 4c is an illustration of a sensor placement in an earthen bank with a buried pipeline.

FIG. 5 is a photograph of a heap leach pile.

FIG. 6 is a graph of the moisture sensor data versus time of a horizontal row of sensors buried within a heap leach pile.

FIG. 7 is a graph of the moisture sensor data versus time of a vertical column of sensors buried within a heap leach pile.

FIG. 8 is a graph illustrating the recorded rainfall at a heap leach pile.

FIG. 9 is a graph of a compaction sensor response versus time at a location buried within a heap leach pile.

FIG. 10 is an illustration showing a two dimensional grid of moisture and compaction sensors buried within a heap leach pile.

FIG. 11 is a graph showing the gold recovered versus time at different irrigation flow rates and in different columns.

FIG. 12 is a graph showing VWC in the ore (y-axis) versus the moisture sensor measurement (x-axis).

FIG. 13 is the moisture sensor response when placed in a body of crushed ore and a solvent formulation is applied.

FIG. 14 is the compaction sensor response when placed in a body of crushed ore and a solvent formulation is applied.

FIG. 15 is a two dimensional visual representation of the moisture sensor signal where the relative two dimensional position of the sensor is represented by the relative two dimensional position in the visualization and the intensity of the moisture signal is represented by a numeric value.

FIG. 16 is a two dimensional visual representation of the change of the moisture sensor signal where the relative two dimensional position of the sensor is represented by the relative two dimensional position in the visualization and the magnitude of change of the moisture signal is represented by a numeric value.

FIG. 17 is a two dimensional visual representation of the compaction sensor signal where the relative two dimensional position of the sensor is represented by the relative two dimensional position in the visualization and the intensity of the compaction signal is represented by a numeric value.

FIG. 18 is an illustration of a cross section of a heap leach and dump pile with sensors and leaky coaxial cable distributed throughout.

FIG. 19 is an illustration of a cross section of a leaky cable with an integrally formed protective barrier or cover.

FIG. 20 is an illustration of a cross section of a leaky cable with a separate and distinct protective barrier or cover.

FIG. 21 is an illustration of a wireless sensor electrically insulated from and electromagnetically coupled to a leaky coaxial cable with a separate and distinct protective barrier or cover.

FIG. 22a is an illustration of a wireless sensor electrically insulated from and electromagnetically coupled to a leaky coaxial cable with a separate and distinct protective barrier or cover and mechanically attached thereto.

FIG. 22b is an illustration of a wireless sensor.

FIG. 23 is an illustration of one or more wireless sensors electrically insulated from and electromagnetically coupled to a leaky coaxial cable.

FIG. 24 is an illustration of one or more wireless sensors, wireless routers or repeaters, or wireless gateway electrically insulated from and electromagnetically coupled to a leaky coaxial cable.

FIG. 25 is an illustration of a distributed in-line leaky coaxial cable.

FIG. 26 is an illustration of a distributed "T" leaky coaxial cable.

FIG. 27 is an illustration of a distributed "T" antenna.

FIG. 28 is an illustration of a cross section of a heap leach and dump pile with sensors and leaky coaxial cable distributed underneath the non-permeable liner.

FIG. 29 is an illustration of a cross section of a moisture sensor in a body of reference material.

FIG. 30 an illustration of a cross section of a compaction sensor in a body of reference material.

FIG. 31 is an illustration of a cross section of a moisture and compaction sensor in a body of reference material.

FIG. 32 is an illustration of a cross section of a moisture and compaction sensor in a body of reference material.

FIG. 33 is an illustration of a cross section of a leaky cable.

FIG. 34 is a graph of moisture sensor versus time for four different irrigation profiles.

FIG. 35 is a graph of sensor temperature versus time.

FIG. 36 is a flow chart illustrating the process of monitoring moisture.

FIG. 37 is a flow chart illustrating the processing of monitoring moisture during the leach process.

FIG. 38 is a flow chart illustrating the process of monitoring compaction.

FIG. 39 is a flow chart illustrating the processing of monitoring compaction during the leach process.

DETAILED DESCRIPTION

[0023] These and other features will become more apparent from the following description in which reference is made to the appended drawings, the drawings are for the purpose of illustration only and are not intended to be in any way limiting, wherein: Referring to FIG. 18, there is shown a system of sensors that can be used to characterize a pile of granular material is shown. The discussion herein will be given in the context of a heap leach. A heap leach piles mined, granular material and uses a hydrometallurgical process to extract desired components from the mined ore. The heap leach may also be described as a dump leach. In the case of a heap (10), information may be collected, reported, allowing operators to take a remedial action(s) to:

1. cause the moisture at a particular location within the heap to increase when the moisture sensors inside the heap indicate the moisture is less than optimal; or,
2. cause the moisture at a particular location within the heap to decrease when the moisture sensors inside the heap indicate the moisture is greater than optimal;

as the case may be, so as to increase the quantity of chemical of economic interest recovered from the leach process, preferably over the duration of an economically favourable period of time.

[0024] In addition to heap leaches, the process and system described herein may also be used to monitor other types of granular material, such as soil-based piles or structures, including river banks, berms, hillsides, etc., and for other purposes. The granular material may be a combination of coarse and fine materials, some of which may aggregate and create a less permeable structure. The system described herein may be adapted to monitor conditions in various types of situations. For example, the system may be used to measure saturation in soil and warn interested parties about the loss of structural stability of the soil. This may be useful in protecting structures build on or in soil, such as a building, a pipeline, roads, etc., the stability of a berm, the bank of a tailings pond, etc. An example of a heap leach is shown in FIG. 4a, an example of a tailings dam is shown in FIG. 4b, and an example of an earthen bank with a buried pipeline is shown in FIG. 4c Other applications will be apparent to those skilled in the art, including monitoring other conditions and characteristics of the granular material for other purposes, or below an impermeable layer of material to detect a leak through the impermeable layer. In other examples, the system may be used to detect other conditions. It will be understood that, when a heap is referred to, similar principles may be applied to other types of granular material. Furthermore, while the heap is described as being irrigated with a solvent, in other examples, the liquid may be water, and may be precipitation from the environment. The types of characteristics being measured will determine the type of sensors used. Some examples of typical sensors that may be used include moisture sensors, soil compaction sensors, force sensors, pressure sensors, temperature sensors, pH sensors, and ion specific sensors, which may be used alone or in combination.

[0025] In the case of a heap leach, it may be possible to monitor the heap in order to determine the compaction of the ore within the heap and take remedial action(s) to decrease or increase the ore compaction, so as to increase the quantity of chemical of economic interest recovered from the leach process, preferably over the duration of an economically favourable period of time and to enable the assessment of the stability of the heap to avoid structural failure of the heap.

[0026] As depicted, the monitoring system uses a plurality of wireless sensors 308 installed in an array that allows the heap 10 adjacent to the array to be monitored. Preferably, the sensors are installed horizontally and vertically within a heap 10, or within layers 14, 16 of the heap 10 as shown, to form a three dimensional grid of sensors. Doing so allows data to be collected using the wireless sensors, and provide a heap leach model for modeling the heap leach operation. Once modeled, the readings can be compared to the model, and treatment steps may be added or adjusted, which may include stopping a treatment step, based on the results of this comparison, and any identified deficiencies, i.e. variations or anomalies when compared to the model, such as an excess of moisture, a lack of moisture, overcompaction, under compaction, consolidation, variations in the concentration of particular ions, etc.. The heap leach operation may include, for example, a solvent formulation and an irrigation setting. Data may be collected from the wireless sensor devices while irrigating the heap lift, where the collected data includes in-situ material parameters of the first heap layer and the subsequent heap layers and in-situ solution parameters of the solution flowing in the first heap layer and the subsequent heap layers, and generating a report describing the data collected from said wireless sensors. In one example, the wireless sensors are buried within the heap. In other examples, the sensors form a single point or a one or two dimensional grid of sensors. In other examples, the grid may be a linear or curved path, a square, rectangular, triangular, a modified Bayer pattern, hexagonal, random or other one, two or three dimensional pattern.

[0027] The solvent formulation may be selected according to principles that are known in the art. In general, the solvent will be used to cause dissolution of the chemical of economic interest. For example, cyanide, thiosulfate, or other complexing ligands may be used to leach gold or silver. In another example, sulphuric acid may be used to leach copper.

[0028] Referring to FIG. 22a, an example of a wireless sensor 308 is shown in close proximity to a "leaky coaxial cable" 300 designed to electromagnetically couple a radio signal 306 to the wireless sensors 308. Both the cable 300 and the sensors 308 will be embedded within the material of the heap leach 10. While this may involve placing the respective elements in a protective covering, this will generally involve the elements and/or their protective covering being in direct contact with, and surrounded by, the granular material, such that they will shift and move as the granular material shifts and moves. While not required, the leaky cable 300 will preferably be mechanically attached by an attachment 310 and electrically insulated, so as to provide a robust and rugged barrier to the mechanical pressure exerted from the ore particles and further resisting the action of forces within the heap to separate the wireless sensor from the leaky cable. Examples of attachment may include tape, zip ties, adhesive, rigid or semi rigid brackets, etc. Some modifications to the cables 300 or the housing of the sensors 308, or the permeable bag in which it is found as will be discussed below, may be made to accommodate or enhance the mechanical attachment. The mechanical attachment 310 may be useful in maintaining a constant relative position between the sensors 308 and cables 300. However, if the attachment 310 were to fail, or were omitted, the sensors 308 may still be able to send and receive signals from the cables 300 if the spacing is not too great, or if the signal strength is strong enough.

[0029] Referring to FIG. 22b, an example of a sensor 308 is shown. Sensors 308 may be a wireless "mote" as available through Scanimetrics Inc. of Edmonton, Alberta, made up of a main sensor body 500 and external sensors 502. External sensors 502 may be moisture sensors, compaction sensors, or any other type of sensor that provides relevant information, as is known in the art. The main sensor body 500 includes a body 504 that isolates the interior components of the main sensor body 500 from the outer environment, and is preferably a molded body that is molded around the internal components. As shown, the main sensor body 500 has a power supply 506, such as a battery, a transceiver 508, and a processor 510 sealed within body 504 and may also include temperature, tilt, vibration, acceleration or other types of sensors sealed within body 504. These are connected to external sensors 502 which may be moisture, compaction, or other types of sensors. These communicate with cable 300.

[0030] Sensor body 500 may be powered using an internal battery or may harvest energy from the leaky cable.

[0031] Referring to FIG. 23 and 24, further design options are depicted, where FIG. 23 shows a plurality of sensors 308 spaced along a leaky cable 300 that are electrically insulated from and electrically connected to leaky coaxial cable 300, and FIG. 24 depicts additional wireless components, such as a wireless sensor 308, a wireless router or repeater 314, and a wireless gateway 312 that are also electrically insulated from and electromagnetically coupled to a leaky coaxial cable 300. The actual types of components, their position, and their number may be selected by a person of ordinary skill based on the intended use.

[0032] Referring to FIG. 20, an example of a leaky coaxial cable 300 is shown, in which the leaky coaxial cable 300 is a coaxial cable, which emits and receives radio waves, functioning as an extended antenna, and is protected by a protective barrier or cover 304. Referring to FIG. 33, the cable 300 may be "leaky" by providing gaps or slots in an outer conductor 326 to allow radio signals to leak into or out of the cable along its length. Because of this leakage of signal, referring to FIG. 25, line amplifiers 320 may be required to be inserted to boost the signal to acceptable levels. In the present example, referring again to FIG. 33, the leaky coaxial cable 300 conducts an electrical signal using an inner conductor 322 (usually a solid copper, stranded copper or copper plated steel wire) surrounded by an insulating layer 324 and all enclosed by an outer conduction or shield 326, which will typically be one or more layers of woven metallic braid or metallic tape. The cable is protected by an outer insulating jacket 328.

[0033] Referring to FIG. 21, in another example, the wireless sensors 308 may be placed in close proximity to a leaky coaxial cable 300, which is designed to electromagnetically couple, represented by waves 306, to the wireless sensors 308 while the wireless sensors 308 are electrically insulated from the leaky cable 300, so as to provide a robust and rugged barrier to the mechanical pressure exerted from the ore particles. The radio signal 306 is electromagnetically coupled to wireless sensors 308 that are placed along the length of the leaky coaxial cable 300. Transmissions from the wireless sensors 308 are picked up by the leaky coaxial cable 300 and carried to other parts of the heap leach pile, allowing two-way radio communication throughout the heap leach pile.

[0034] Referring to FIG. 22a, the wireless sensors 308 may be mechanically attached 310 to said leaky coaxial cable 300 to further resist the action of forces within the heap to separate the wireless sensor 308 from the leaky cable 300 or to increase the barrier between the wireless sensor and the leaky cable 300.

[0035] Referring to FIG. 20, the protective barrier or cover 304 of leaky coaxial cable 300 may be used to resist the action of forces within the heap to pull, sheer, puncture or otherwise damage or compromise the ability of the leaky cable to electromagnetically couple said wireless sensors. The protective cover may be integrally formed as illustrated in FIG. 19 as element 302, or may be provided as a separate and distinct protective barrier or cover as illustrated in FIG. 20 as element 304. The protective barrier or cover 302 or 304 may be applied or attached at the time the leaky cable is manufactured or installed or buried within the heap leach or dump pile. In some examples, a protective casing for leaky cable 300 may be constructed of one or more of a polymer such as high density polyethylene (HDPE), PVC, CPVC, polycarbonate; or other material such as steel; carbon fibre; fiberglass or other suitable material.

[0036] The leaky cables 300 and sensors 308 may be placed in various locations throughout the material, in order to detect different properties, or the same properties in different locations. For example, referring to FIG. 18, the leaky cables 300 and sensors 308 may be placed on the surface of a non permeable liner 12, and the heap and dump leach material 10 may be stacked on top of the leaky cables 300 and sensors 308. In some examples, the leaky cables 300 and sensors 308 may be placed on or just below the surface of an existing heap and dump leach pile 14, and thereafter additional heap and dump leach material 16 may be stacked on top of the existing pile 14, leaky cables 300 and wireless sensors 308. This allows the properties to be measured at different depths in the heap leach 10.

[0037] In another example, referring to FIG. 28, the leaky cables 300 and the wireless sensors 308 may be placed below a non permeable liner 12 of a heap and dump leach pile 10 to monitor and detect the presence of the solvent formulation outside the non permeable liner 12. The presence of the solvent formulation outside the non permeable layer 12 may indicate a puncture, tear, or otherwise indicate a leak of the non permeable liner. In some examples, the leaky cables 300 and wireless sensors 308 may be placed under a non permeable liner 12 that containing a barren or pregnant solvent formulation or mine tailings in a pond, tank or retaining dam to monitor for punctures, tears, or otherwise detect a leak from the non permeable liner, pond, tank or dam.

[0038] In other examples, horizontal or vertical drilling techniques may be used to install the monitoring system in existing heaps. For a new leach pad, the base of the heap may be packed with sand or ore to prevent penetration of the liner at the base of the pile or lift. In another embodiment, the system maybe extended vertically by attachment of another protective casing and backfilled with ore as additional lifts or layers are added to the heap.

[0039] Referring to FIG. 25, in another aspect, the leaky coaxial cable 300 may be combined with a coaxial cable 316 using couplers 320 to join the leaky coaxial cable 300 to the coaxial cable 316. Such a configuration prevents leakage and loss of the radio signal thought the coaxial cable 300 and provides a longer signal path by localizing the ability to couple electromagnetic signals to and from sensors 308. Moreover, couplers 320 may include an amplifier to boost the signal to compensate for signal loss of the coaxial cable or leaky cable or both.

[0040] Referring to FIG. 26, in another example, the leaky cable 300 may be combined with a coaxial cable 316 using a three way coupler 320. The leaky cable 300 may be a short stub or a branch connection connected to coaxial cable 316.

[0041] Referring to FIG. 27, in another example, coaxial cable 316 may be combined with an antenna 322 using a two way or three way coupler 320.

[0042] Referring to FIG. 29, in one example, a sensor 402, such as a moisture sensor, may be placed within a body of reference material 406, which is made up of material from the heap and dump leach pile that can be calibrated and/or characterized, such as by providing known particle sizes that are substantially similar. Preferably, the difference of the size between any two or more particles is absolute or relative and maybe a function of shape, radii or volume. For instance, the absolute difference in particle size may be +/- 0.1, 0.2, 0.3, 0.4, 0.5, or 1mm or more. Alternatively, the relative difference in particle size of +/- 1%, 2%, 5%, 10%, or 20% or more. The particle sizes may be of a similar size and distribution. The moisture sensor 402 and body of reference material 406 is preferably placed within a permeable membrane 400 so as to provide a barrier between the reference material 406 surrounding the sensor 402 and the material within the heap and dump leach pile 10, where the permeable membrane 400 provides a low resistance pathway for flow of the solvent formulation from the surrounding heap and dump leach material 10 through the reference material 406 surrounding the sensor 402. The reference material 406 provides a known particle size and distribution so that the one or more moisture sensors 402 embedded within the heap can be calibrated relative to each other.

[0043] Generally speaking, the depicted system may be considered to be made up of data collection elements, such as sensors 308, data transmission elements, such as leaky cable 300, regular coaxial cable 316 antenna 322, etc., and a data collection system, which collects and processes the data. the details of the data collection system are not provided in detail as they will be generally known by those skilled in the art, but will generally be made up of a general or specific purpose computer system with the necessary processing and memory storage systems, as well as the data entry and display devices common to these systems.

[0044] Referring to FIG. 30, in another example, a compaction sensor 404 may be placed within the body of reference material 406. The reference material provides a known particle size and distribution so that the compaction sensor 404 embedded within the heap can be calibrated relative to other compaction sensors 404 in the heap.

[0045] Referring to FIG. 31, in another example, the compaction sensor 404 and the moisture sensor 402 may be placed together within the same body of reference material 406. Referring to FIG. 32, in another example, the compaction sensor 404 may be placed outside the permeable membrane 400 with moisture sensor 402 within the body of reference material 406, and may be juxtaposed 406 to the body of reference material 406, i.e. the compaction sensor 404 may be within, above, below or beside the body of reference material 406.

[0046] Referring to FIG. 18, in another example, the method of heap leaching may include the steps of forming a heap leach or dump pile or pad 10 made up of a first heap lift or layer 14 and upon which additional heap lifts or layers 16 may be applied. The heap leach is formed by placing ore extracted from a mine onto a leach pad 12, where the heap lift is irrigated using a solvent formulated to leach a first chemical element of economic interest from the ore into a solution comprising the solvent and the first chemical element. A plurality of wireless sensors 308 are installed horizontally and/or vertically within the lift to forming a three dimensional grid or array of sensors 308 with a communication network, such as leaky cables 300, to collect the data from the wireless sensors 308. The communication network may allow communications in two directions, such that sensors 308 may be controlled or instructed as well. A horizontal solution collection system may be installed under the first heap layer 14 to collect the leachate after the chemical has passed through the heap. A heap leach model may be provided that allows an operator to model the heap leach operation. In a preferred example, the heap leach operation will generally include a solvent formulation that is distributed throughout the heap leach using an irrigation setting, with data collected from the wireless sensor devices 308 while the heap lift 10 is irrigated. The collected data will include in-situ material parameters of the first heap layer 14 and subsequent heap layers 16 and may include in-situ solution parameters of the solution flowing in the first heap layer 14 and subsequent heap layers 16. The heap leach operation may be analyzed using the collected data based on the heap leach model to generate a result, and the heap leach operation may be adjusted based on the results of the analysis.

[0047] **Moisture sensor calibration**

[0048] Soil-specific calibration is preferably used to achieve the best possible accuracy in volumetric water content measurements. Measurement accuracy increases to ±1-2% for all soils with soil-specific calibration. Recent tests by independent researchers indicate that soil-specific calibration of soil moisture probes achieves performance results similar to that of TDR (Time Domain Reflectometry) instruments. Note that the resolution, precision, repeatability, and probe to probe agreement of the soil moisture probes is high, so the soil specific calibration of one probe can be applied to all other probes of that type in that particular soil.

[0049] Because of the water's high dielectric permittivity, changes in water volume have the most significant effect on the total dielectric permittivity, which is measured by the moisture sensor.

[0050] Ore samples with known VWC (volumetric water content) may be used to calibrate the sensor. Referring to FIG. 12, a linear method may be used to relate the VWC in the ore (y-axis), measured using a reference instrument, versus the moisture sensor output (x-axis). A two point calibration method may be used for the sensor at the VWC range of 10% - 30%. Other multipoint and non linear methods may also be used to increase accuracy.

[0051] Once buried under the leach pad, the variance of moisture due to changes in temperature is minimized due to a small fluctuation in temperature inside the heap.

[0052] **Temperature measurement**

[0053] A distribution of temperatures (referred to as a "temperature profile") within a heap leach and dump pile can be observed and recorded using temperature sensors alone or in combination with other sensors embedded within a heap as described earlier. When combined with one or more other sensors, cost savings can accrue when compared to installation of other distributed temperature sensing systems.

[0054] The observed temperature profile may be used to adjust the irrigation process to compensate for chemical rates of reaction, chemical solubility, solution viscosity and surface tension, microbial activity, and the development of ice wedges so as to increase recovery of the chemical of economic interest.

[0055] **Examples**

[0056] There will now be given certain examples of methods of monitoring and operating a heap leach. It will be understood that the various principles discussed below may be combined in any suitable combination, and that the examples given below are not exhaustive. Furthermore, it will be understood that the principles of operation may be applied to monitoring other structures, as discussed previously.

[0057] Example 1

[0058] FIG. 1 illustrates some results of some testing using a heap leach process measurement and monitoring system.

[0059] The x axis is time and the y axis is the reading from the moisture sensor. In this example, the moisture sensor was not calibrated to a particular moisture content and so the values on the y axis should not be interpreted as absolute values but rather as relative change in moisture content. The area between the bold lines generally indicates the sensor position in the column (the sensor was oriented longitudinally in the column between 18 - 24 cm).

[0060] From previous measurements, the moisture sensor response in dry air was found to be about 740 and the response when immersed fully in a dilute solution of aqueous sodium cyanide adjusted to pH of 11 was found to be about 1600. When the moisture sensor was introduced into the dry column, the sensor response was about 990. At the end of the column experiment, the sensor reading was about 1340. Thus, the column measurements were found to be within the range limits we observed in the lab experiments, which is what was expected.

