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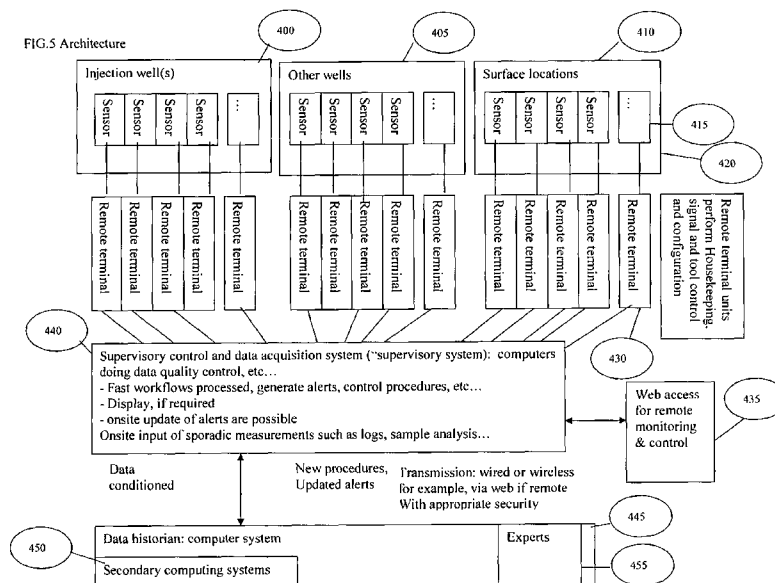
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(54) Title: METHOD, APPARATUS AND SYSTEM FOR A SUPERVISORY SYSTEM FOR CARBON SEQUESTRATION

(57) Abstract: A method of sequestering CO₂ comprises collecting carbon dioxide and preparing the carbon dioxide for sequestration, selecting a storage site, obtaining permits for using the storage site for sequestration, preparing the storage site, transporting the carbon dioxide to the storage site, measuring the carbon dioxide as desirable, and placing and monitoring CO₂, using a real time monitoring, analysis and optimization system.



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METHOD, APPARATUS AND SYSTEM FOR A SUPERVISORY SYSTEM FOR CARBON SEQUESTRATION

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] This invention relates to improved methods and systems for use in carbon sequestration. In particular, the invention provides methods, apparatuses and systems for more effectively and efficiently transporting, measuring, sequestering carbon, as well as carbon sequestration site selection, carbon sequestration site preparation, carbon sequestration site design, decommissioning a carbon sequestration site and providing post-decommissioning monitoring of the carbon sequestration site.

Background of the Invention

[0002] Addition of carbon dioxide (CO₂, properly but sometimes written herein as “CO2” for ease of formatting) to the atmosphere, for example by burning fossil fuels such as oil, natural gas and coal, is believed to contribute to global warming. Exhausts from petrochemical and other manufacturing plants may also be sources of CO₂ additions to the atmosphere. Of course, one could collect the CO₂ for commercial use or use it to enhance agricultural production in greenhouses. But sequestering CO₂, that is, placing and storing CO₂ at a location where the CO₂ cannot enter the atmosphere, is a way of mitigating the possible effect of additions of CO₂ to the atmosphere. Carbon dioxide sequestration is also referred to as “carbon sequestration.” Carbon capture and storage (CCS) is capture and isolation of carbon dioxide from high carbon-emitting sources, such as power

plants, and storage or sequestration in a location where the carbon dioxide will not enter the atmosphere. Other forms of carbon like carbon monoxide for example could also be sequestered in a like manner.

[0003] One could sequester CO₂ using a number of methods and locations. CO₂ may be sequestered by placing the CO₂ in the depths of the ocean (unless there are unacceptably adverse effects on ocean life) or in the sub-ocean floor such as in basalt formations. But one could also inject the CO₂ into underground formations. For example, one could inject CO₂ underground in deep saline reservoirs or depleted in hydrocarbon (oil and/or natural gas (gas)) reservoirs. One could inject CO₂ into underground coal beds (displacing natural gas, which may then be produced) or into peridotite formations. One could use the CO₂ for enhanced oil recovery (EOR) or enhanced gas recovery (EGR) by injecting the CO₂ via one or more injection wells into reservoirs containing hydrocarbons and using the CO₂ to facilitate mobilization of the hydrocarbons towards one or more producing wells.

[0004] Selecting appropriate reservoirs for sequestration pose special challenges. The reservoir would have to have adequate capacity for storage of the desired amount of CO₂. The reservoir should have a trapping mechanism to keep the CO₂ in place and prevent its migration to the surface.

[0005] A “formation” is a “body of rock that is sufficiently distinctive and continuous that it can be mapped.” (This and other definitions in this paragraph are taken from the Schlumberger Oilfield Glossary (“Glossary”), available online at <http://www.glossary.oilfield.slb.com>). Underground formations are comprised of

rock which, in turn, are composed of rock grains (of one or more minerals) and pore spaces. (Coal is an exception as it is a rock composed of organic material, not minerals which are inorganic.) An underground reservoir is an underground formation “with sufficient porosity and permeability to store and transmit fluids.” A formation suitable for CO₂ sequestration would likely be a reservoir, but the terms are sometimes used interchangeably. Porosity of a formation is the percentage of space (pores) between the rock grains of the formation, space which may contain fluids (liquids, condensates or gases). Permeability is a measure of how well a rock of a formation allows fluids which occupy the pore space of the rock to flow through the rock. Fracturing, if carefully performed so as not to disturb the trapping mechanism of the reservoir, might be used to enhance injectivity.

[0006] Analysis of the formation, its composition, porosity and permeability, as well as other characteristics and surrounding lithology, may be important to the selection of an underground formation in which to sequester CO₂. The underground storage formation selected must sufficient porosity to receive the desired volume of CO₂ to be sequestered and must have sufficient permeability so that the CO₂ may be pumped into the formation and flow through the rock of the formation. The storage formation should be placed with respect to other, preferably impermeable formations so that the CO₂ would be trapped within the sequestration formation and not be able to migrate through other formations to the surface. (Though as noted above, fracturing, if carefully performed so as not to disturb the trapping mechanism of the reservoir, might be used to enhance

injectivity.) Adverse reactions of the CO₂ with minerals in the storage formation would preferably be minimized, either by selecting storage formations without minerals the CO₂ would likely adversely react with or by taking other steps to minimize such reactions or minimize their adverse effects. In addition, the environment of an underground reservoir used for carbon sequestration might have high temperatures or pressures or have other hazards such as hydrogen sulfide, which might provide challenges to the material selection, well construction and/or placement process. CO₂ combined with water can form carbonic acid, which could damage some conventional materials that might be used to transport, place or contain the CO₂, so material selection is important.

[0007] It is preferable that the CO₂ becomes affixed within the underground storage formation, such as by crystallizing in place, to minimize or prevent the possibility of the CO₂ leaking either to the surface and into the atmosphere or into formations bearing potable water. One may want to prepare surface of the sequestration location in such a way that any leakage of CO₂ to the surface after placement is easily detectable and/or mitigated. It is desirable that the site be properly decommissioned after a preferably optimum amount of CO₂ is in place and the site monitored for sometime afterwards to ensure that the CO₂ placement is stable. It is desirable to ascertain the amount, location and state of the CO₂ during the placement process, after the CO₂ has been placed and for some period thereafter to ensure public safety.

[0008] Cost is a consideration throughout the process. Budgets may have to be prepared which make provision for investigating possible sequestration sites, acquiring

rights to the desired sequestration site, capturing and treating the CO₂, transporting the CO₂ if necessary, constructing surface facilities and injection wells, monitoring and measuring the CO₂, operating the site, decommissioning the site, posting a bond if necessary to cover any post-decommissioning problems, and monitoring the CO₂ after decommissioning the site until the CO₂ is determined to be in a stable state of sequestration. Obtaining proper permission from governmental bodies and owners of the space in the reservoir must also be accomplished as part of the process. Risk analysis can also be important.

[0009] There are also many challenges with carbon sequestration that involve the collection, isolation, transport, measurement, placement and post-placement of the CO₂. CO₂ may have to be isolated, dried and/or collected, for example from the exhaust of power plants or other high volume sources of CO₂. One could sequester CO₂ while in a gaseous state but it would generally be preferable to do so while the CO₂ is in a supercritical fluid state, generally at temperatures above 31.2 °C and pressures above 72.8 atmospheres. CO₂ is generally stored in supercritical phase for efficiency reasons. CO₂ in a supercritical phase can be very dense (compared to the gaseous state of CO₂) which allows more CO₂ (in mass units) to be injected into a defined pore space in a formation. Accordingly, CO₂ may have to be converted from a gaseous state to a supercritical liquid state. On the other hand, CO₂ may also be sequestered in some other state, for example, as a CO₂-saturated brine.

[0010] In some cases, CO₂ may be sequestered close to where it is produced, but in many cases, the CO₂ may have to be transported some distance to a suitable

sequestration site. One may have to provide for buffering the CO₂ (storing the CO₂ temporarily, for example, in properly constructed vessels at a surface location) to allow for periods of down-time or disruption in the sequestration process.