[0061] In the column experiment, the sensor first detects the moisture shortly before 4 hours after start. As the moisture front advances along the length of the sensor, the sensor responds in a linear manner until shortly before 5 hours after start. This behaviour is consistent with the lab results. From the data in this linear region it appears the moisture front is progressing at about 6 cm / hour. After this point, the sensor response curve changes from a linear response to more of an exponential response. Also note that at this point in time, the sensor is fully immersed by moisture along its entire sensor length. The shape of the sensor response after 12:50p suggests that the moisture content of the surrounding ore continues to increase, which is expected. The tail at the end of the graph may be a result of the saturation of the ore with the applied moisture. That is, the ore no longer has the capacity to absorb all the moisture and it is beginning to pool. Note, the last point is inferred since we were not able to make an observation of pooling. This seems like a reasonable judgment because the drip rate is about 2x the normal drip rate. From analysis of the data over the duration of the experiment, the moisture front is advancing at about 6 cm / hour which is consistent with the measurement taken from the linear region as the fluid moved passed the sensor.

[0062] Example 2:

[0063] Below is a summary of results of additional testing that was undertaken to evaluate the performance of a "heap leach process measurement and monitoring system" in further column tests.

[0064] An experimental test was started at two irrigation rates: normal (8 l/hr/m2, inner column, CI) and fast (17.6 l/hr/m2, outer column, C2). From the mine's standard water weight ratio measurement, the ore sample had an initial averaged water weight ratio of 2.54%.

[0065] Converting the water weight ratio to the Volumetric Water Content: VWC or Θ = Vw/VT = (mwet-mdry)/mwet x(dwet/dwater) = (PH-PS)/PH *(dwet/dwater). For water weight ratio 2.54%, the calculated VWC was approximately 4.22%. Here the specific gravity of the ore sample (dwet) was calculated from the weight ~ 57.5 kg and the volume of the ore samples: 6" column at a height of ~ 190 cm and was approximately 1.66.

[0066] In each column, there were two moisture sensor locations. A first sensor location had sensor 13 in C2 outer column and sensor 15 in CI inner column positioned at 115 cm below the top surface; the other sensor location had sensor 14 in C2 outer and sensor 16 in CI inner positioned at 15 cm below the top surface.

[0067] Column inspection was completed on day 34 after the start date. Ore samples were removed from the columns. Under visual inspection, the water content in the ore samples was quite even, and no large water pooling was observed. The mine's standard water weight ratio measurement was used to calculate the ore sample's final water weight ratio and it was 8.92% for CI and 8.95% for C2.

[0068] Converting the final water weight ratio to the Volumetric Water Content (VWC), it was approximately 16.7% ± 0.1% for both columns. Note: the specific gravity of the wet ore in the column was increased to 1.87 due to the compaction.

[0069] Referring to FIG. 2 and 3, the moisture sensor data, the Volumetric Water Content (VWC) for each sensor location is plotted.

[0070] Similar patterns in the data are seen for both columns at the beginning of the test and the data appears consistent with the data collected during the column test of Experiment 1.

[0071] There was a maximum 3% differences in the sensor initial VWC readings (baseline). However, these sensors are calibrated in both dry air and in water to be within ±0.5% VWC accuracy. And the temperature correlated fluctuation is quite small as well, as seen from the above figures. In this case, the sensor data show that there is a different initial moisture content in the ore sample. We understand that the ore samples for both columns were taken from the same container in the room next to the columns. However, there is a gradient of moisture distributed throughout the ore in the container which affected the baseline moisture sensor reading between the two columns. This explains why the sensor S16 measured the highest moisture content initially and SI5 measured the 2nd highest.

[0072] Referring to FIG. 2 and 3, it took approximately 5.4 hours (C2) and 15.7 (CI) hours for the water front to be detected by the bottom sensor after it is detected by the top sensor. Using the water front travel speed (-18.5 cm/hr for C2 and -6.4 cm/hr for CI) and the corresponding irrigation rate, the water content in the above the sensor in the column at the time the water front reached the bottom sensor was calculated to be approximately 13.7% in C2 and *16.9%* in CI. For comparison, these calculations are similar to the detected VWC from these sensors, i.e. the VWC in CI was approximately 3% percent higher than the VWC in C2 at the same time.

[0073] After that, the VWC at both sensor locations increased a further 1 - 2% slowly. This was expected because more water was absorbed by the ore particles. Note: there were a few times that the VWC in the columns dropped more than 1% and was attributed to some temporary "pause" of the irrigation system.

[0074] At the end of the test, VWC at sensor location #13 and #14, inside the C2 column with the fast irrigation rate, still had a lower VWC than the same location inside the CI with the slower irrigation rate, even though the total *water weight ratio* for columns was approximately the same (8.92% for CI, and 8.95% for C2) and the VWC since the specific density of the ore in both columns was approximately the same too (weight: 61.85 Kg for CI and 62.2 Kg for C2, volume height: 180 ±lcm). It is believed this behavior is explained by the non-uniform application of the drip to the column at the higher rate and lower initial VWC created a preferential fluid path through the column around the sensors #13 and #14. Note: Typical VWC of ore samples that undergo agglomeration is approximately 10% initially.

[0075] At the end of the test, both columns had approximately 10 cm height loss (180 ±lcm from the beginning 190 cm) due to the compaction. Total weight increased approximately 4 kg ± 0.2 Kg.

[0076] On day 34, the ore samples were removed from the columns and the sensors were removed. Referring to FIG. 2 and 3, the sensor signals decreased to nearly 0% of VWC after the sensors were exposed to the air.

[0077] Example 3

[0078] Below is a summary of results of additional testing that was undertaken to evaluate the performance of a heap leach process measurement and monitoring system in-situ in an operating heap leach operation.

[0079] Leach pad moisture measurements were recorded as of the start date. All sensors were confirmed operational at installation. Referring to FIG. 4a, the moisture sensors 308 were placed within the heap leach pile 10 both horizontally (sensors H7 - HI 1) and vertically (sensors VI - V6). Additionally, a compaction sensor 26 was placed at location CI within the heap leach pile.

[0080] From a report provided by Mine operations, it was confirmed that the ore backfill was completed on day 2 after the start date and the irrigation drip started on the morning of day 3.

[0081] Volumetric Water Content (VWC) at each sensor location is calculated from the sensor data using the data from the column test described in Example 2 to calibrate the sensors. Referring to FIG. 6 and 7, moisture was detected by all the sensors within 2 days of the start of the irrigation. No rainfall was recorded at the leach pad until day 5 as illustrated in FIG. 8. The largest observed rainfall recorded during the period of the experiment at the leach pad was 26mm on day 10. The relative increase in fluid due to this rainfall averaged approximately 1.08 l/hr/m2 on top of the irrigation water flow of the day. Assuming the leach pad irrigation flow rate was at 8 1/hr/m^2, the rainfall on day 10 incrementally added approximately 13.5% additional water to the leach pad averaged over a 24 hour period. Thus, comparing with the irrigation water flow, the effect of the rainfall is a small incremental factor.

[0082] The temperature at the sensor locations was measured by Motes and is illustrated in FIG. 35 in 4 sensor groups. It shows that the sensor temperature fluctuated during installation (as expected) and the temperature at all locations stabilized to approximately 20°C after day 10.

[0083] The compaction sensor detected a large increase in pressure on day 2 as illustrated in FIG. 9. According to the report provided by Mine operations, this was within the time window of the ore backfill. On day 4, the compaction recorded another increase in pressure. This is attributed to the water front reaching the compaction sensor as recorded by moisture sensors 3 and 5 in FIG. 7, which further compacted the ore around the sensor, and was expected. During the day 4 - day 9 period, the compaction signal dropped which correlates with the sensor temperature drop. This is expected since the compaction sensor is sensitive to temperature due to the equation PV=nRT. This can be compensated with sensor calibration. During the period between day 9 and day 20, the sensor temperature was quite stable. The slow rise of compaction is attributed to the settlement of the ore particles during the irrigation application as was observed during the column test Example 2 where settlement caused approximately 5% of total ore volume reduction in approximately one month.

[0084] A leaky cable was used in the system, as seen in FIG. 4a and 5, and proved to be as reliable as other coax cables used within the heap leach pile for sensor signal transmission. The leaky cable provided a superior solution to simplify the sensor installation by avoiding urethane pipe for sensor protection.

[0085] Referring to FIG. 4a the leach pad is approximately 5m in height, and the slope of the face of the bench, at the location of the sensors positioned vertically, was estimated to be about 45 degrees. The top sensor (Sensor VI in the illustration below) is approximately 2 - 3m inside the perimeter of the leach pad.

[0086] With reference to the vertical column of sensors illustrated in FIG. 4a, the sensor located at position VI is approximately 0.3 meter below the surface of the upper lift 16. The vertical distance between each two neighboring sensors in the vertical column is approximately 0.95m (i.e. 1.35 x cos45) except that between sensor 3 and 4, which is approximately 1.2m. The sensor V6 is actually a little bit below the horizontal ground level of the lower lift 14. The compaction sensor is located 0.95m below the sensor V3.

[0087] With reference to the horizontal row of sensors, the router 28 in FIG. 4a is approximately 2 - 3 m outside the perimeter of the heap, while the sensor at location H7 is approximately 7.5m from that end. The horizontal distance between each two neighboring horizontal sensors is 5m.

[0088] A leaky coaxial cable 300 was placed near compaction sensor CI and exited the side of the heap leach pile at router 30 about half way up the slope. A distributed antenna 22 was placed near sensors VI - V6 and H7 - H11. The distributed antenna exits the heap leach pile at the base of where the lower lift 14 and upper lift 16 meet. Gateway 32 was electromagnetically coupled to routers 28 and 30 connected to a WiFi modem. The Gateway communicates with another WiFi access point located at the mine that provides internet access.

[0089] The compaction in the leach pad rose quickly at beginning of the installation but went up at a very slow rate for the remainder of the period. No indication of degrading stability or undesirable settlement was detected at the location.

[0090] These results demonstrate that the heap leach process measurement and monitoring system performs well in the intended application and that the following can be observed:

1. The progression of the "moisture front" as it progresses along the length of the sensor.
2. The moisture content of the ore.
3. A determination of whether the ore is saturated (pooling).
4. A direct measurement of the moisture content
5. Resolution: 0.1% VWC

6. Range: 0% VWC to saturation
7. Proven to work with an environment using Sodium Cyanide (NaCN) leachate
8. Affordable and easy installation
9. Wireless communication for sensor data
10. Data sampling every minute and daily feedback option for control
11. Measured moisture content at the horizontal sensor locations shows that the inner area of the leach pad achieved optimum VWC.
12. The sensors near the edge of the leach pad suggest this area was under irrigated.
13. Measured moisture volume water content near the surface was more dynamic.
14. Large rainfalls at the leach pad in months 2 and 3 are easily seen as transients in the sensor data.
15. The effect of rainfall overall is small compared to the irrigation flow rate.
16. Sensors near the surface indicate saturation of the ore near the surface during heavy rainfall events.
17. The moisture volume water content returned to its average level after rainfall events.
18. Differences of the moisture volume water content level at different locations was observed. Uneven moisture levels can reduce efficiency of the leaching process.
19. Monitor the stability of the entire leach pad, especially the slopes and prevent the undesirable settlement of the leach pad at the same time resulting in a safer and compliant operation.

[0091] Example 4

[0092] This test was undertaken to evaluate if the information provided by installing a grid of sensors in a heap leach pile can provide information that can be used to increase recovery of gold and/or silver in sufficient quantities so as to pay for the cost of the sensors and subsequent monitoring and achieve a positive return on investment.

[0093] The test involved installing 42 compaction sensors and 42 moisture sensors within ½ the area of a 5.2 hectare leach pad under construction (approximately 140m x 120m).

[0094] The goal of this example was to improve the leach process by characterizing and modeling changes in heap moisture and compaction and in doing so increase the recovery of gold and gold equivalent ounces during the process.

[0095] This example focuses on what is considered to be one of the most important aspects, moisture and its impact on yield and irrigation. By characterizing moisture changes within the heap we can correlate the moisture profile to the irrigation process to ensure that the moisture profile is optimized for best yield. The project characterizes the changes in heap moisture and compaction, in context of the existing profiles for irrigation, density and mining processes. The premise being that better management of the irrigation, both sprinkler head placement and flow rates, and heap surface preparation shall result in higher yields of the leach process. From this data we are able to model and monitor:

- Heap irrigation effectiveness (through moisture profile), and
- Heap geotechnical stability and the relationship to heap compaction profile (data from the compaction sensors).

[0096] The process and scope of work included provision and installation of moisture and compaction sensors, wireless data logging devices (called "Motes"), which may be sensors such as those described in United States patent no. 9,329,579 (Slupsky) entitled "Wireless Sensor Device" or available from Scanimetrics Inc. located in Edmonton, Alberta, and data analytics. Data from the sensors was monitored, collected and stored in the Motes and then transmitted via a wireless connection to an Internet Gateway and then forwarded to the MoteScan cloud where the data is processed, stored in a database, analyzed and visualized.

[0097] Referring to FIG. 10, moisture and compaction sensors 308 electromagnetically coupled to leaky coaxial cables 300 were arranged in a triangular grid pattern 1000 with a spacing of 16 m and buried within a heap leach pile to form an in-situ wireless sensor network. A moisture and a compaction sensor (not shown) connect with one wireless Mote 308 at each grid point; wireless Motes 308 and the Internet Gateway (not shown) are electromagnetically coupled to a leaky coaxial cable 300 and wireless routers. The Internet Gateway was located at the edge of the heap. The leaky coaxial cable was selected to be suitable for the radio frequency used by the wireless motes, routers and Internet Gateway and to minimize signal loss.

[0098] The Gateway uploaded the data to data analytics software, entitled the "Scanimetrics' MoteScan Cloud", where it is analyzed and reports are generated and data is visualized. The Internet Gateway communicates to the Scanimetrics' MoteScan Cloud via an Internet connection. A Wi-Fi network relayed the data from the heap Gateway to the Internet access point at the mine. Alternatively, a point to point radio or cellular or satellite or land line connection to the internet could have been used.

[0099] Each Mote can be programmed to a specific sample rate and the number of samples taken during a specific window of time can also be programmed. For this application, the Motes were configured with a sample rate of one sample per minute. The number of samples taken was set to one and the sample window was configured to 1 minute.

[0100] The Motes generally need to be placed within 30 meters of the Internet Gateway to communicate directly with it. Router/repeater devices were used to improve the throughput and reliability of communication between the Motes and the Internet Gateway since the Internet Gateway was located more than 30 meters from many of the Motes.

[0101] Below is a summary of results of the testing described above.

[0102] Leach pad moisture and compaction measurements were recorded for 90 days. All sensors were confirmed operational at installation and the health of each sensor or mote was monitored for the duration of the project. Health monitoring comprised monitoring:

1. Frequency and interval of the data downloaded from the mote devices and size of the data payload
2. The data and system logs from the gateway
3. The wireless signal strength of the mote and router devices
4. The radio duty cycle of the mote devices
5. The frequency and interval of unexpected mote device resets or reboots
6. The mote and router device battery and temperature
7. The duty cycle of the mote memory storage device

[0103] From the data and discussion with Mine operations, it was observed and confirmed that:

1. Sensor installation was completed on day 1.
2. Irrigation began at day 3.
3. Irrigation continued until day 47.
4. Crushed ore was placed on the surface of the existing heap beginning day 49.
5. Crushed ore placement was completed on day 78.
6. Irrigation resumed on day 59.

[0104] Volumetric Water Content (VWC) at each sensor location is calculated from the sensor data using data collected from the sensors and data collected from a column test used to calibrate the sensors. All the sensors detected ambient moisture at the time the sensor was installed and then a large transient increase when irrigation was initiated.

[0105] The temperature at the sensor locations was measured by Motes shows that the sensor temperature fluctuated after installation (as expected) until the temperature at all locations stabilized when the crushed ore was placed on the surface of the existing heap.

[0106] The compaction sensors show an increase when the sensors were initially buried under up to 60cm of ore. The sensors fluctuate due to temperature of the surface of the heap. The sensors recorded a large increase corresponding to the placement of ore on the surface of the existing heap. Each compaction sensor recorded a corresponding increase when the irrigation of the new ore material began. As settlement of the ore occurred due to irrigation underneath the compaction sensor, the sensor response decreased.

[0107] The leaky coaxial cables used in the system proved to be reliable within leach pad for sensor signal transmission. The cables provide a reliable solution and simplify the sensor installation.

[0108] Referring to FIG. 11, the gold recovery of the reference material placed in a column is represented. The graph shows the gold recovery versus time determined by assay of the solvent formulation for four different irrigation profiles.

[0109] Referring to FIG. 34, a moisture sensor was placed within a body of reference material within a column and monitored the moisture sensor versus time for four different irrigation profiles. Each line represents a different column, C1 - C4, being monitored.

[0110] The flow rates were changed every 7 days as follows (values are in $l/m^2/hr$):

Column	Rate 1	Rate 2	Rate 3	Rate 4
CI	4.1	8.2	16	8.2
C2	8.2	16	8.2	4.1
C3	8.2	4.1	8.2	16
C4	16	8.2	4.1	8.2

[01 11] Preferential gold recovery can be observed from the C2 column results which illustrate a 33% increase in gold recovery after 30 days compared to column C3.

[01 12] Referring to FIG. 12, ore samples with known VWC are used to calibrate the sensor. We use a linear method to relate the VWC in the ore (y-axis) measured using a reference instrument versus the moisture sensor output (x-axis). A two point calibration method is used for the sensor at the VWC range of 10% - 30%. Other multipoint and non linear methods could be used to increase accuracy.

[01 13] Referring to FIG. 13, the moisture signal rises at point 100 when the sensor is placed into the ore. The moisture sensor response increases as the ore absorbs moisture from the surrounding ore. When the irrigation of the chemical solvent solution is applied at pointl02 the moisture rises rapidly and stabilizes according to the ore particle size and flow rate of the applied irrigation. The irrigation is stopped temporarily and the moisture sensor response decreases accordingly at pointl04. When the irrigation continues, the moisture response increases rapidly at pointl06 and stabilizes.

[01 14] Referring to FIG. 14, the compaction sensor signal rises at point 200 when the sensor is placed into the ore body and additional ore is placed over the sensor to cover the sensor. The compaction sensor response oscillates due to the proximity of the sensor to the surface of the ore body and the day-night temperature cycle. When the next lift of ore is placed on the heap leach pile, there is a large change in the sensor response at point 202. When the irrigation of the chemical solvent solution is applied at point 102 the compaction sensor response increases accordingly. As the ore settles below the compaction sensor, the compaction decreases and the sensor response decreases at point 206 accordingly.

[01 15] Referring to FIG. 15, volumetric water content (VWC) was calculated from the data obtained from the moisture sensors and the reference material used during the column test to calibrate the sensors. Data is visualized using a two dimensional grid.

Each grid point in the visualization aggregates the data to illustrate the average, median, max, min or standard deviation of the volumetric water content for that point. The data aggregations can be performed on time ranges of one or more minutes, one or more hours, one or more days or other periods of time. Moreover, the magnitude of the data at each grid point may be represented using chrominance or luminance or a combination of both to represent the data resulting in a "heat map" representation of the data.

[01 16] Referring to FIG. 16, the change in volume water content (VWC) was calculated from the data obtained from the moisture sensors and the reference material used during the column test to calibrate the sensors.

[01 17] Referring to FIG. 17, the compaction was calculated from the data obtained from the compaction sensors and the reference material used during the column tests to calibrate the sensors.

[01 18] Referring to FIG. 36, an example of a process of preparing and monitoring moisture is illustrated. In step 422, a sample of the ore material is taken from the material intended to be placed on the heap and dump leach pile. The sample is sorted according the particle size in step 424 to select a preferable material for placement with the sensor. In step 426, the sample is placed in a column and leached at the preferred leach flow rate and the pregnant solution is assayed at regular intervals during the column leach process. A moisture sensor is placed within the body of ore contained in the column and moisture sensor data is collected for the duration of the column leach process. The data from the moisture sensors and the particle size is used to calibrate the sensors in step 428 that will be placed within the heap leach and dump pile. Next, in step 430, a plan for the grid of sensors to be placed within the heap and leach dump pile is developed. In step 432, the sensors are then placed on the surface of or within the heap and leach dump pile or liner in accordance with the sensor plan. Next, in step 434, a layer of heap and leach dump pile material is placed on the lift or liner. When complete, the lift is leached and the moisture is monitored in step 436 according to the leach process and sensor plan. This process is repeated continuously.

[01 19] Referring to FIG. 37, an example of a process of monitoring the moisture during the leach process is illustrated in the flow chart. The baseline of the moisture is determined in steps 440, and the irrigation is initiated in step 442. After initiation, in step

444 the moisture front propagation may be determined.

[0120] Moisture sensor data is collected in step 446 and reported in step 448 on a regular interval during the irrigation period. Moisture data may be used to provide an indication of the recovery curve so that the extraction process can be optimized to increase the recovery of the chemical of economic interest from ore mined and put through a heap leach extraction process.

[0121] In decision step 450, moisture VWC is compared to a wet limit. If Moisture VWC exceeds the wet limit a remediation or treatment of the irrigation process may be undertaken in step 452. Moisture VWC is compare to a dry limit in decision step 454. If Moisture VWC is less than the dry limit, a remediation or treatment of the irrigation process may be undertaken in step 456. During the irrigation process, the VWC is totalized in step 458 to measure to estimate the total amount of the solvent formulation applied. When the leach process is complete as decided in block 460, the irrigation is stopped in step 462.

[0122] Referring to FIG. 38, an example of a process of preparation and monitoring compaction is illustrated in the flow chart. A sample of the ore material is taken in step 464 from the material intended to be placed on the heap and dump leach pile. In step 466, the sample is sorted according the particle size to select a preferable material for placement with the sensor. The sensors are calibrated in step 468 to the particle size. In step 470, a plan for the grid of sensors to be placed within the heap and leach dump pile is developed. In step 472, the sensors are then placed on the surface of or within the heap and leach dump pile or liner in accordance with the sensor plan. Next, a layer of heap and leach dump pile material is placed on the lift or liner in step 474. When complete, the lift is leached in step 476 and the compaction is monitored according to the leach process and sensor plan. This process is repeated continuously.