[0011] When one is producing oil and gas, for example, one may obtain indirect measurements of the underground formations such as seismic surveys, logging with various types of instruments well known in the art and these may be indicative of the structure of the underground formations, their make-up (content such as sandstone, limestone, dolomite, coal beds, shale, salt, as well as other minerals and clays; formation qualities such as porosity and permeability) and/or the fluids they contain between the pore spaces of the rock particles that make up the formations.. For more direct indications, one may for example review drill cuttings carried to the surface by the drilling mud while drilling a monitoring or injection well. One may obtain a full core of a segment of a well. One might also obtain sidewall cores at various depths. One might test the pressure of or take samples of fluid in the reservoirs at one or more depths (“formation testing”). It is advantageous to confirm the accuracy of the indirect measurements by results of the more direct methods. With oil and gas production, this is accomplished by the production of oil, gas and/or other fluids at the surface. The fluids may be physically measured at the surface which provides “ground truthing” or verification that the indirect measurements are reliable.

[0012] In contrast to the production of hydrocarbons, the intention with CO₂ sequestration is that there will be nothing produced at the surface. The kind of

“ground truthing” provided by production is thus not available for the CO₂ sequestration process. While one can measure the CO₂ at the surface before sequestration, that only tells how much CO₂ there is at the surface, not where it goes and what state it is in as it is sequestered underground. Indirect measurements such as seismic and logging techniques are very useful in characterizing the structure and make up of underground formations and the movement of the CO₂ in the underground formations. One may take cores (full bore or sidewall cores) or conduct formation testing during the process of drilling a well for CO₂ sequestration, but it would be helpful to have direct measurements during the CO₂ injection process, to provide “ground truthing” for the sequestration process. There are processes and tools that can take direct measurements at more shallow depths, for example, for ground water monitoring. See for example, US Patent Nos. 5,704,425; 6,062,073; 6,192,982; 6,196,064 and 6,302,200, incorporated in their entirety herein by reference.

[0013] The carbon sequestration process may be monitored, which requires careful measurements to be made. Interpretation of such measurements requires the combined analysis of multiple sensors deployed in the wells, at the surface or in the air that generate data, continuously for some sensors and sporadically for others. For operational and safety issues, real time analysis of the measurements allow fast decision making in case of irregularities. More specifically, measurement and monitoring may serve several objectives, such as injection rate optimization, pressure monitoring and cap rock integrity control, assuring well integrity, assuring reservoir integrity and providing migration and leakage

detection, quantifying CO₂ injected, stored and leaked, quantifying CO₂ gas stored, and monitoring for health, safety and environmental reasons.

SUMMARY OF THE INVENTION

[0014] An object of the present invention is to provide methods, apparatuses and systems for transporting, measuring, sequestering carbon, as well as site preparation and design, decommissioning a carbon sequestration site and providing post-decommissioning monitoring of the sequestration site, while eliminating or minimizing the impact of the problems and limitations described.

[0015] Specifically, the present invention includes implementation of a supervisory control and data acquisition system for carbon sequestration to acquire data in real time, provide a data repository, provide a methodology to analyze the data and display the analysis in real time, trigger alerts, or/and generate response actions. The present invention could also be applied to other fluid storage, such as natural gas storage.

[0016] Other objects, features and advantages of the present invention will become apparent to those of skill in art by reference to the figures, the description that follows and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. 1 is a conceptual-level depiction of CO₂ generation and sequestration.

[0018] FIG. 2 depicts a flowchart for a generalized CO₂ sequestration process.

[0019] FIG. 3 is a flowchart for a CO₂ sequestration process, including an embodiment of the instant invention.

[0020] FIG. 4 depicts an overview of an embodiment of the present invention.

[0021] FIG. 5 depicts an architecture of an embodiment of the present invention.

[0022] FIG. 6 depicts an embodiment of the present invention more specifically addressing injection rate optimization and cap rock integrity control processes.

[0023] FIG. 7 depicts an embodiment of the present invention more specifically focused on a well equipment integrity monitoring process.

[0024] FIG. 8 depicts an embodiment of the present invention more specifically focused on reservoir integrity and migration of or detection of leakage processes.

[0025] FIG. 9 depicts an embodiment of the present invention with a process focused on monitoring CO₂ and determining the amount of CO₂ stored.

[0026] FIG. 10 depicts an embodiment of the present invention with respect to a process focused on health, safety and environmental (“HSE”) monitoring, including impact of potential CO₂ leakage on freshwater aquifers, soil and atmosphere.