[0123] Referring to FIG. 39, an example of a process of monitoring the compaction during the leach process is illustrated in the flow chart. In step 480, the baseline of the compaction is determined and the irrigation is initiated in step 482. Compaction sensor data is collected in step 484 and reported on a regular interval during the irrigation period in step 486.

[0124] Compaction sensor data may be compared to an upper limit in decision step

488. If compaction exceeds the upper limit a remediation or treatment of the irrigation process may be undertaken in step 490. Compaction sensor data may also be compared to a lower limit in step 492. If compaction is less than the lower limit a remediation or treatment of the irrigation process may be undertaken in step 494. When the leach process is complete as determined in decision step 496, the irrigation is stopped in step 498.

[0125] Moisture and compaction remediations or treatments may involve global or local adjustment of the irrigation flow rates, global or local adjustment of the irrigation emitters, global or local mechanical disturbance ("ripping") of the surface of the heap leach and dump pile, global or local application of a chemical agent, wieking the heap to remove a "pool" of suspended fluid, drilling into the heap, fracturing of the heap and leach dump pile using explosives, hydraulic fracturing of the heap and dump leach pile or steam injection; to selectively irrigate and form new flow pathways, interrupt fluid short circuits, interrupt fluid channelling in a manner that increases the flow of the solvent formulation at dry spots and reduces the flow of the solvent formulation at wet spots so as to provide adequate flow and even or uniform flow of solution through the heap to thoroughly leach the heap in an economical time.

[0126] In this patent document, the word "comprising" is used in its non-limiting sense to mean that items following the word are included, but items not specifically mentioned are not excluded. A reference to an element by the indefinite article "a" does not exclude the possibility that more than one of the elements is present, unless the context clearly requires that there be one and only one of the elements.

[0127] The scope of the following claims should not be limited by the preferred embodiments set forth in the examples above and in the drawings, but should be given the broadest interpretation consistent with the description as a whole.

What is claimed is:

1. A method of monitoring a body of granular material, the method comprising the steps of:

installing a plurality of wireless sensors in a body of granular material to be monitored, each wireless sensor being adapted to measure one or more physical conditions of the granular material;

installing one or more leaky cables in the body of granular material, the one or more leaky cables and the wireless sensors being embedded within the body of granular material, each wireless sensor being sufficiently close to at least one leaky cable to communicate wirelessly with the at least one leaky cable;

providing a data collection system that is communicatively connected to the one or more leaky cables;

transmitting electronic data related to the one or more physical conditions from the wireless sensors to the data collection system via the one or more leaky cable; and characterizing the body of granular material based on the electronic data received by the data collection system.

2. The method of claim 1, wherein the wireless sensors are selected from a group consisting of moisture sensors, soil compaction sensors, force sensors, pressure sensors, temperature sensors, pH sensors, ion specific sensors, or combinations thereof.

3. The method of claim 1, wherein the wireless sensors are distributed horizontally and vertically within the body of granular material to form an array of sensors.

4. The method of claim 1, wherein the body of granular material is a heap leach, and further comprising the steps of applying a treatment step or adjusting an applied treatment step to the heap leach, and causing the wireless sensors to monitor changes to the heap leach in response to the treatment step.

5. The method of claim 4, wherein the treatment step that is applied to the heap leach is determined by the characterization of the heap leach based on the electronic data from the wireless sensors.

6. The method of claim 4, wherein the characterization of the heap leach comprises comparing the electronic data to a predetermined model of the heap leach to identify one or more deficiency relative to the predetermined model.

7. The method of claim 6, wherein the one or more deficiency comprises an excess of moisture, a lack of moisture, overcompaction, under compaction, consolidation, or combination thereof.

8. The method of claim 1, further comprising the step of electrically connecting one or more transmission cables to one or more leaky cables, each leaky cable having a portion of its shielding removed to permit radio frequency signals to escape or be received.

9. The method of claim 1, wherein each of the wireless sensors comprises a fully enclosing housing that houses a wireless transceiver, a processor, and a power supply, and a sensor element that is external to the fully enclosed housing and electrically connected to the processor.

10. The method of claim 9, wherein each of the wireless sensors is electrically insulated from the leaky cables and the data collection system.

11. The method of claim 10, wherein one or more wireless sensors are mechanically attached to one or more leaky cables.

12. The method of claim 1, wherein the body of granular material comprises a tailings dam, and the one or more physical conditions comprise compaction levels and moisture levels of the granular material.

13. The method of claim 1, wherein the body of granular material comprises an earthen bank adjacent to a buried pipeline, and the one or more physical conditions comprise compaction levels and moisture levels of the granular material.

14. The method of claim 1, further comprising the step of positioning one or more wireless sensors within a flexible, permeable enclosure filled with reference granular material.

15. The method of claim 14, wherein the one or more wireless sensors comprise at least one of a compaction sensor element and a moisture sensor element, and wherein the compaction sensor element is positioned outside the enclosure.

16. The method of claim 14, further comprising the step of calibrating wireless sensors based on the reference granular material in the flexible, permeable enclosure prior to embedding the sensor in the body of granular material.

17. In combination:
a body of granular material; and
a system for monitoring the body of granular material, the system comprising:

a plurality of wireless sensors in the body of granular material to be monitored, each wireless sensor being adapted to measure one or more physical conditions of the granular material;

one or more leaky cables installed in the body of granular material, the one or more leaky cables and the wireless sensors being embedded within the body of granular material, each wireless sensor being sufficiently close to at least one leaky cable to communicate wirelessly with the at least one leaky cable; and

a data collection system that is communicatively connected to the one or more leaky cables;

wherein the wireless sensors are adapted to transmit electronic data related to the one or more physical conditions from the wireless sensors to the data collection system via the one or more leaky cable, the data collection system comprising instructions to characterize the body of granular material based on the electronic data received by the data collection system.

18. The combination of claim 17, wherein the wireless sensors are selected from a group consisting of soil compaction sensors, force sensors, pressure sensors, temperature sensors, ion specific sensors, or combinations thereof.

19. The combination of claim 17, wherein the wireless sensors are distributed horizontally and vertically within the body of granular material to form an array of sensors.

20. The combination of claim 17, wherein the body of granular material is a heap leach, and further comprising the steps of applying a treatment step or adjusting an applied treatment step to the heap leach, and causing the wireless sensors to monitor changes to the heap leach in response to the treatment step.

2 1. The combination of claim 20, wherein the treatment step that is applied to the heap leach is determined by the characterization of the heap leach based on the electronic data from the wireless sensors.

22. The combination of claim 20, wherein the instructions of the data collection comprise instructions to compare the electronic data to a predetermined model of the heap leach to identify one or more deficiency relative to the predetermined model.

23. The combination of claim 22, wherein the one or more deficiency comprises an excess of moisture, a lack of moisture, overcompaction, under compaction, consolidation, or combination thereof.

24. The combination of claim 17, further comprising the step of electrically connecting one or more transmission cables to one or more leaky cables, each leaky cable having a portion of its shielding removed to permit radio frequency signals to escape or be received.

25. The combination of claim 17, wherein each of the wireless sensors comprises a fully enclosing housing that houses a wireless transceiver, a processor, and a power supply, and a sensor element that is external to the fully enclosed housing and electrically connected to the processor..

26. The combination of claim 25, wherein each of the wireless sensors is electrically insulated from the leaky cables and the data collection system.

27. The combination of claim 26, wherein one or more wireless sensors are mechanically attached to one or more leaky cables.

28. The combination of claim 17, wherein the body of granular material comprises a tailings dam, and the one or more physical conditions comprise compaction levels and moisture levels of the granular material.

29. The combination of claim 17, wherein the body of granular material comprises an earthen bank adjacent to a buried pipeline, and the one or more physical conditions comprise compaction levels and moisture levels of the granular material.

30. The combination of claim 17, wherein the one or more wireless sensors are positioned within a flexible, permeable enclosure filled with reference granular material.

31. The combination of claim 30, wherein the one or more wireless sensors comprise at least one of a compaction sensor element and a moisture sensor element, and wherein the compaction sensor element is positioned outside the enclosure.

32. The combination of claim 30, wherein the wireless sensors are calibrated based on the reference granular material in the flexible, permeable enclosure prior to embedding the sensor in the body of granular material.

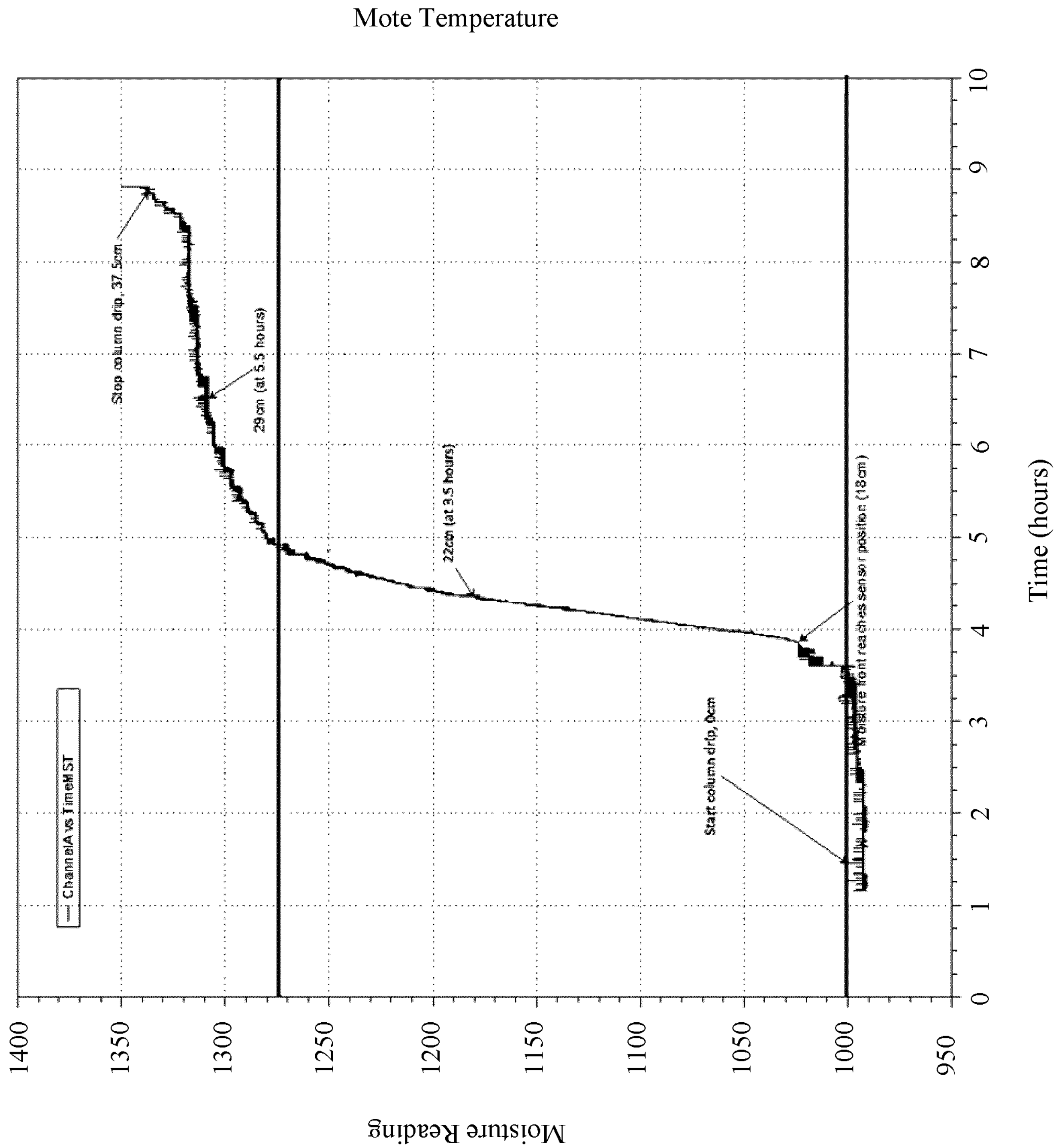
Mote Temperature
ChannelA vs TimeMST
Stop column drip, 37.5cm
29cm (at 5.5 hours)
22cm (at 3.5 hours)
Moisture front reaches sensor position (18cm)
Start column drip, 0cm
Moisture Reading
Time (hours)
1400
1350
1300
1250
1200
1150
1100
1050
1000
950
0
1
2
3
4
5
6
7
8
9
10

FIG. 1

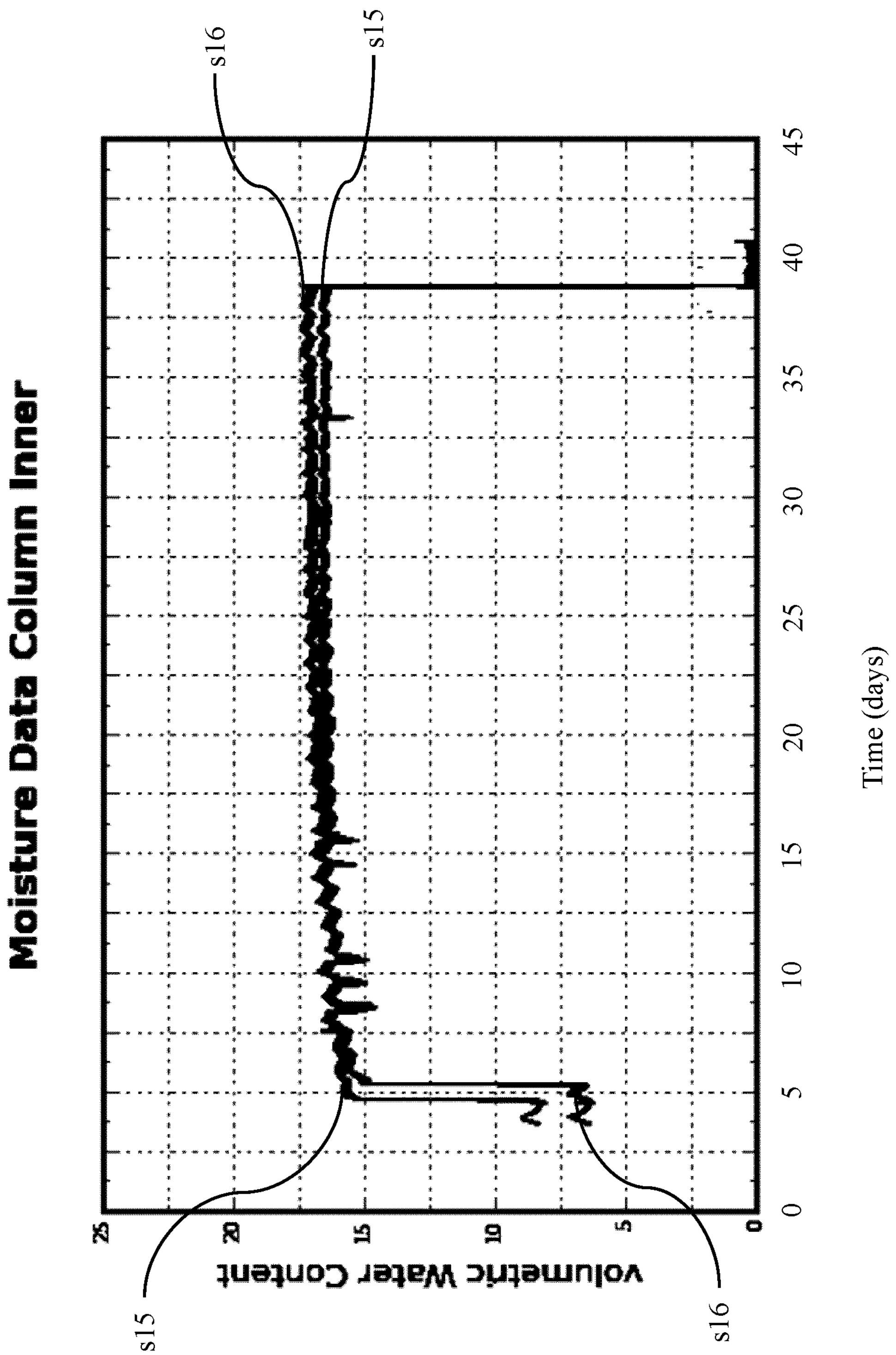
Moisture Data Column Inner
volumetric Water Content
Time (days)
s15
s16
0
5
10
15
20
25
30
35
40
45

FIG. 2

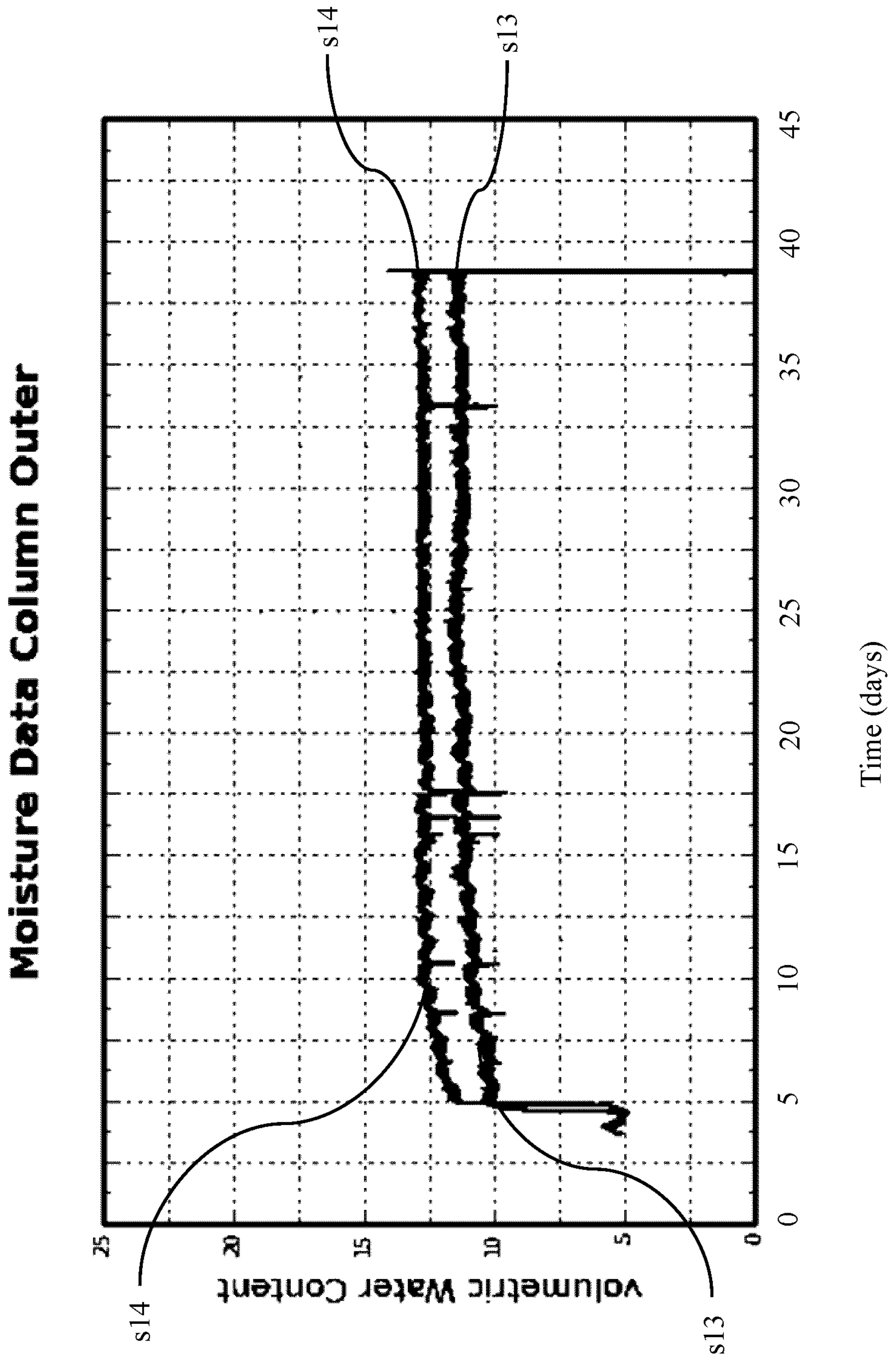
Moisture Data Column Outer
volumetric Water Content
Time (days)
0 5 10 15 20 25
0 5 10 15 20 25 30 35 40 45
s13
s14

FIG. 3

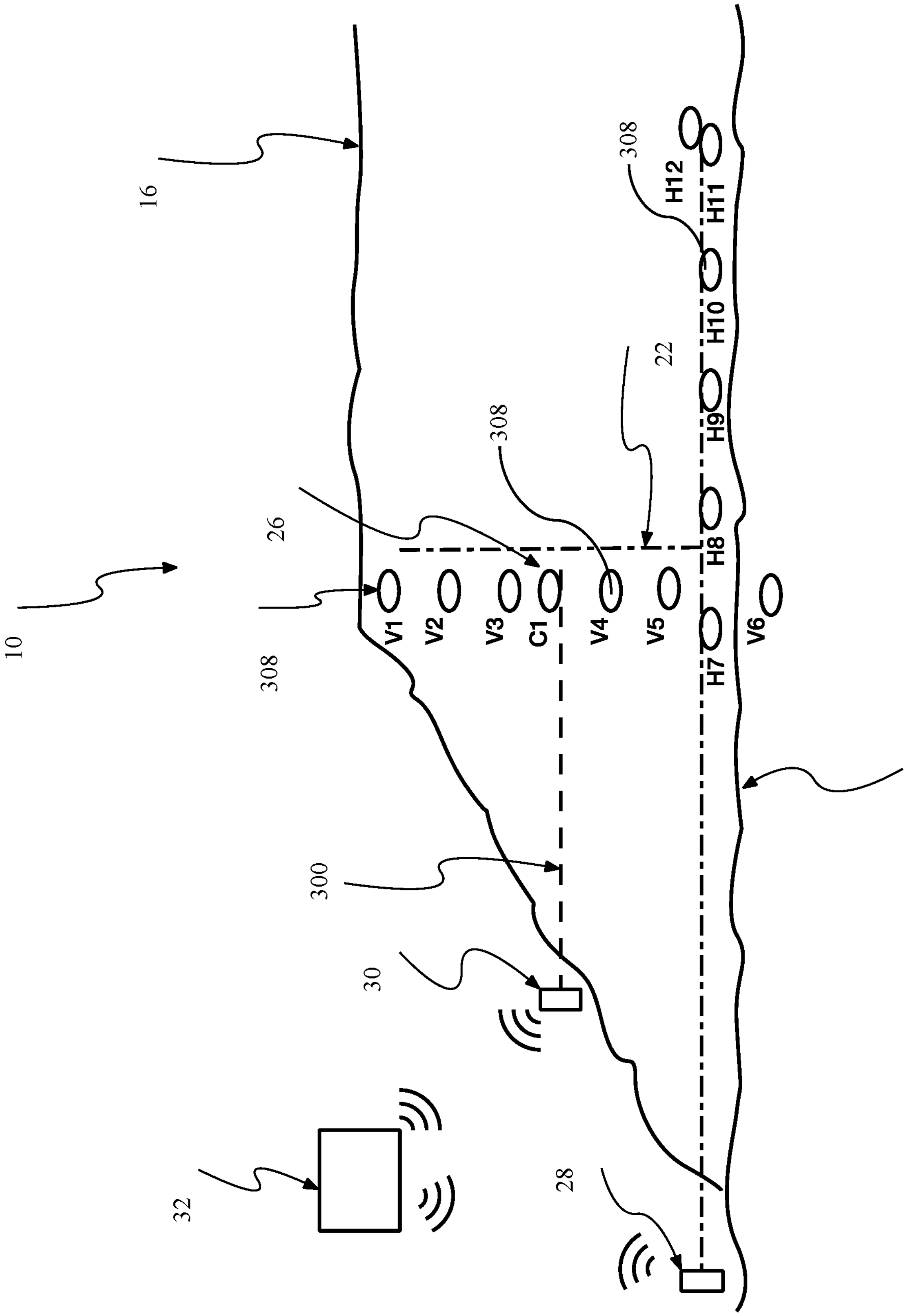
10
16
14
308
26
22
300
30
28
32
V1
V2
V3
C1
V4
V5
V6
H7
H8
H9
H10
H11
H12

FIG. 4a

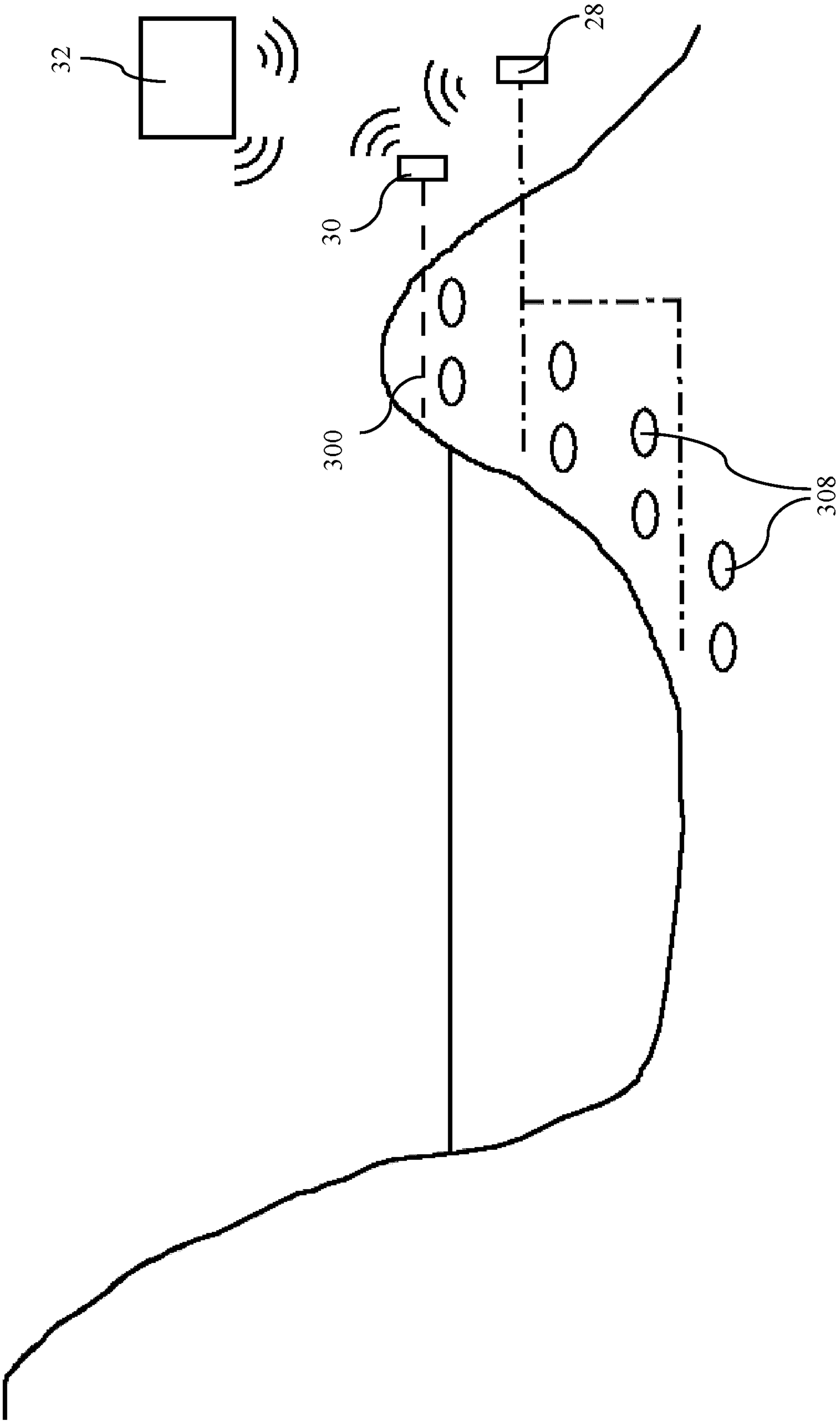

FIG. 4b

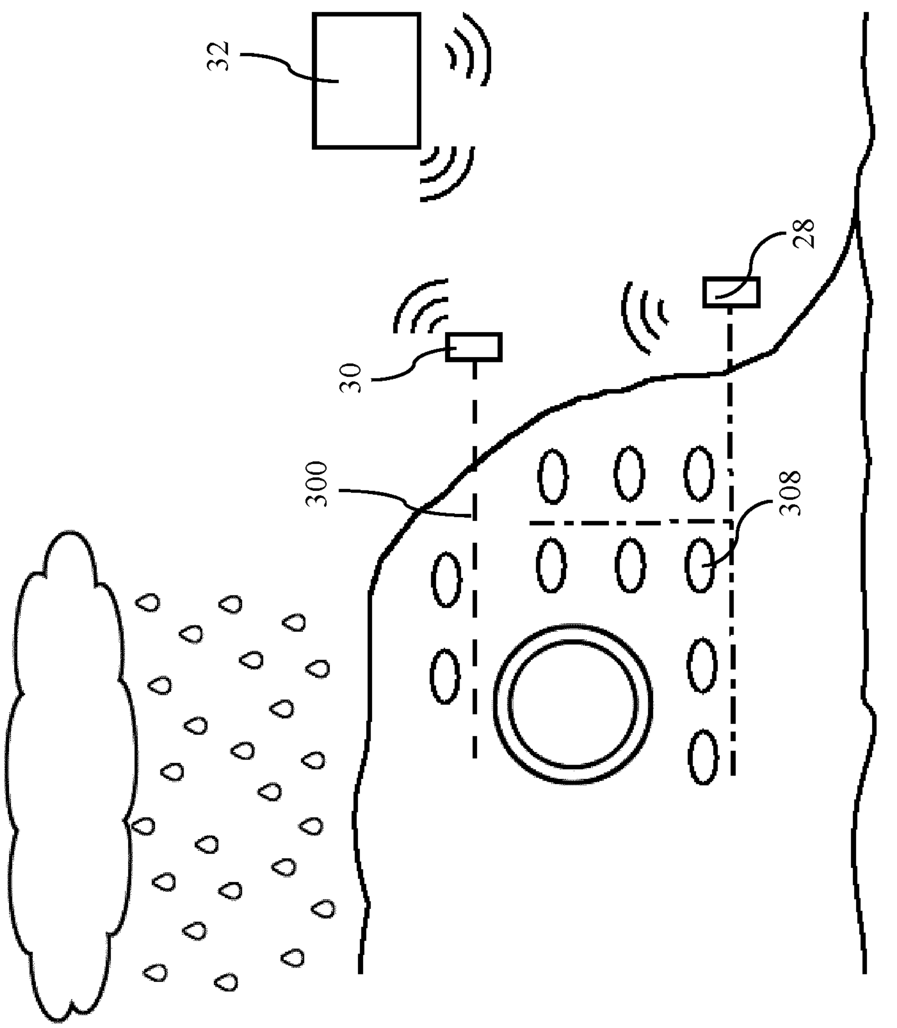

FIG. 4c

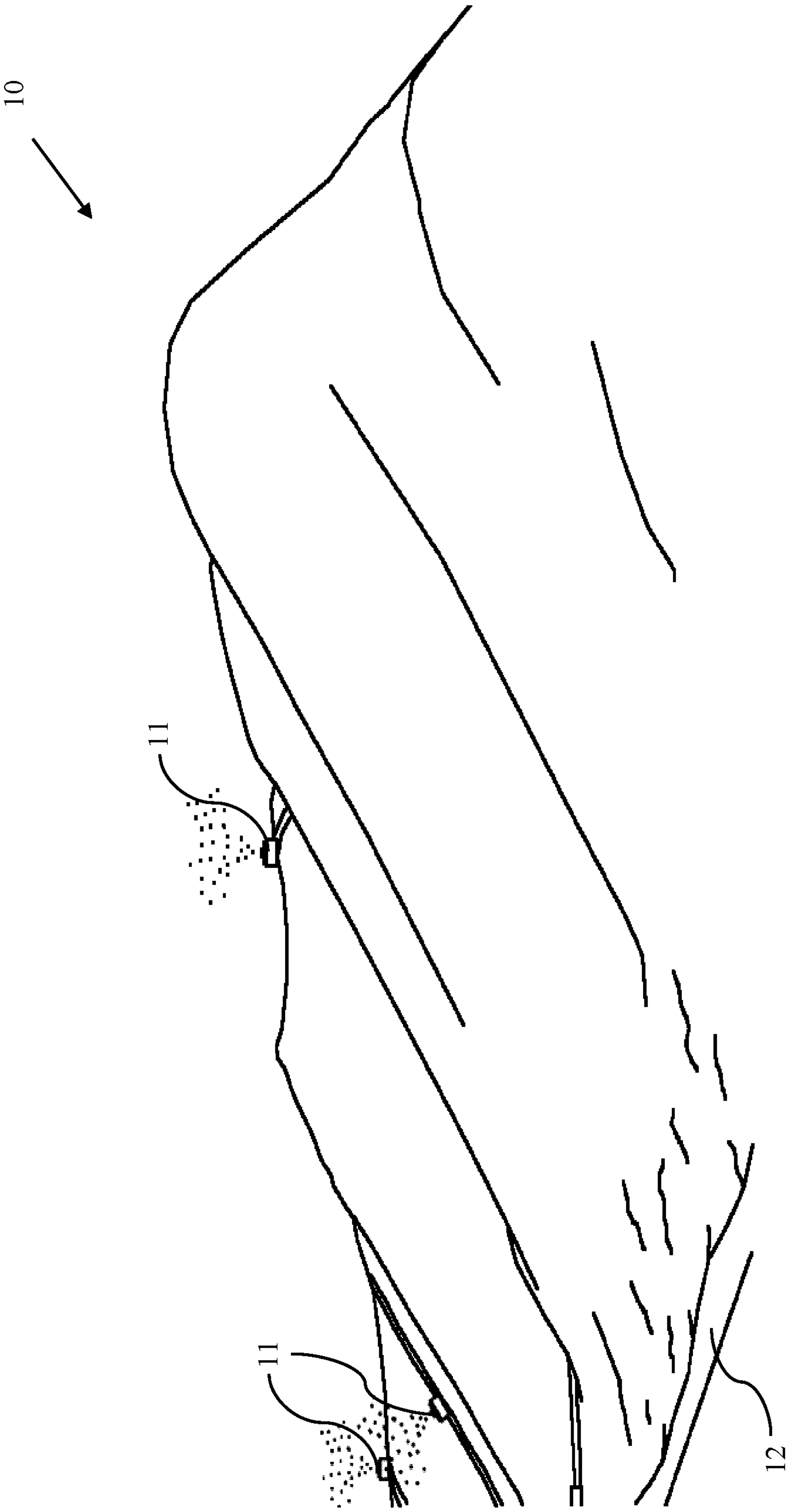

FIG. 5
Prior Art

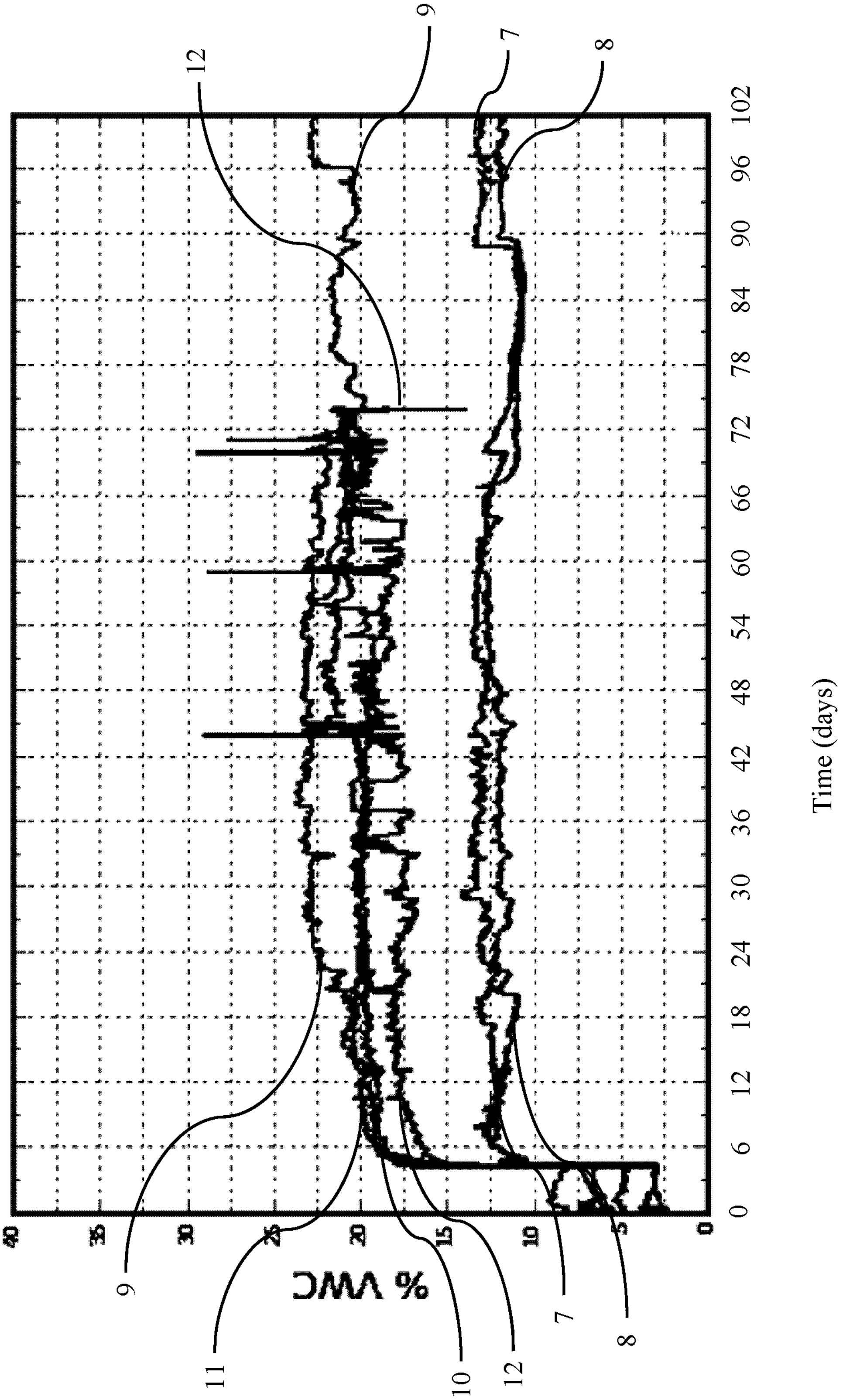
% VWC
Time (days)
0
5
10
15
20
25
30
35
40
0
6
12
18
24
30
36
42
48
54
60
66
72
78
84
90
96
102
7
8
9
10
11
12

FIG. 6

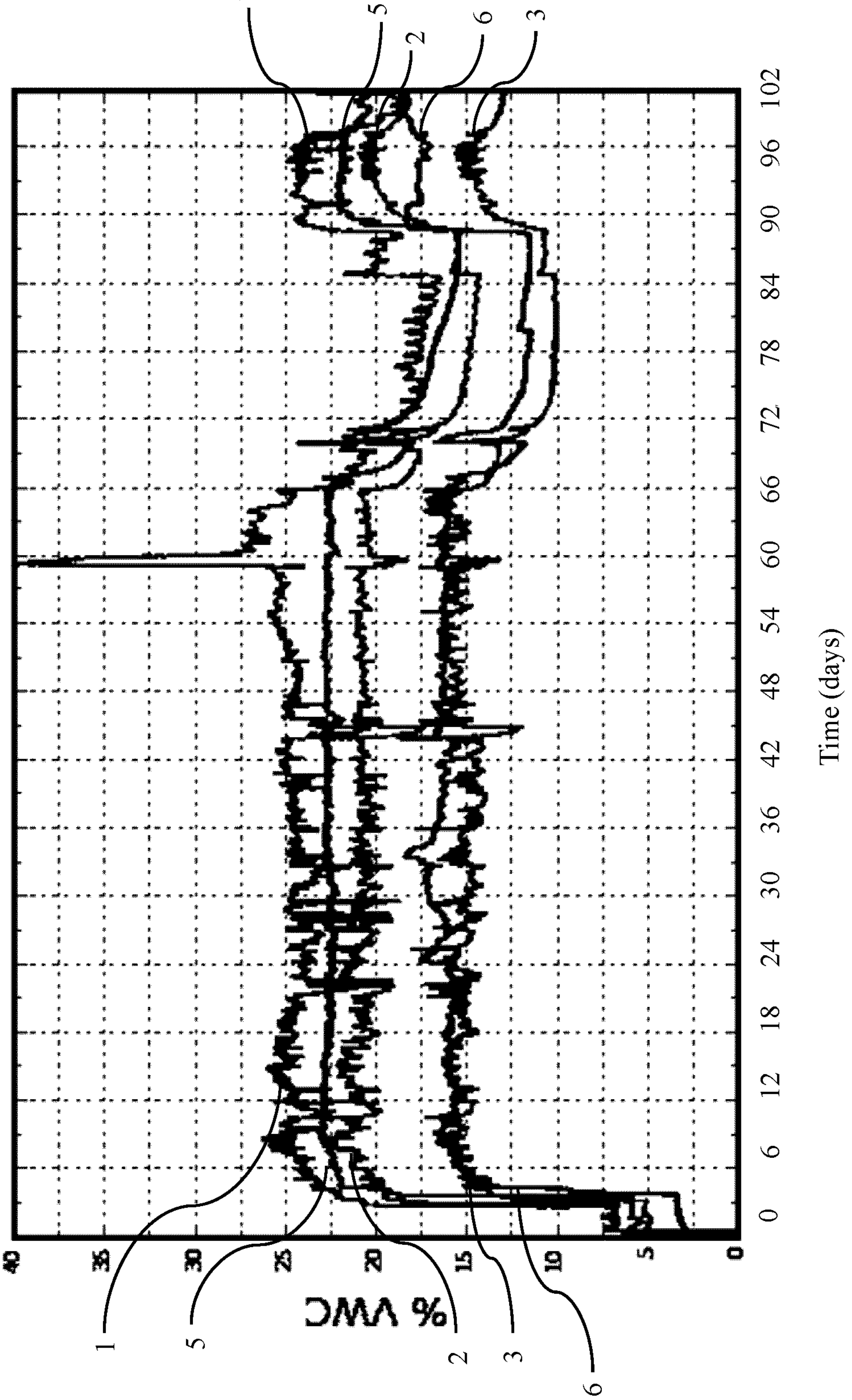
% VWC
0
5
10
15
20
25
30
35
40
Time (days)
0
6
12
18
24
30
36
42
48
54
60
66
72
78
84
90
96
102
1
5
2
3
6

FIG. 7

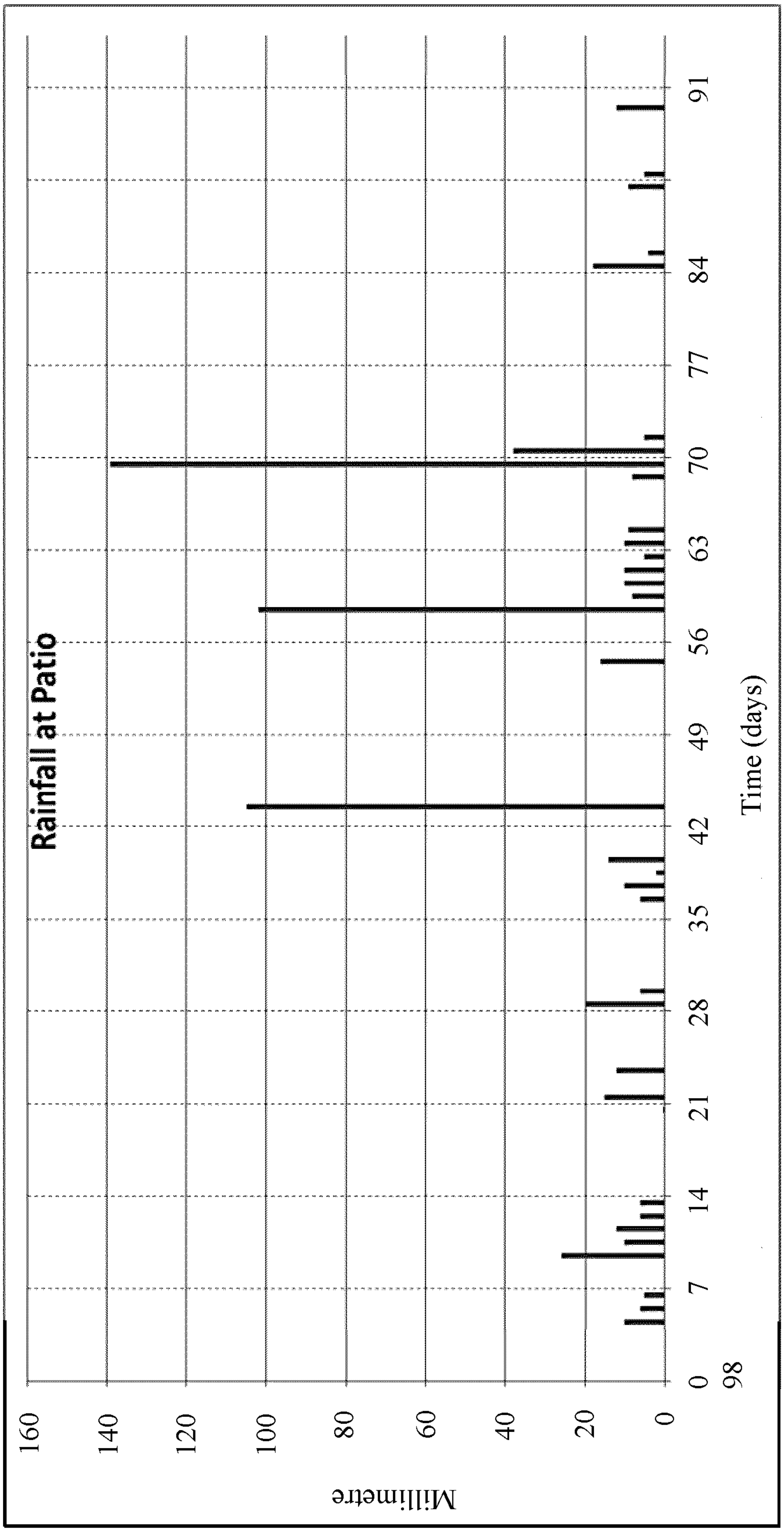
Rainfall at Patio
Millimetre
0
20
40
60
80
100
120
140
160
Time (days)
0
7
14
21
28
35
42
49
56
63
70
77
84
91
98