DETAILED DESCRIPTION

[0027] In the following detailed description of a preferred embodiment and other embodiments of the invention, reference is made to the accompanying drawings. It is to be understood that those of skill in the art will readily see other embodiments and changes may be made without departing from the scope of the invention.

[0028] FIG. 1 is a conceptual-level depiction of CO₂ generation and sequestration. Large-scale CO₂ sources 1, for example, ethanol plants, cement factories, steel factories, refineries, electricity generation plants, coal and biomass operations generate CO₂ and usually vent it as atmospheric CO₂ 2. Some large scale CO₂

sources may transport the CO₂ to factories 3 where the CO₂ can be used for industrial processes or for food and drink products. Some CO₂ is sequestered through natural processes such as from trees 4 “inhaling” CO₂ and “exhaling” O₂ (oxygen). But CO₂ may be taken to a CO₂ capture facility 5, where the CO₂ is processed and then geologically sequestered. In geologic sequestration, the CO₂ is injected down one or more wells 6 and into an appropriate formation, such as a coal seam 7 where the CO₂ can displace methane to a production well 11 by which the methane can be produced. Another appropriate formation might be a suitable depleted oil and/or gas reservoir 8. Another appropriate formation might be a suitable reservoir with trapped oil 9 that the CO₂ may be used to displace to a production well 11 by which the oil may be produced. Another appropriate formation might be a saline reservoir 10 with a suitable trapping structure. Other appropriate formations would be known to those of skill in the art.

[0029] FIG. 2 is a depiction of an overview of a CO₂ sequestration process, which may be used with or without embodiments of the instant invention. One selects and prepares 110 a sequestration site. This may be a lengthy and involved process involving many steps and considerations. One consideration might be whether the CO₂ can be separated underground (which might be possible if produced with hydrocarbons) or whether it must be separated at the surface. If the CO₂ is being collected at the surface, a determination would be made as to whether there was a place to sequester the CO₂ onsite or whether the CO₂ might have to be transported to another site. If transportation is necessary, the possible sites

available would be considered along with their relative advantages and disadvantages.

[0030] Referring again to FIG. 2, CO₂ is collected and prepared 115 for storage. How the CO₂ is collected and prepared depends in part on the source of the CO₂. The source of the CO₂ may be a power plant, refinery, factory or other industrial site or the source of the CO₂ may be from hydrocarbon production. There are countless sources of CO₂, including every human being and animal on the planet and most automobiles, but carbon sequestration is currently most practical where the CO₂ is produced in large amounts and can be easily collected. The source of the CO₂ helps to determine whether the CO₂ requires processing, such as removal of moisture or other contaminants before transportation and/or sequestration. (Removal of moisture or of contaminants may not be practical or advisable and the CO₂ may in some cases be sequestered without such processing.) The CO₂ may be measured 120 as and/or after the CO₂ is collected and/or processed.

[0031] Referring again to FIG. 2, the process may be different, depending on whether the CO₂ is separated at the surface 125 and whether the sequestration is co-located with the CO₂ production site 130. If the CO₂ is not separated at the surface but rather underground as it is produced, for example with hydrocarbons, it might be possible to have the CO₂ placed and monitored 145 underground. In the more typical case of collecting and separating the CO₂ at the surface, then a determination is made as to whether the selected sequestration site is co-located with CO₂ production site. If the CO₂ is co-located with the sequestration site the

CO₂ may still need to be transported a short distance and measured as part of being placed and monitored 145, but if the sequestration site is not co-located with the CO₂ production site substantial transportation system 135, such as through a pipeline system, may be necessary. Measurements 140 may have to be taken at several points to ascertain that there is no CO₂ leakage occurring or to determine a location of any CO₂ leakage or simply to determine the amount of CO₂ at various points in the process.

[0032] Continuing to refer to FIG. 2, at the sequestration site, the CO₂ is placed and monitored 145. Buffering may be provided to store CO₂ in case the sequestration site has to be temporarily shut down. As monitored sequestration progresses, if problems are indicated 150, they are evaluated and ameliorated or if possible, completely fixed 155. Monitoring may be used to determine whether the sequestered CO₂ is stable or whether the sequestered CO₂ is becoming permanently affixed in the storage formation. Sequestration continues until complete 160. Completion might occur for example, if the source of the CO₂ permanently shuts down or if the storage formation cannot accept any more CO₂. The sequestration site would then be properly decommissioned 165 and post-decommissioning monitoring 170 might begin. If the post-decommissioning monitoring detects 175 a problem, the problem situation may have to be improved or fixed 180.