FIG. 8

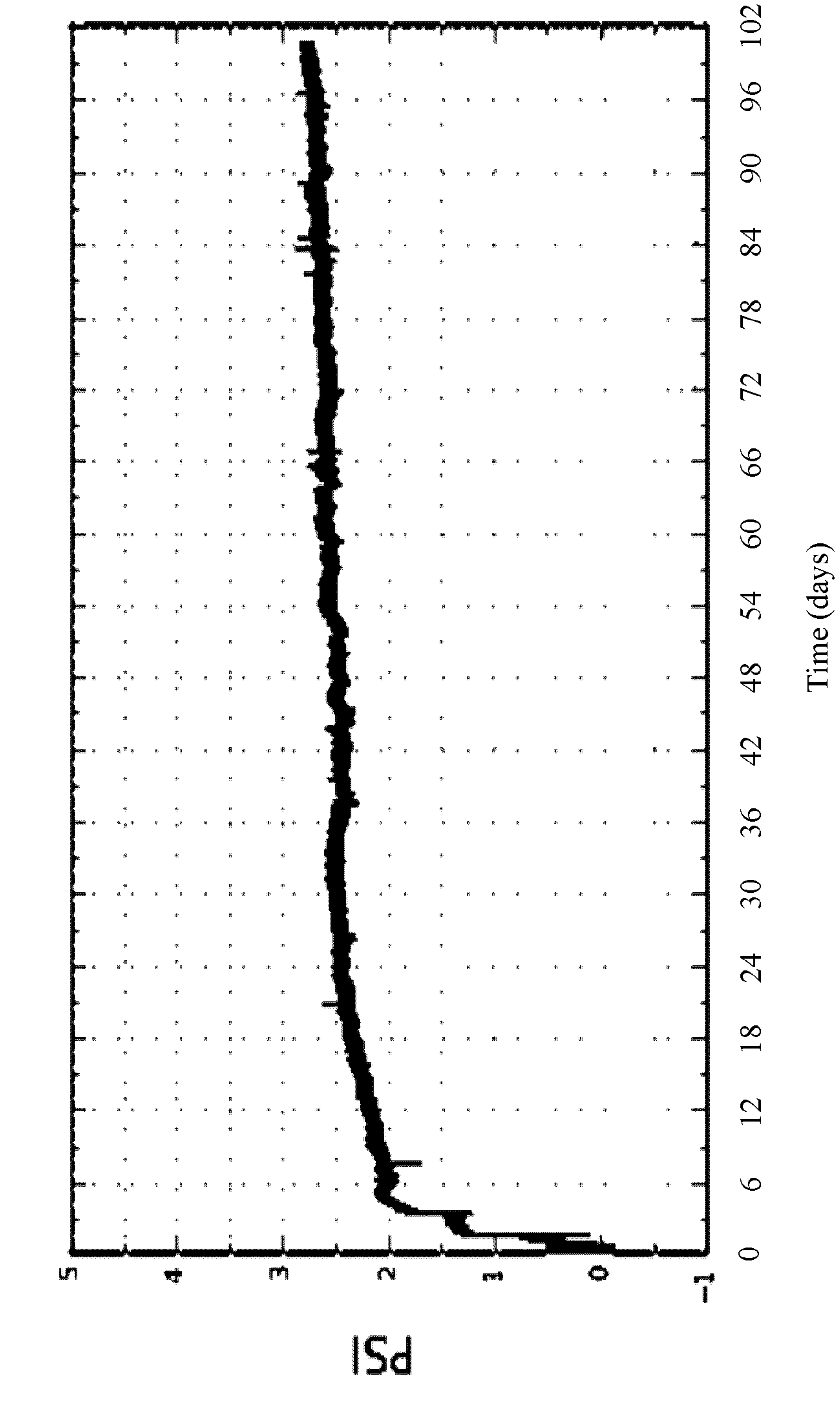
PSI
Time (days)
5
4
3
2
1
0
-1
0
6
12
18
24
30
36
42
48
54
60
66
72
78
84
90
96
102

FIG. 9

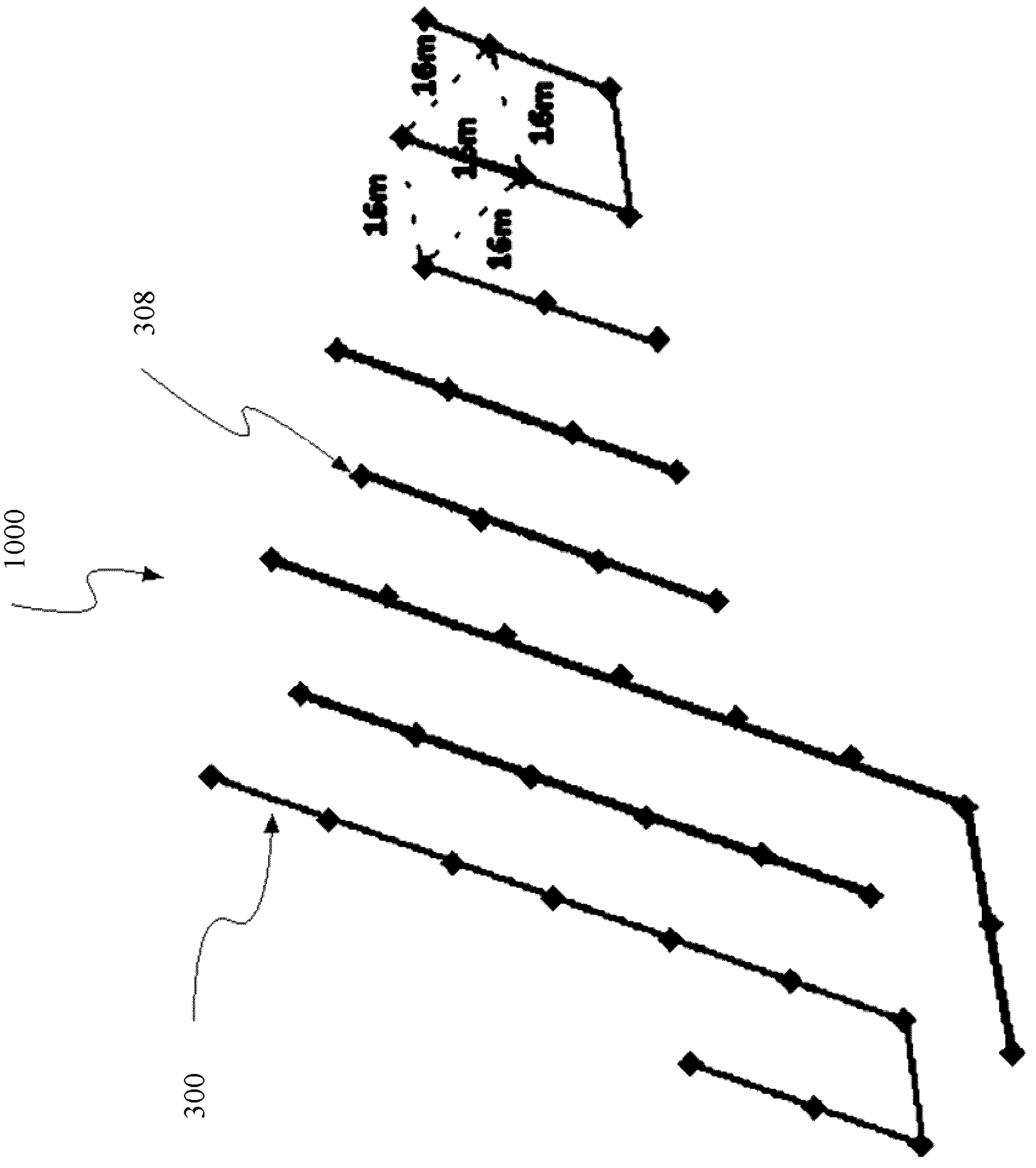

FIG. 10

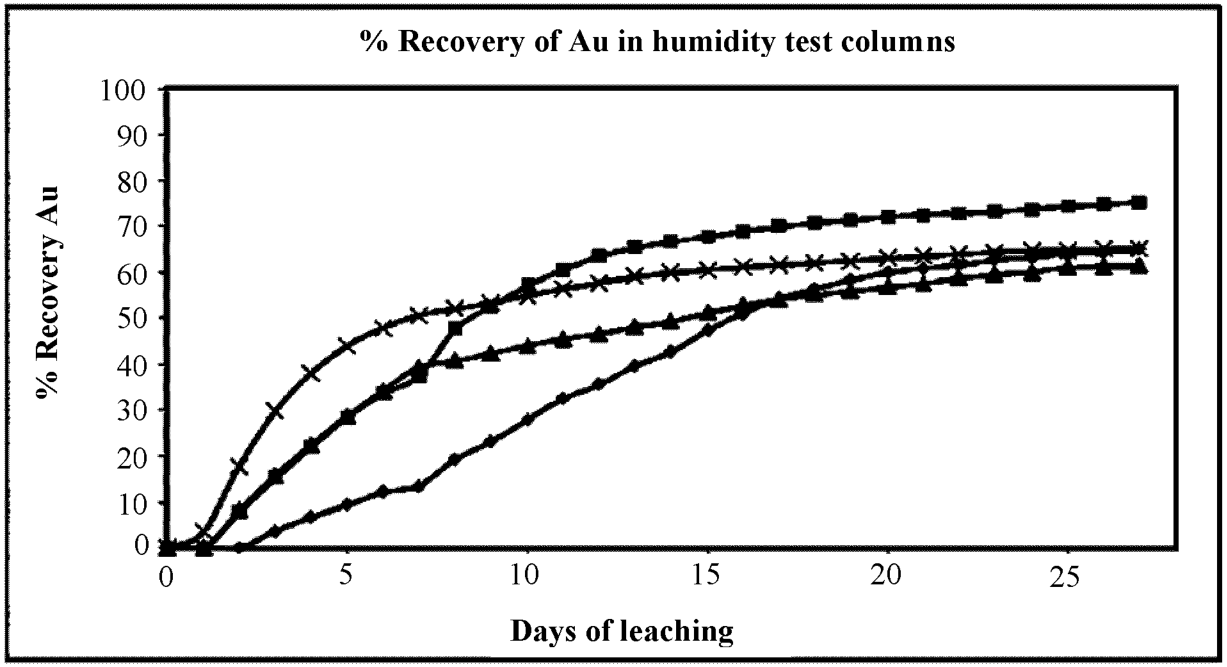

FIG. 11a

Ruler rate 4, 8, 16 lt/hr.m2	% Recovery Au	% Recovery Ag	% Recovery Cu	Kg NaCN/Ton
Moisture column test 1	64.86	55.41	8.32	0.52
Moisture column test 2	75.32	62.26	9.42	0.48
Moisture column test 3	61.36	42.50	7.72	0.60
Moisture column test 4	65.23	54.00	8.93	0.50

FIG. 11b

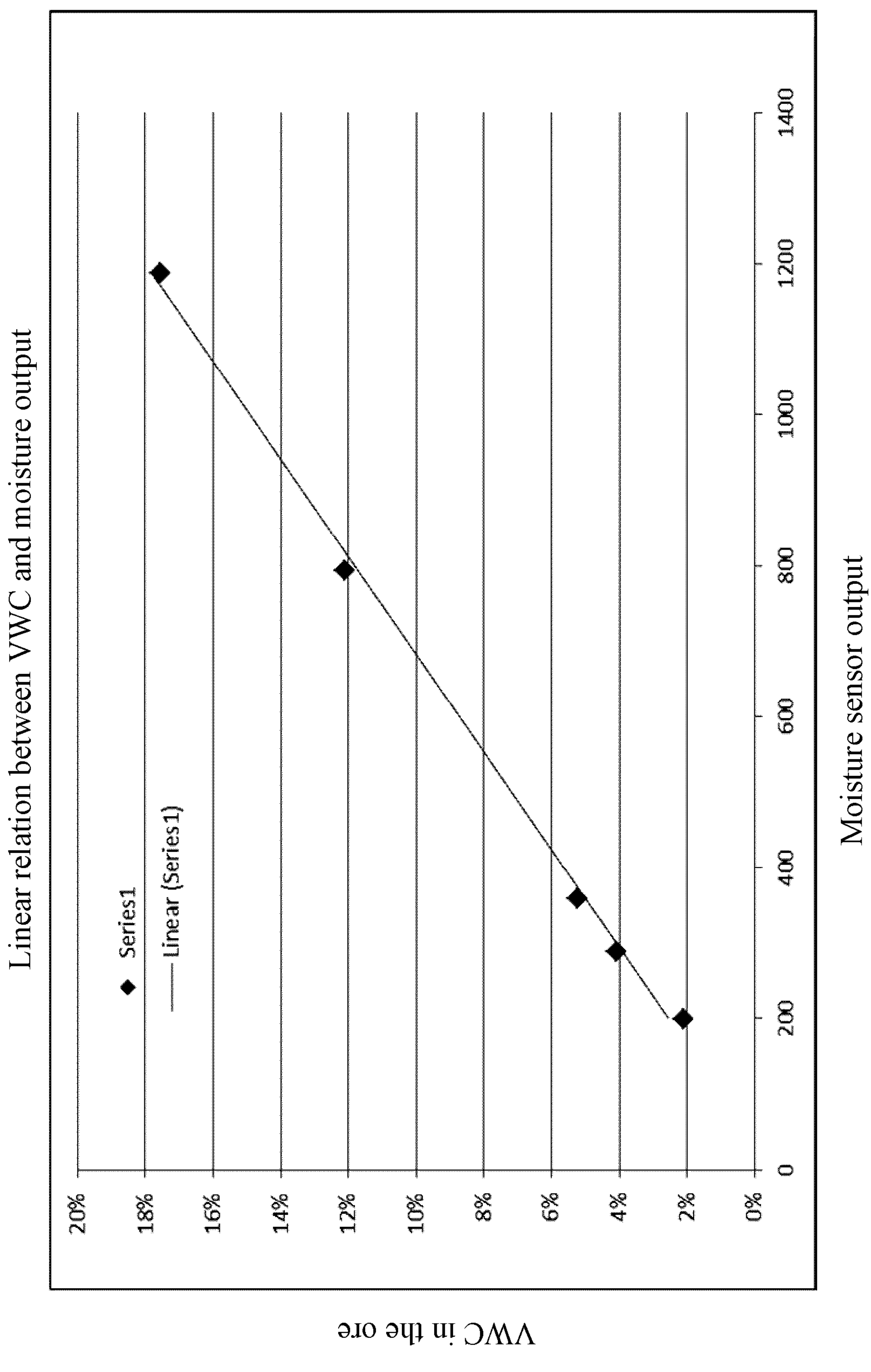
Linear relation between VWC and moisture output
Series1
Linear (Series1)
VWC in the ore
20%
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
0
200
400
600
800
1000
1200
1400
Moisture sensor output

FIG. 12

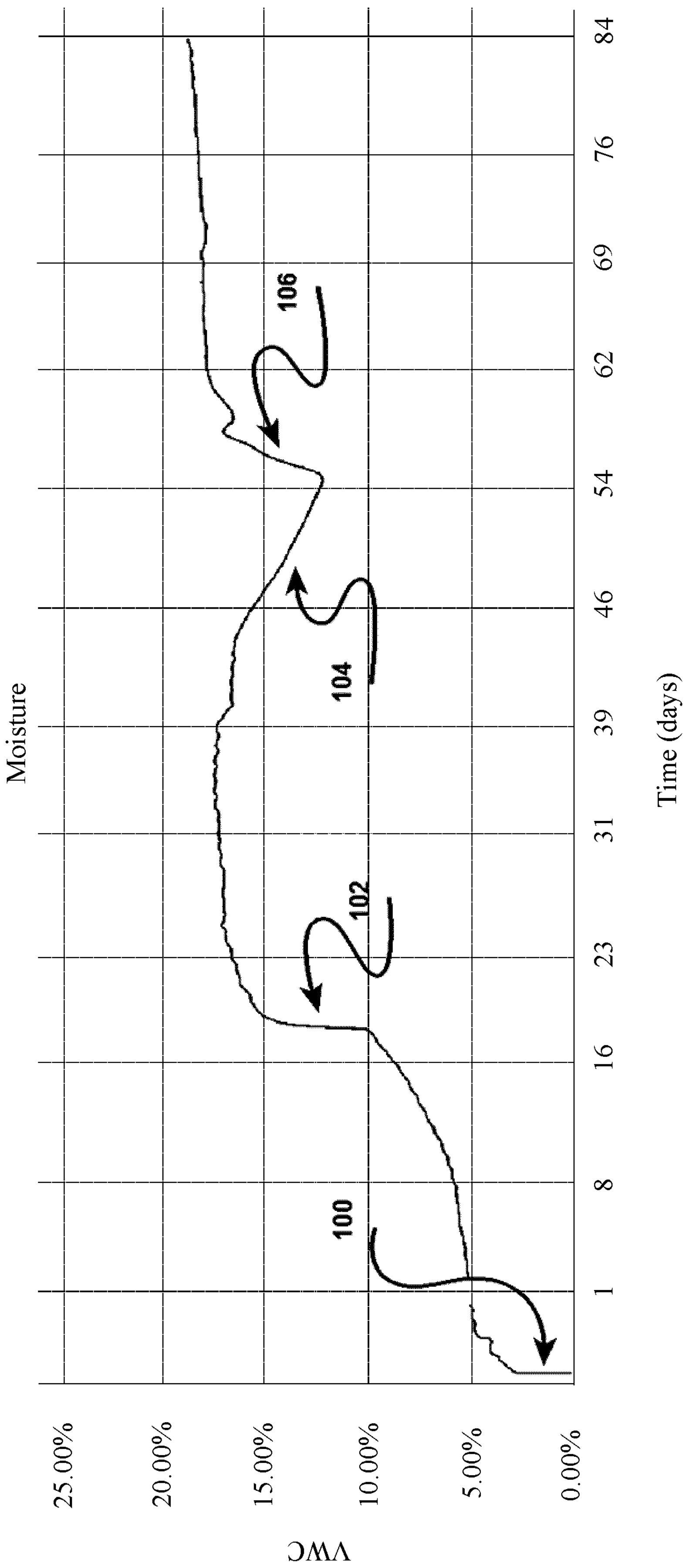
Moisture
VWC
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
Time (days)
1
8
16
23
31
39
46
54
62
69
76
84
100
102
104
106

FIG. 13

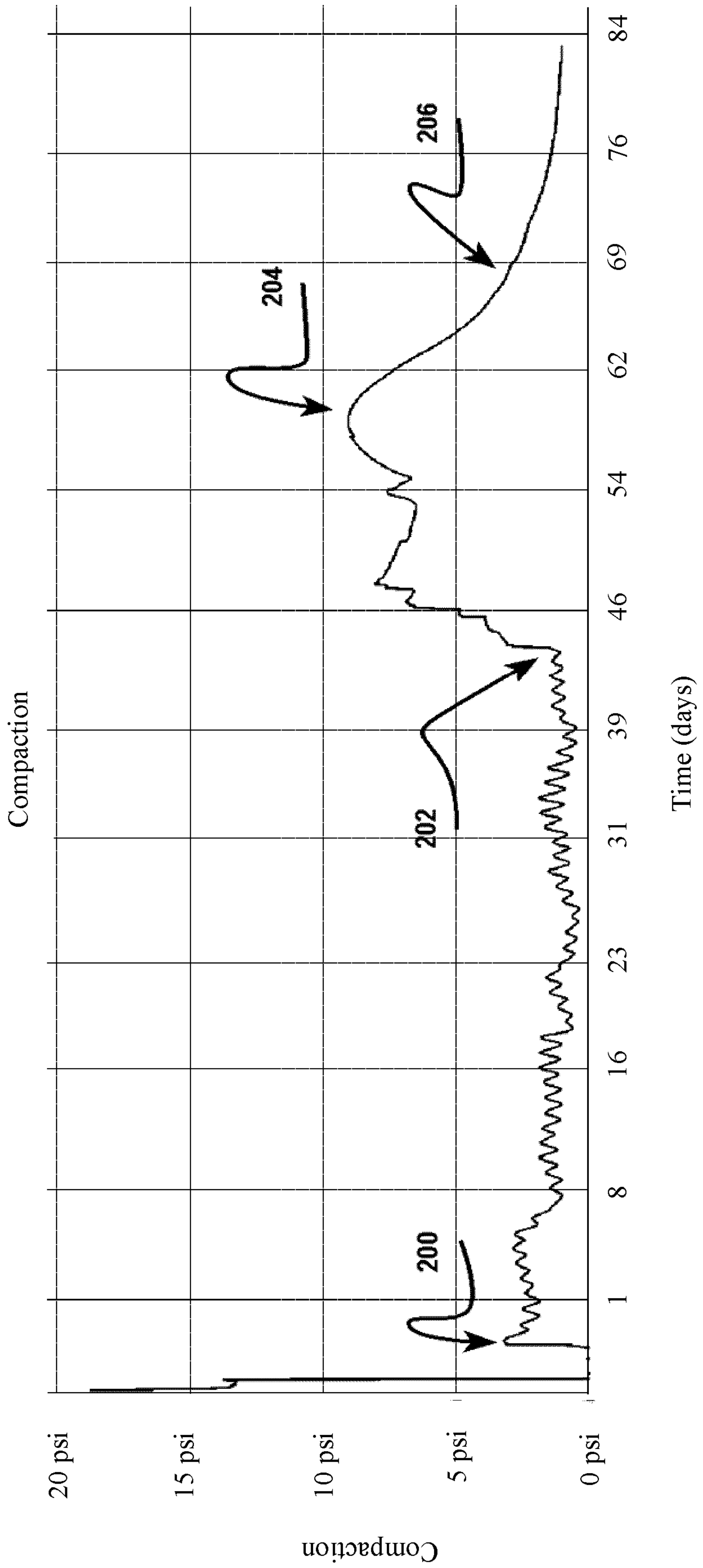
Compaction
20 psi
15 psi
10 psi
5 psi
0 psi
Compaction
1
8
16
23
31
39
46
54
62
69
76
84
Time (days)
200
202
204
206

FIG. 14

Volume Water Content (VWC)

	X1	X2	X3	X4	X5	X6	X7	X8	X9
Y0	-	-	-	-	-	-	-	-	21.1%
Y1	-	12.6%	-	20.4%	-	19.0%	-	20.6%	-
Y2	-	-	21.2%	-	20.5%	-	18.9%	-	19.6%
Y3	-	13.3%	-	17.3%	-	20.3%	-	18.7%	-
Y4	-	-	17.1%	-	19.8%	-	19.8%	-	17.8%
Y5	-	12.4%	-	21.3%	-	19.9%	-	18.5%	-
Y6	-	-	16.9%	-	20.5%	-	19.6%	-	-
Y7	-	12.0%	-	19.2%	-	26.6%	-	-	-
Y8	-	-	15.8%	-	20.7%	-	-	-	-
Y9	-	13.9%	-	20.9%	-	-	-	-	-
Y10	7.6%	-	17.6	-	-	-	-	-	-
Y11	-	11.5%	-	22.1%	-	-	-	-	-
Y12	4.9%	-	16.1%	-	-	-	-	-	-
Y13	-	31.6%	-	18.8%	-	-	-	-	-
Y14	4.5%	-	-	-	-	-	-	-	-
Y15	-	-	-	-	-	-	-	-	-

FIG. 15

Change of Volume Water Content (VWC)

	X1	X2	X3	X4	X5	X6	X7	X8	X9
Y0	-	-	-	-	-	-	-	-	0.0%
Y1	-	-0.9%	-	0.0%	-	0.0%	-	0.0%	-
Y2	-	-	-0.3%	-	0.0%	-	0.1%	-	0.0%
Y3	-	-1.0%	-	0.1%	-	0.0%	-	0.0%	-
Y4	-	-	-1.0%	-	0.0%	-	0.0%	-	0.1%
Y5	-	-0.3%	-	0.0%	-	0.0%	-	0.0%	-
Y6	-	-	-0.3%	-	0.0%	-	0.0%	-	-
Y7	-	-0.8%	-	0.1%	-	0.4%	-	-	-
Y8	-	-	-0.7%	-	0.4%	-	-	-	-
Y9	-	-0.4%	-	-0.1%	-	-	-	-	-
Y10	-0.1%	-	-0.9	-	-	-	-	-	-
Y11	-	0.1%	-	0.1%	-	-	-	-	-
Y12	0.0%	-	-1.9%	-	-	-	-	-	-
Y13	-	0.0%	-	0.0%	-	-	-	-	-
Y14	0.0%	-	-0.8%	-	-	-	-	-	-
Y15	-	-	-	-	-	-	-	-	-

FIG. 16

Compaction

	X1	X2	X3	X4	X5	X6	X7	X8	X9
Y0	-	-	-	-	-	-	-	-	0.9 psi
Y1	-	9.7 psi	-	1.0 psi	-	-1.0 psi	-	-1.4 psi	-
Y2	-	-	3.1 psi	-	0.5 psi	-	-0.8 psi	-	-0.9 psi
Y3	-	6.1 psi	-	0.4 psi	-	-0.4 psi	-	-2.8 psi	-
Y4	-	-	0.7 psi	-	-1.4 psi	-	-	-	-1.9 psi
Y5	-	10.2 psi	-	0.6 psi	-	0.0 psi	-	-1.5 psi	-
Y6	-	-	3.1 psi	-	0.0 psi	-	-	-	-
Y7	-	5.8 psi	-	0.4 psi	-	-1.1 psi	-	-	-
Y8	-	-	2.9 psi	-	-1.1 psi	-	-	-	-
Y9	-	7.3 psi	-	-	-	-	-	-	-
Y10	2.3 psi	-	4.5 psi	-	-	-	-	-	-
Y11	-	9.9 psi	-	-1.2 psi	-	-	-	-	-
Y12	8.9 psi	-	3.7 psi	-	-	-	-	-	-
Y13	-	-	-	0.2 psi	-	-	-	-	-
Y14	9.2 psi	-	-	-	-	-	-	-	-
Y15	-	-	-	-	-	-	-	-	-

FIG. 17

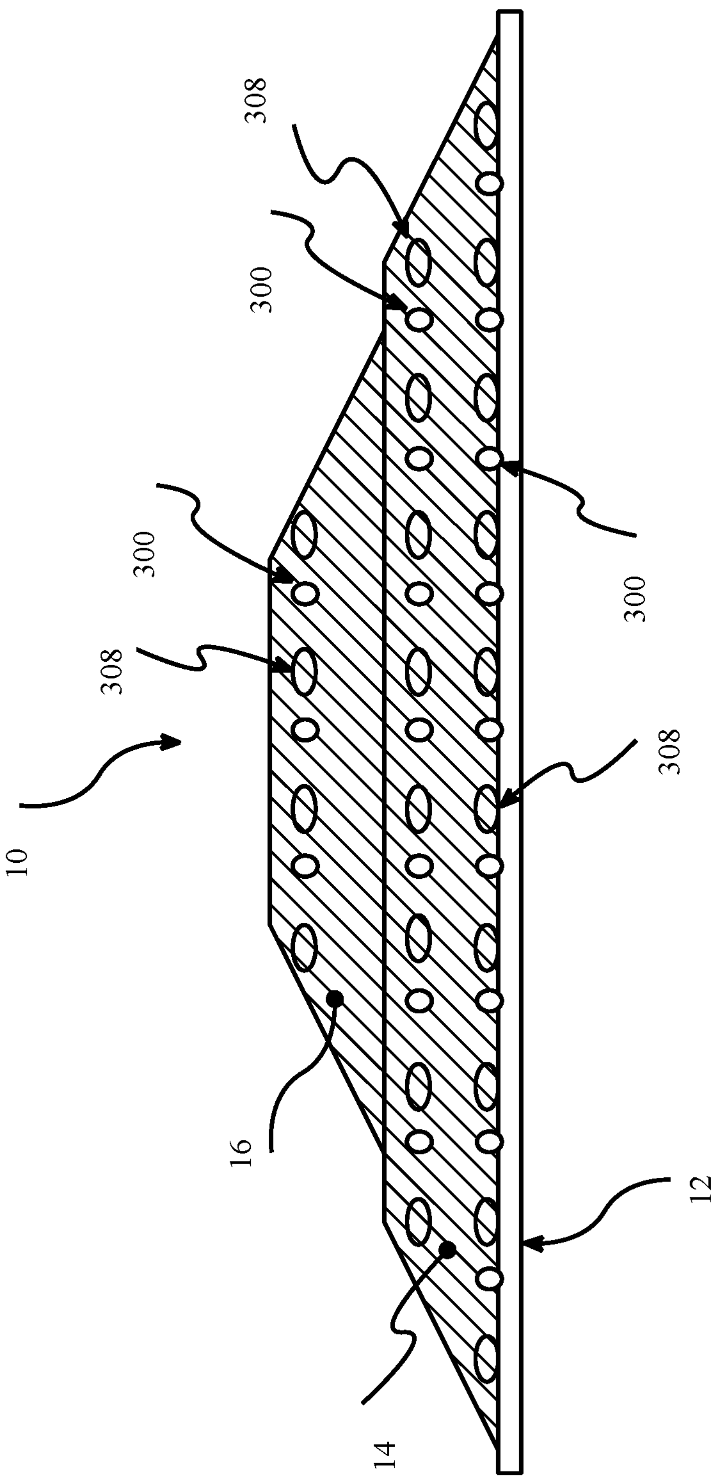

FIG. 18

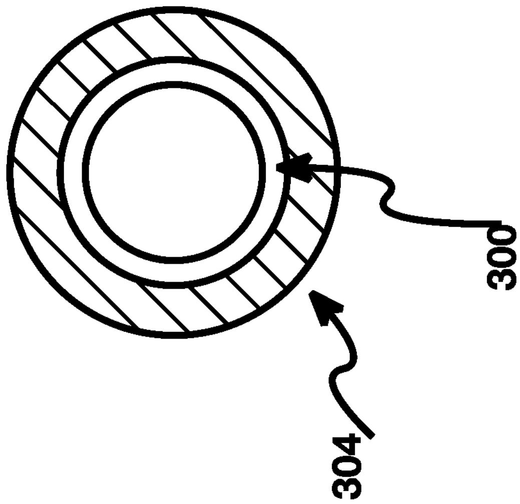

FIG. 20

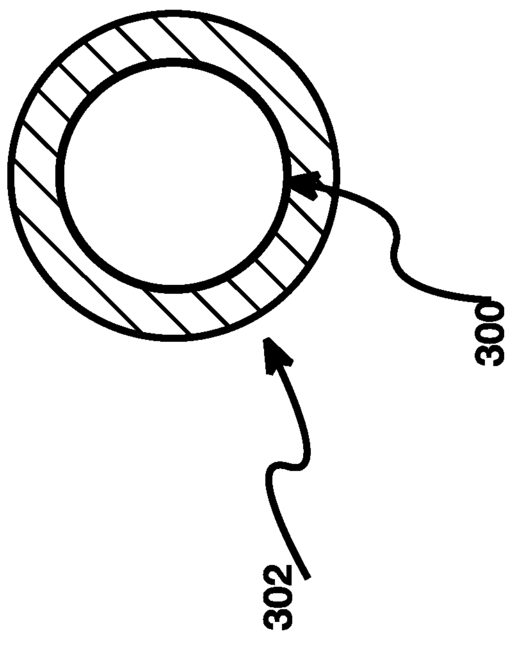

FIG. 19

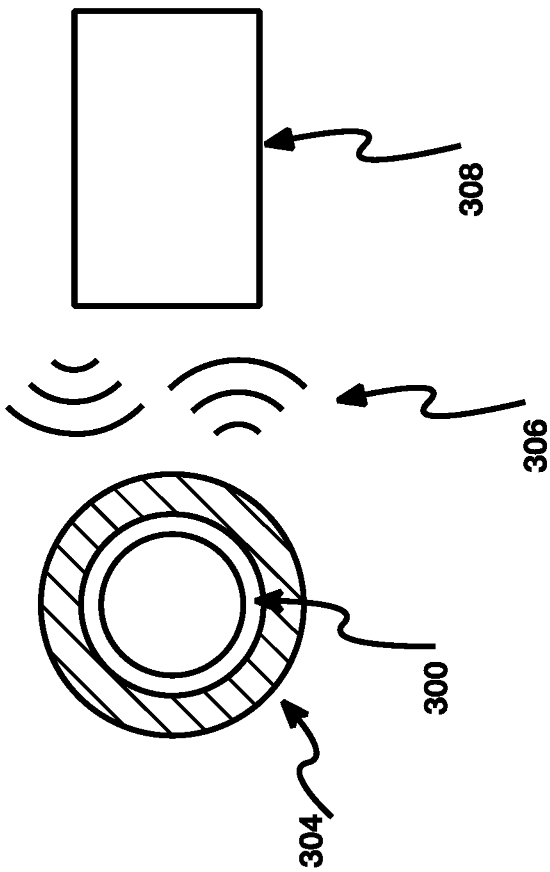

FIG. 21

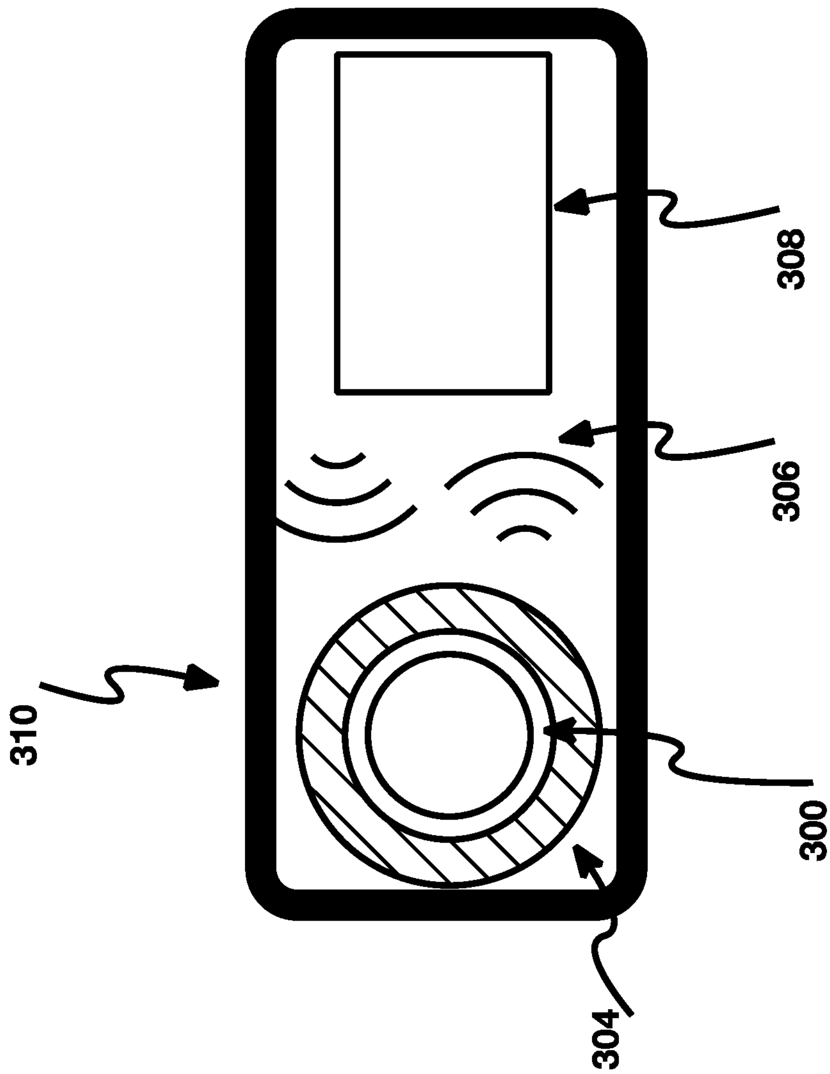

FIG. 22a

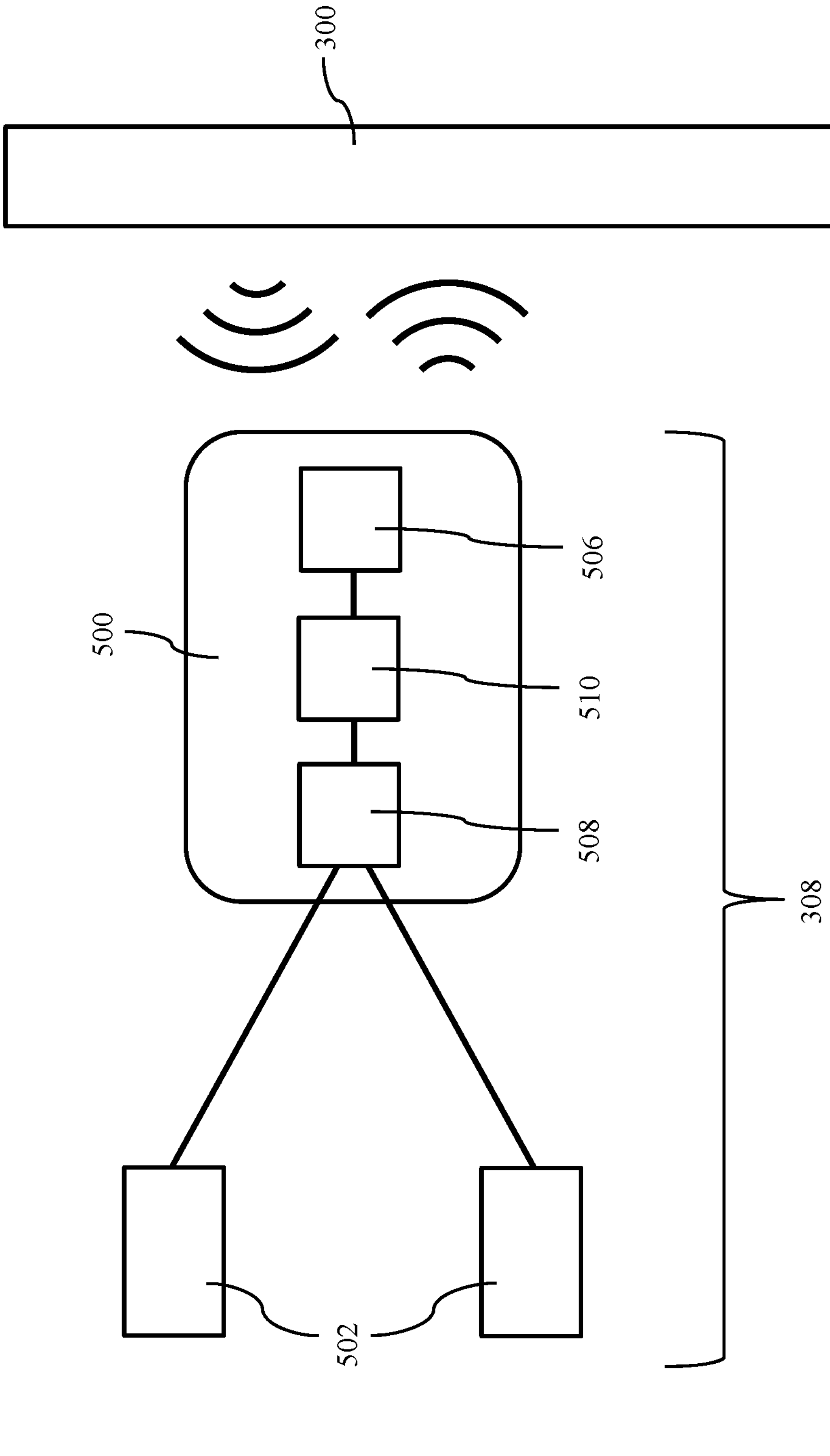

FIG. 22b

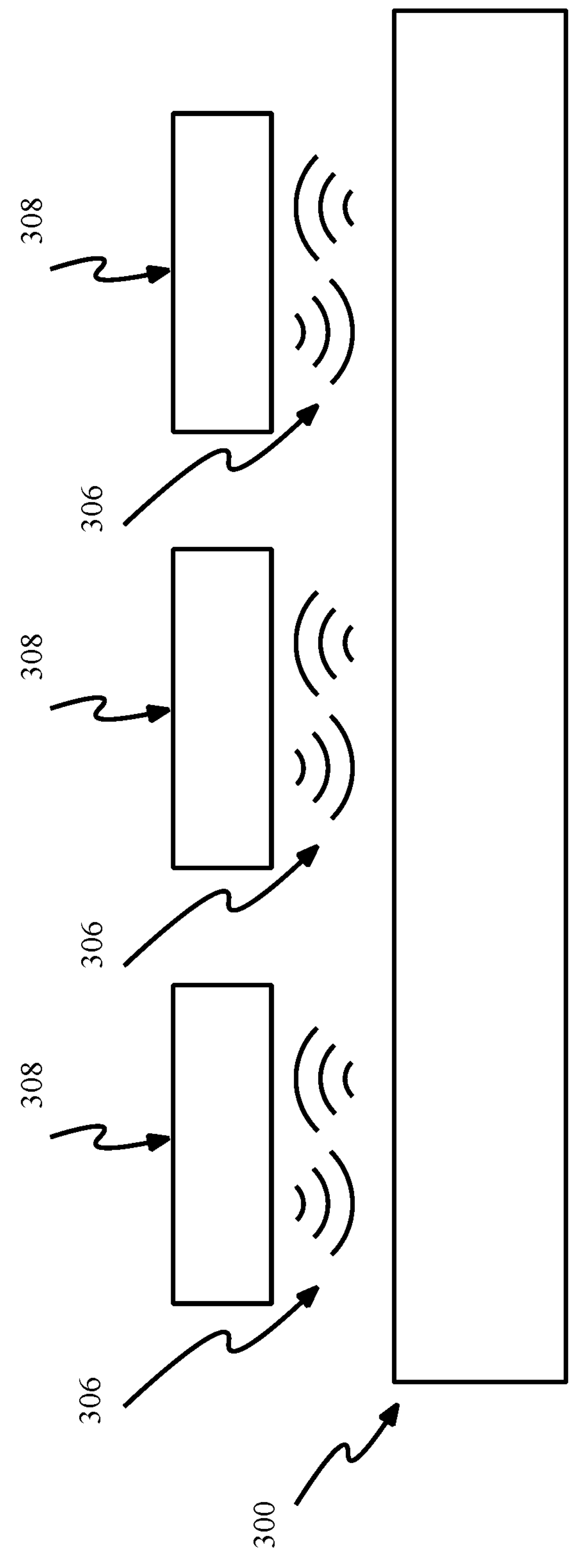

FIG. 23

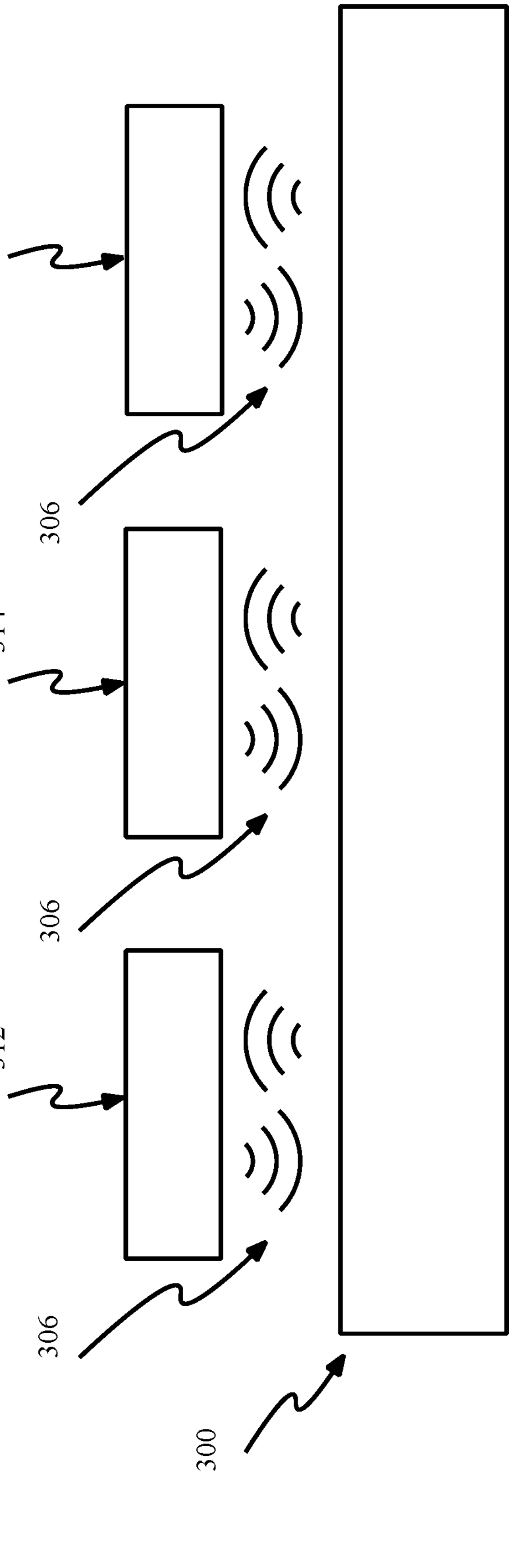

FIG. 24

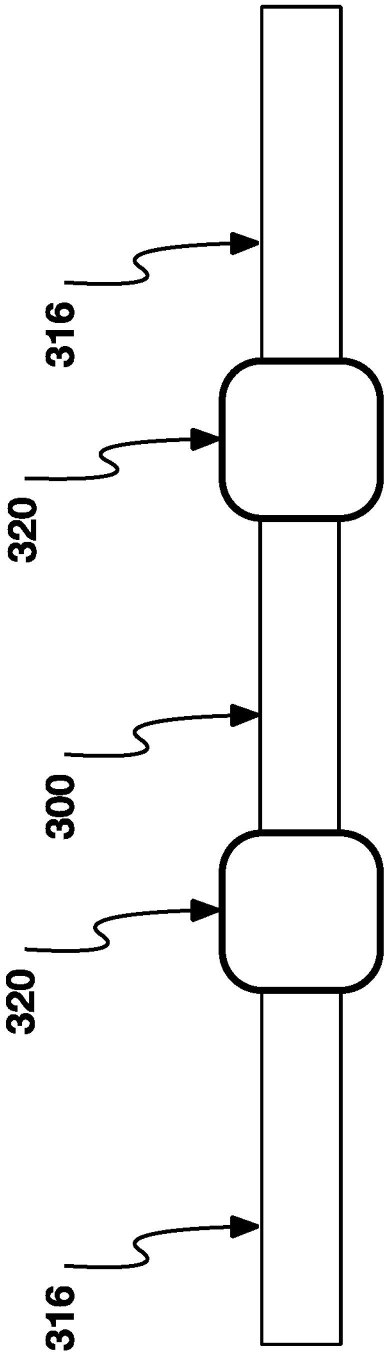

FIG. 25

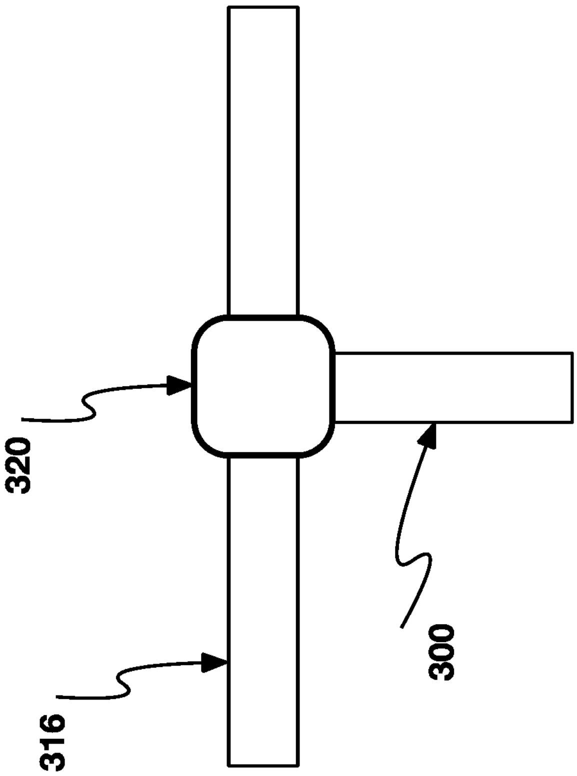

FIG. 26

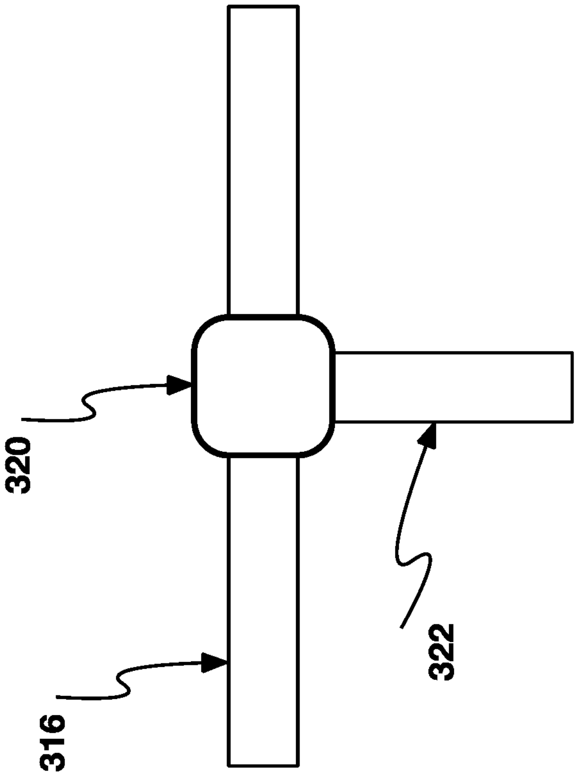

FIG. 27

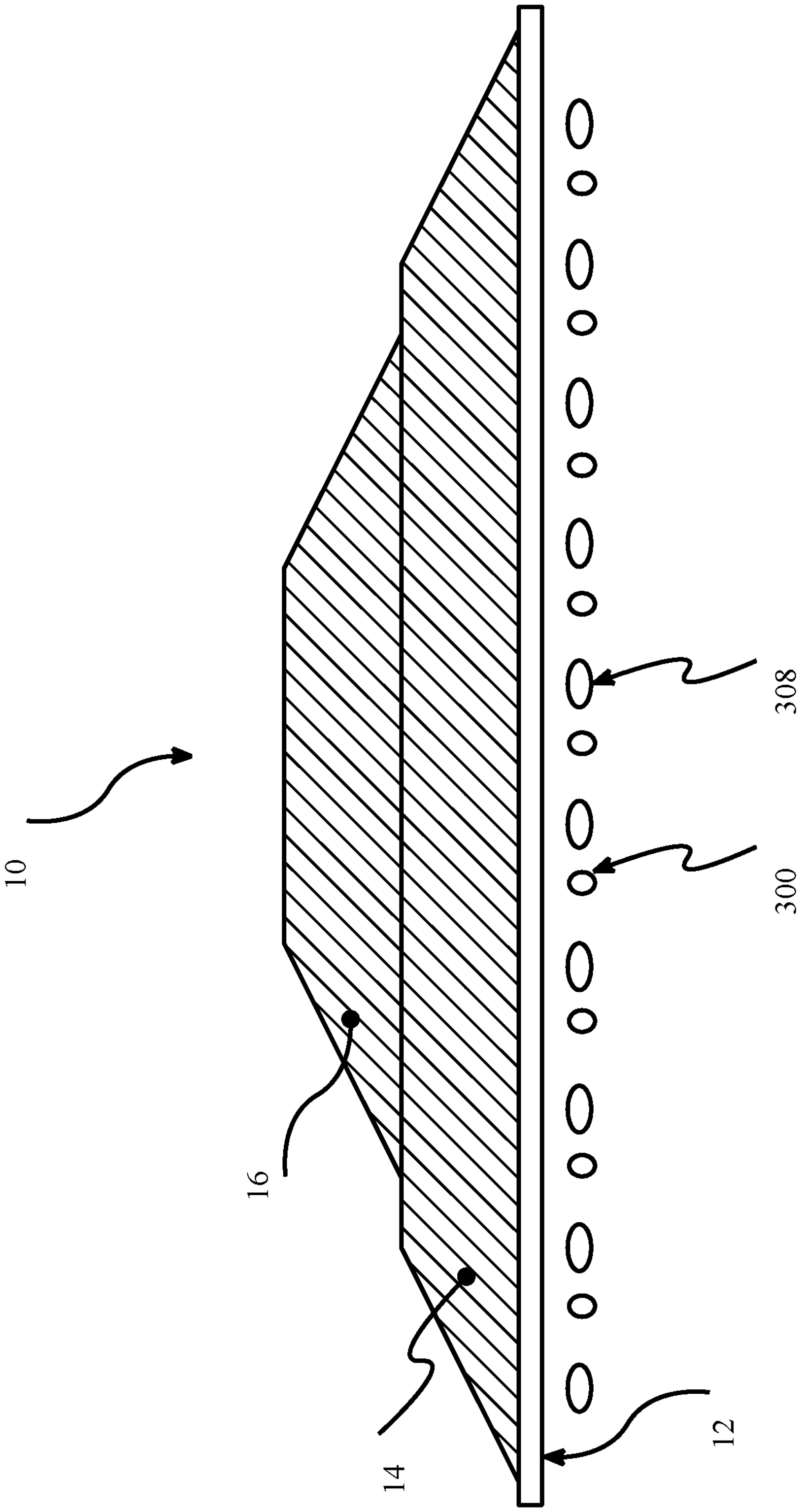

FIG. 28

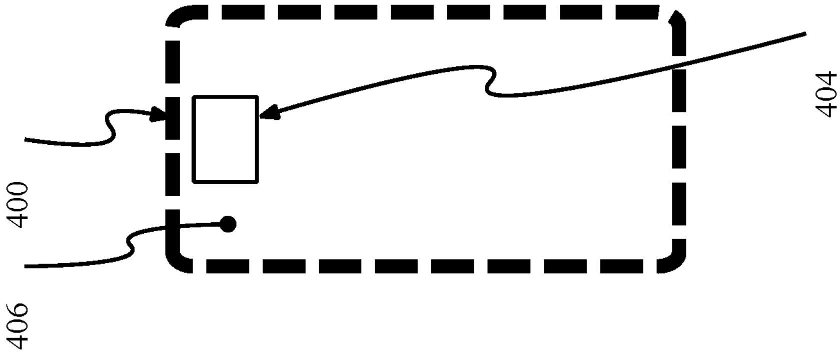

FIG. 30

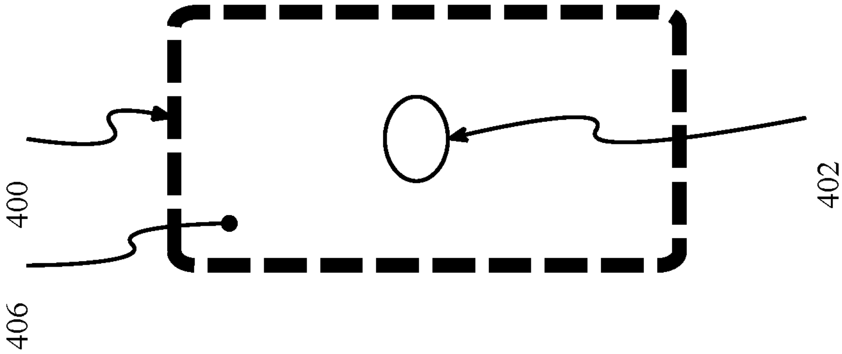

FIG. 29

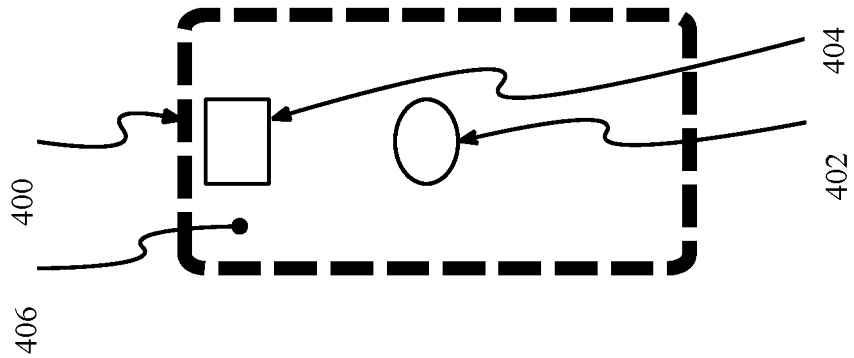

FIG. 31

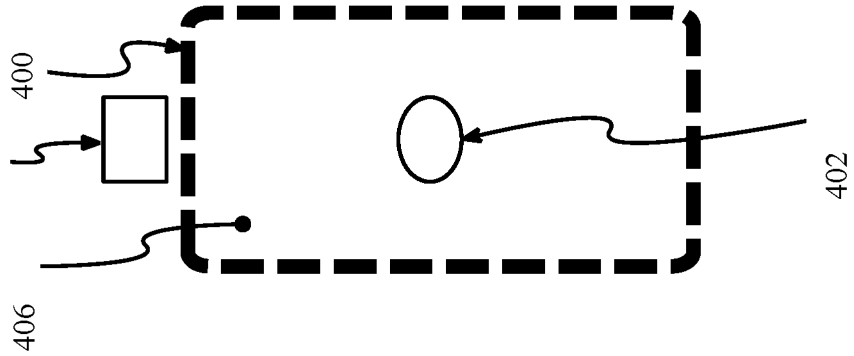

FIG. 32

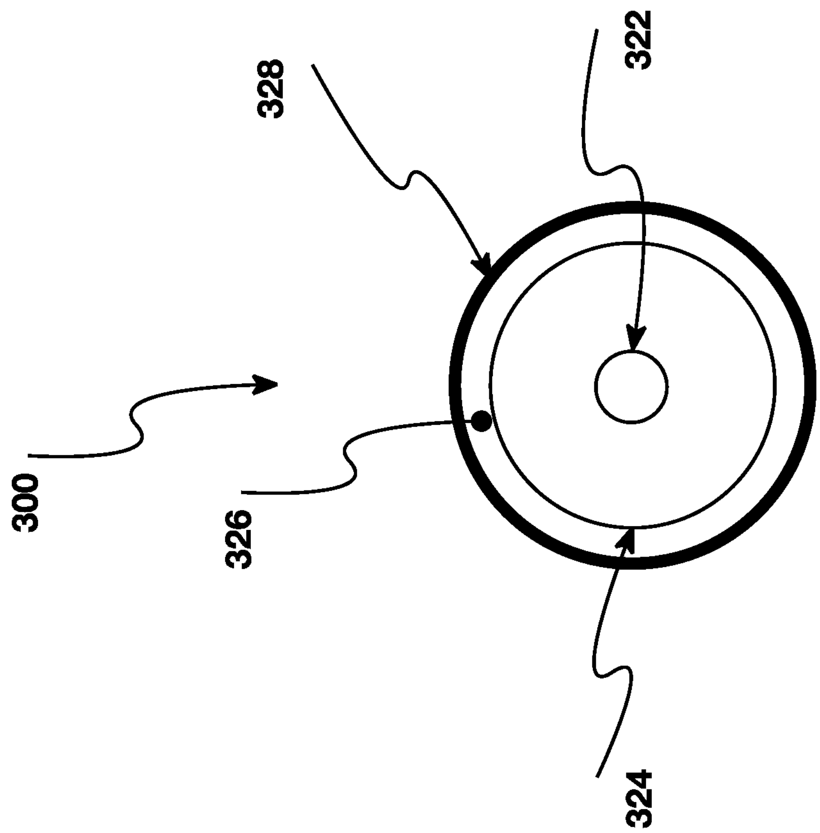

FIG. 33

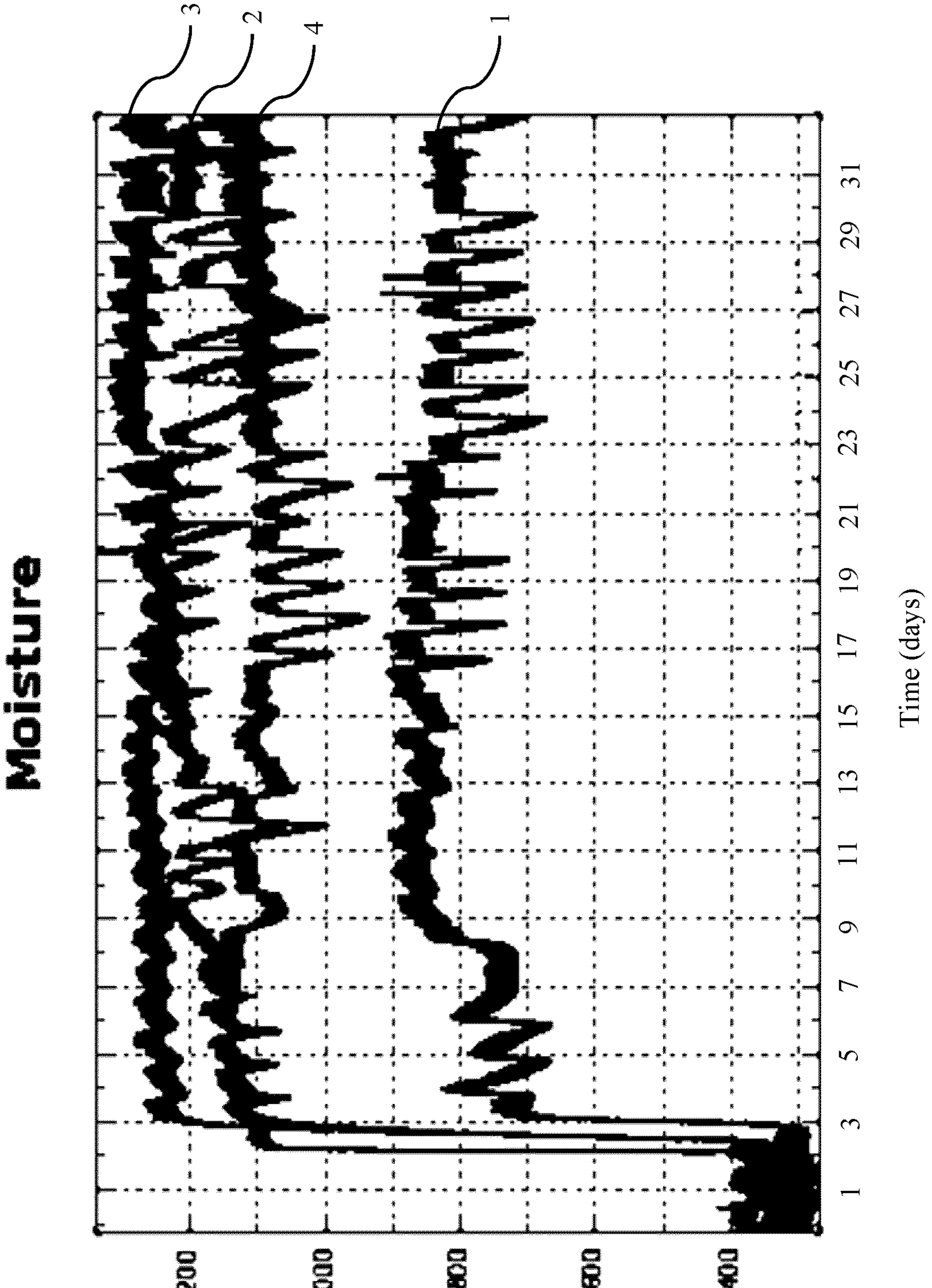
Moisture
1200
1000
800
600
400
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Time (days)
3
2
4
1

FIG. 34

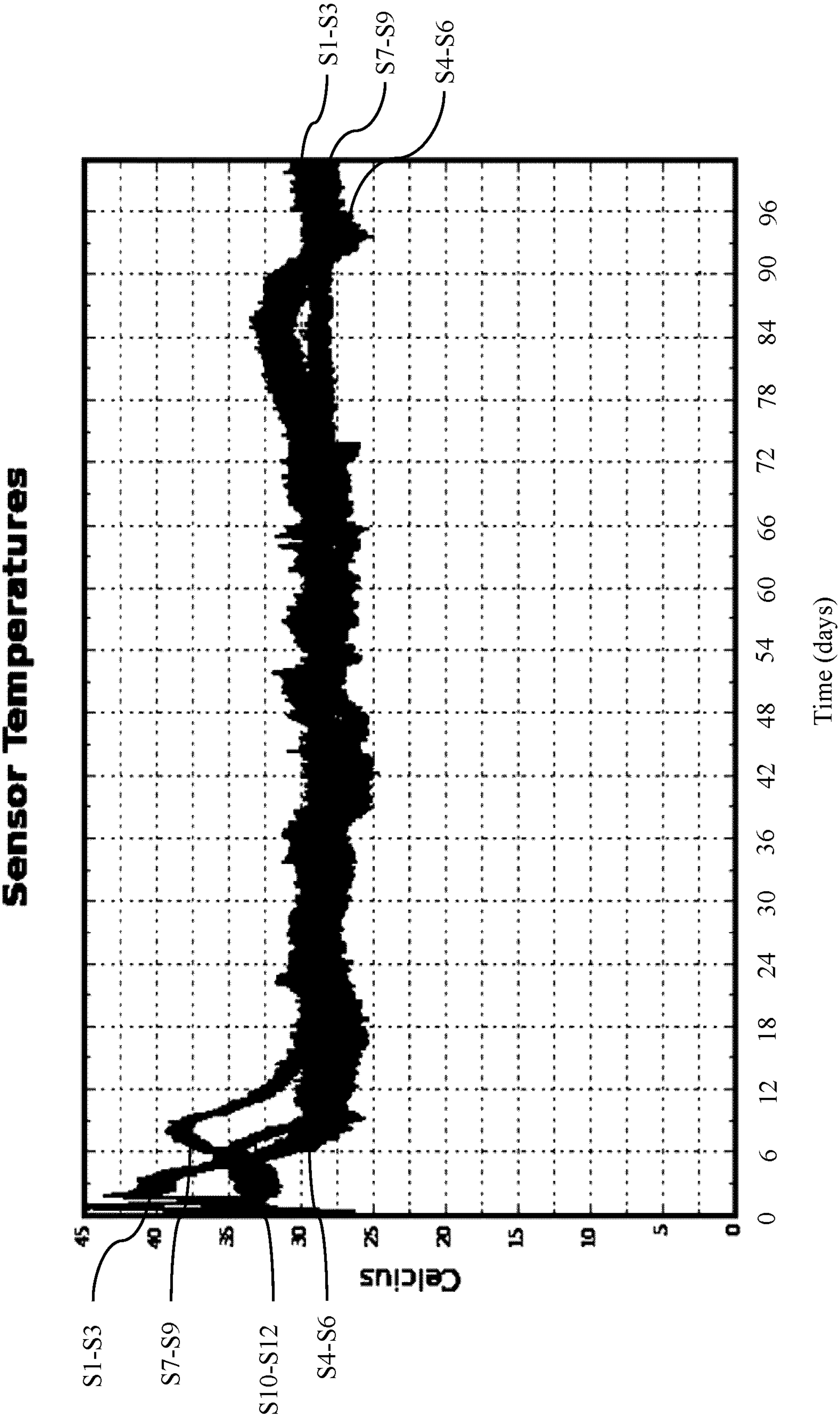
Sensor Temperatures
Celcius
Time (days)
0
5
10
15
20
25
30
35
40
45
0
6
12
18
24
30
36
42
48
54
60
66
72
78
84
90
96
S1-S3
S7-S9
S10-S12
S4-S6
S1-S3
S7-S9
S4-S6

FIG. 35

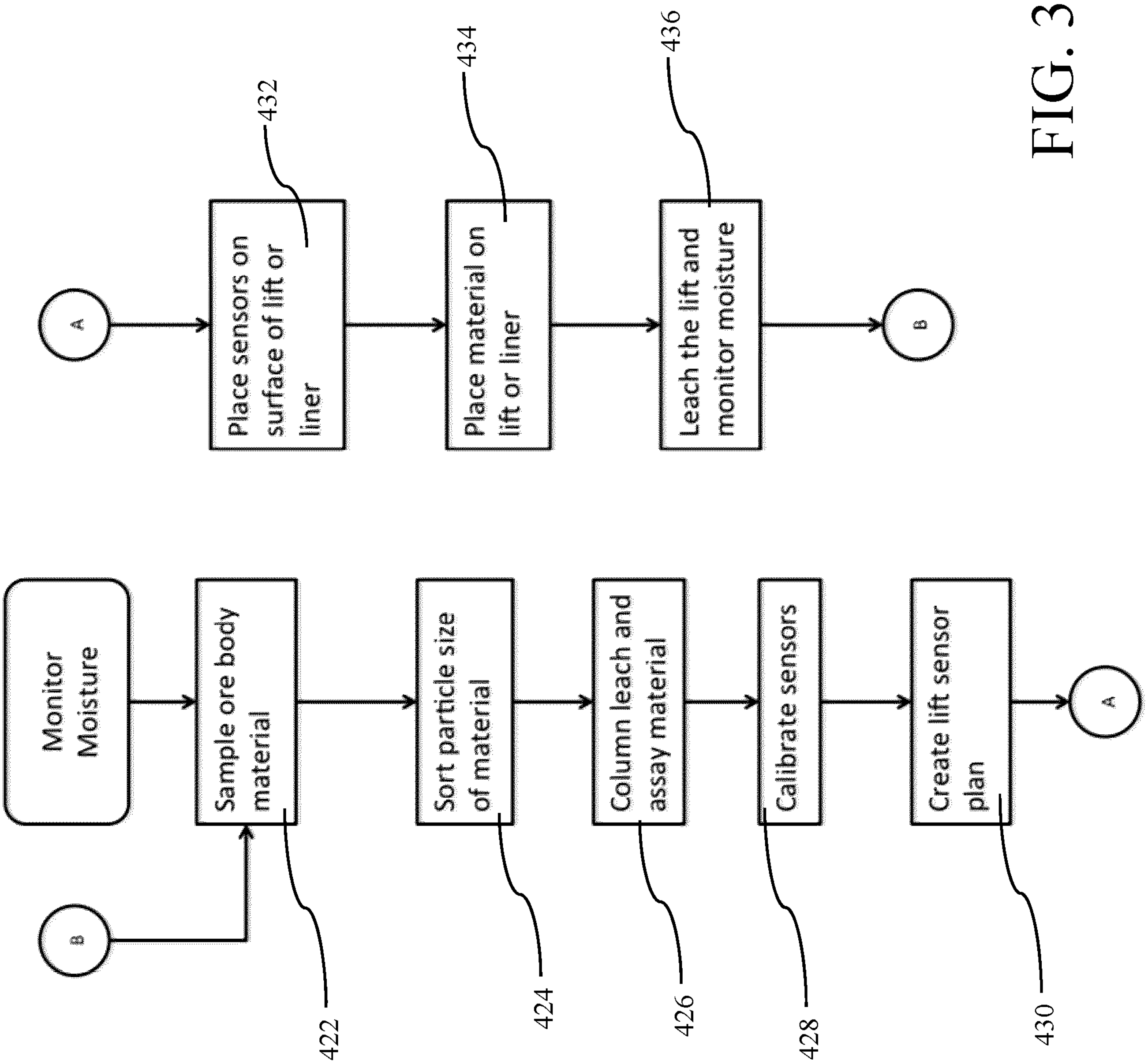
Monitor Moisture
Sample ore body material
422
Sort particle size of material
424
Column leach and assay material
426
Calibrate sensors
428
Create lift sensor plan
430
A
B
Place sensors on surface of lift or liner
432
Place material on lift or liner
434
Leach the lift and monitor moisture
436
B

FIG. 36

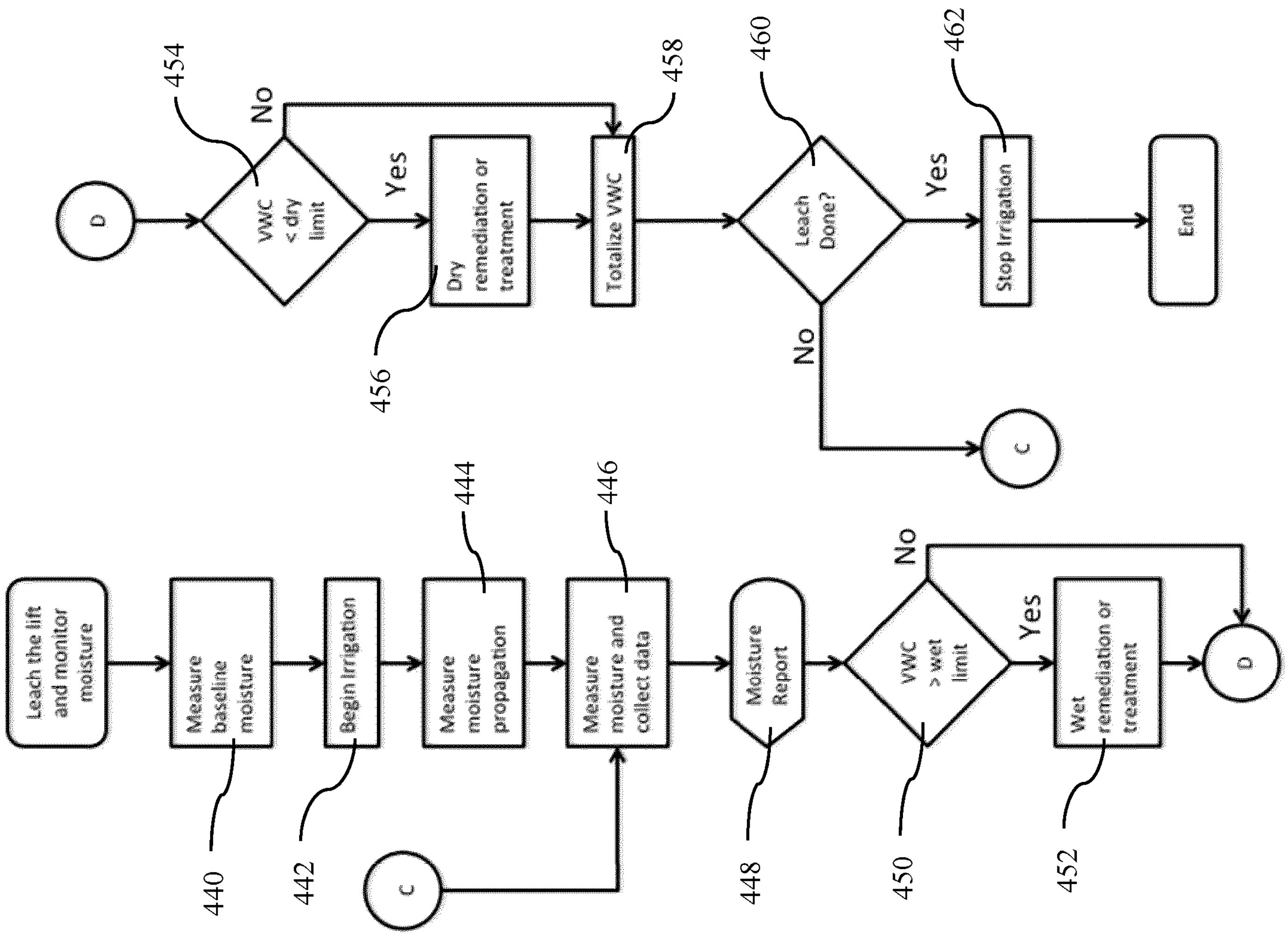
Leach the lift and monitor moisture
Measure baseline moisture
440
Begin Irrigation
442
Measure moisture propagation
444
Measure moisture and collect data
446
C
Moisture Report
448
VWC > wet limit
450
No
Yes
Wet remediation or treatment
452
D
D
VWC < dry limit
454
No
Yes
Dry remediation or treatment
456
Totalize VWC
458
Leach Done?
460
No
C
Yes
Stop Irrigation
462
End

FIG. 37

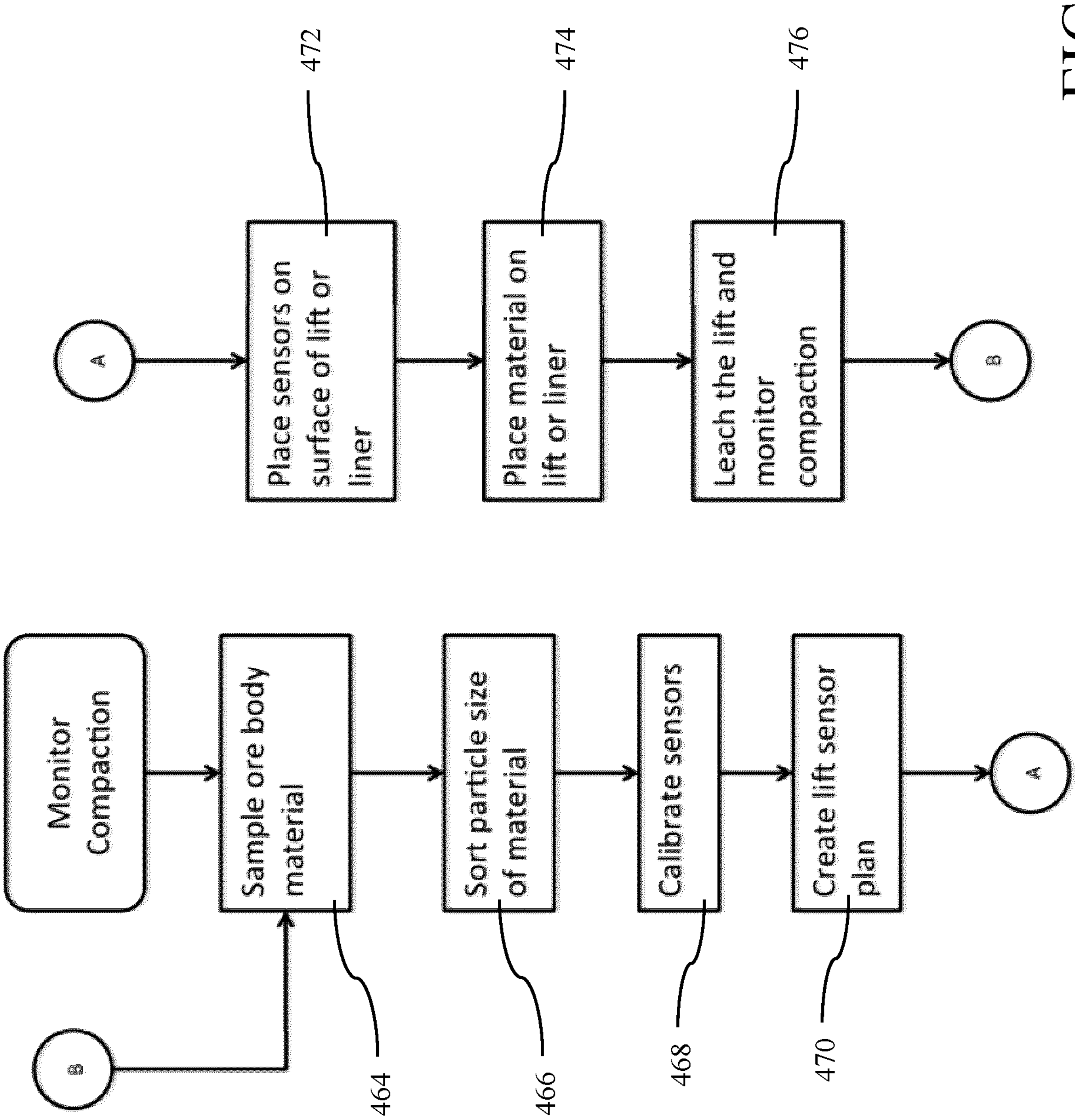
Monitor Compaction
Sample ore body material
Sort particle size of material
Calibrate sensors
Create lift sensor plan
A
B
464
466
468
470
A
Place sensors on surface of lift or liner
Place material on lift or liner
Leach the lift and monitor compaction
B
472
474
476

FIG. 38

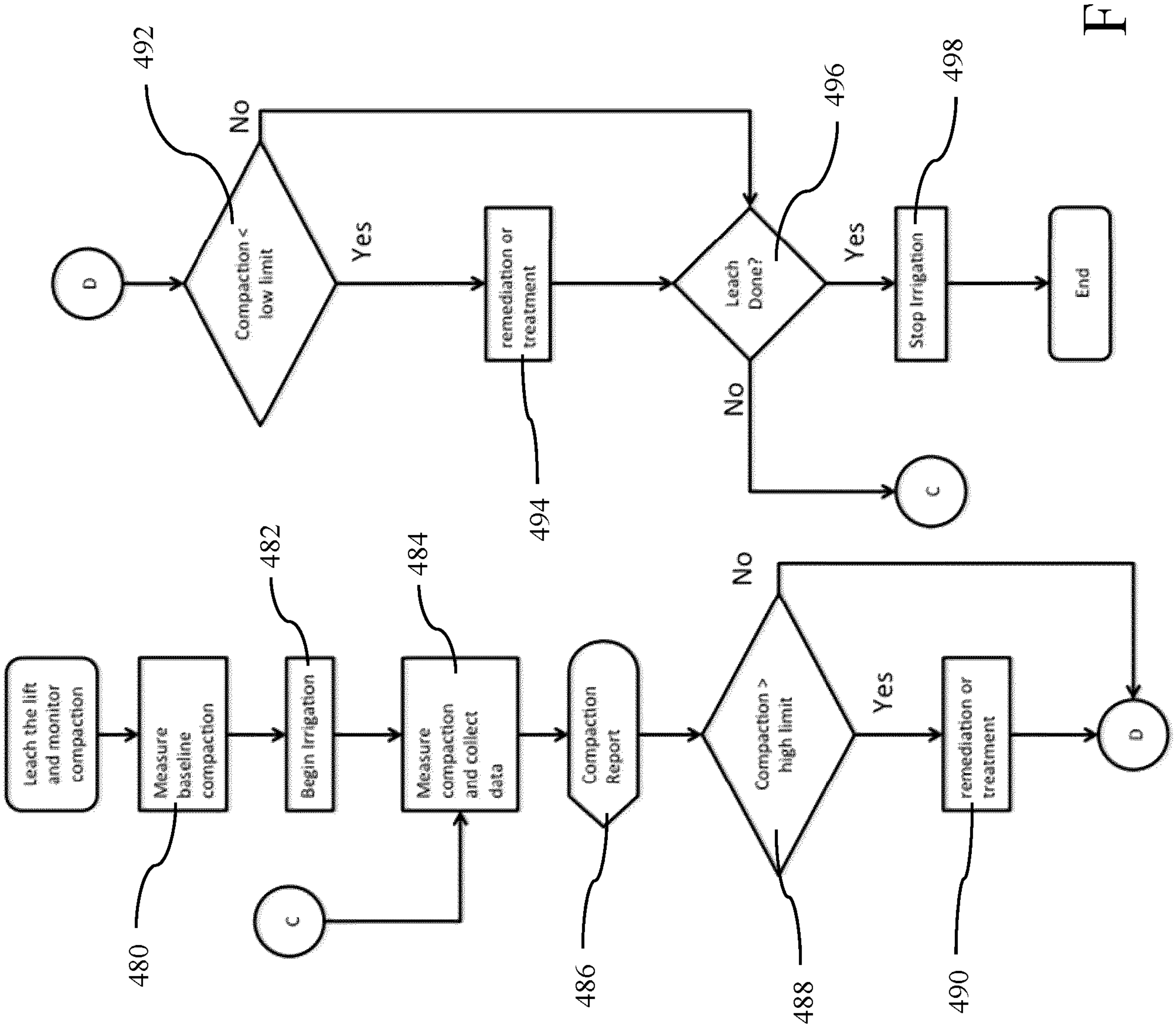
Leach the lift and monitor compaction
Measure baseline compaction
Begin Irrigation
Measure compaction and collect data
Compaction Report
Compaction > high limit
Yes
No
remediation or treatment
D
C
480
482
484
486
488
490
Compaction < low limit
Yes
No
remediation or treatment
Leach Done?
Yes
No
Stop Irrigation
End
492
494
496
498

FIG. 39

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2016/051454

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***G01D 21/00*** (2006.01) , ***E02D 17/00*** (2006.01) , ***G01N 37/00*** (2006.01) , ***G08C 17/02*** (2006.01) , *H01Q 13/12* (2006.01)

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: G01D 21/00 (2006.01) , E02D 17/00 (2006.01) , G01N 37/00 (2006.01) , G08C 17/02 (2006.01) , H01Q 13/12 (2006.01)

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

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Google Patents, Questel Orbit
Keywords, soil, sensor, moisture, leaky cable, coax, tailing, array, heap,

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	DE 10245411 B3 (BRANDELIK et al.) 24 June 2004 (24-06-2004) Paragraphs 0002-0006 and 0013-0017 Figure 1	1, 2, 4-10, 17, 18, and 20-26
Y	US 2010/0283584 (McALLISTER et al.) 11 November 2010 (11-11-2010) Paragrpahs 0202-0207 Figures 8-10	1, 2, 4-10, 17, 18, and 20-26
A	CN 201993108 U (HUI et al.) 28 September 2011 (28-09-2011) The entire document	1 - 32
A	US 4341112 A (MACKAY et al.) 27 July 1982 (27-07-1982)	1 - 32

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

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

Date of the actual completion of the international search
30 January 2017 (30-01-2017)

Date of mailing of the international search report
02 February 2017 (02-02-2017)

Name and mailing address of the ISA/CA
Canadian Intellectual Property Office
Place du Portage I, C114 - 1st Floor, Box PCT
50 Victoria Street
Gatineau, Quebec K1A 0C9
Facsimile No.: 819-953-2476

Authorized officer

Timothy Kotylak (819) 639-8171

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
DE10245411B3	24 June 2004 (24-06-2004)	DE10245411B3	24 June 2004 (24-06-2004)
		AT501580A1	15 September 2006 (15-09-2006)
		AT501580B1	15 October 2007 (15-10-2007)
		CH696559A5	31 July 2007 (31-07-2007)
US2010283584A1	11 November 2010 (11-11-2010)	US2010283584A1	11 November 2010 (11-11-2010)
		US8228198B2	24 July 2012 (24-07-2012)
		US2007125836A1	07 June 2007 (07-06-2007)
		US7551087B2	23 June 2009 (23-06-2009)
		US2007040684A1	22 February 2007 (22-02-2007)
		US7830258B2	09 November 2010 (09-11-2010)
		US2011018689A1	27 January 2011 (27-01-2011)
		US8159349B2	17 April 2012 (17-04-2012)
		US2010289627A1	18 November 2010 (18-11-2010)
		US8917159B2	23 December 2014 (23-12-2014)
		US2012256732A1	11 October 2012 (11-10-2012)
		US9272805B2	01 March 2016 (01-03-2016)
		US2009314829A1	24 December 2009 (24-12-2009)
		US2010001848A1	07 January 2010 (07-01-2010)
		US2016162773A1	09 June 2016 (09-06-2016)
		WO2012011979A1	26 January 2012 (26-01-2012)
CN201993108U	28 September 2011 (28-09-2011)	None	
US4341112A	27 July 1982 (27-07-1982)	US4341112A	27 July 1982 (27-07-1982)
		CA1130863A	31 August 1982 (31-08-1982)