[0033] FIG. 3 is a flowchart for a CO₂ sequestration process, including an embodiment of the instant invention. As with the general process presented in FIG. 2, one selects and prepares 210 a sequestration site. This may be a lengthy and involved

process involving many steps and considerations. If the CO₂ is being produced with hydrocarbons, the CO₂ might be separated underground and be sequestered without reaching the surface. If the CO₂ is being collected at the surface, a determination would be made as to whether there was a place to sequester the CO₂ onsite or whether the CO₂ might have to be transported to another site. If transportation is necessary, the possible sites available would be considered along with their relative advantages and disadvantages.

[0034] Referring again to FIG. 3, as presented in FIG. 2, CO₂ is collected and prepared 215 for storage. The CO₂ may be measured 220 as and/or after the CO₂ is collected and/or processed.

[0035] Referring again to FIG. 3, as discussed with respect to FIG. 2, the process may be different, depending on whether the CO₂ is separated at the surface 225 and whether the sequestration is co-located with the CO₂ production site 230. If the CO₂ is not separated at the surface but rather underground as it is produced, for example with hydrocarbons, it might be possible to have the CO₂ placed and monitored 245 underground. In the more typical case of collecting and separating the CO₂ at the surface, then a determination is made as to whether 230 the selected sequestration site is co-located with CO₂ production site. If the CO₂ is co-located with the sequestration site the CO₂ may still need to be transported a short distance and measured as part of being placed and monitored 245, but if the sequestration site is not co-located with the CO₂ production site substantial transportation system 235, such as through a pipeline system, may be necessary. Measurements 240 may have to be taken at several points to ascertain that there is

no CO₂ leakage occurring or to determine a location of any CO₂ leakage or simply to determine the amount of CO₂ at various points in the process.

[0036] Continuing to refer to FIG. 3, at the sequestration site, the CO₂ is placed and monitored 245, using a real time monitoring, analysis and optimization system in accordance with an embodiment of the present invention and further described herein. Placement of the CO₂ is preferably in an appropriate formation having properties allowing the formation to safely receive and store the CO₂, as previously discussed herein. Buffering may be provided to store CO₂ in case the sequestration site has to be temporarily shut down. As monitored sequestration progresses, if problems are indicated 250, they are evaluated and ameliorated or if possible, completely fixed 255. Monitoring may be used to determine whether the sequestered CO₂ is stable or whether the sequestered CO₂ is becoming permanently affixed in the storage formation

[0037] Continuing to refer to FIG. 3, sequestration continues until complete 260. Completion might occur for example, if the source of the CO₂ permanently shuts down or if the storage formation cannot accept any more CO₂. The sequestration site would then be properly decommissioned 265 and post-decommissioning monitoring 270 might begin. The post-decommissioning monitoring system may include using a real time monitoring, analysis and optimization system in accordance with an embodiment of the present invention and further described herein. If the post-decommissioning monitoring detects 275 a problem, the problem situation may be improved or fixed 280.

[0038] FIG. 4 depicts additional detail for the step of monitoring the CO₂ in accordance with an embodiment of the present invention (such as steps 245 and 275 of FIG. 3). Data is collected 300, either continuously or sporadically, from sensors deployed at various physical locations with the carbon sequestration site. The collected data is analyzed and used 310 to perform diagnoses. The information derived from the analyses and diagnoses can be used to implement 320 improvements, optimization and/or control of the carbon sequestration process.

[0039] FIG. 5 depicts an architecture of an embodiment of the present invention. One or more sensors 415 located in one or more injection wells 400, in one or more monitoring wells 405 and/or on the surface 410 send real time and/or near real time measurements (both called “real time measurements” herein) to one or more remote terminal units 430 via a first transmission system (not depicted), which may be wired or wireless. The remote terminal units 430 may be co-located with the sensors 415 or may be located at a more remote site. Wireless signals of the first transmission system may include but not be limited to radio signals or mud pulses. The real time measurements might include but not be limited to continuous or frequent measurements of pressure and/or temperature. In addition, sporadic measurements may be presented in real time (thus falling under the category of “real time measurements”) or may be historical. Sporadic measurements may include but are not limited to logs, seismic measurements or sample analysis.

[0040] Continuing to refer to FIG. 5, the remote terminal units 430 would preferably control the sensor configuration and status, and all other sensor key operating

parameters such as power. The remote terminal units 430 may send signals via a second transmission system (not depicted) to a supervisory control and data acquisition system (“supervisory system”) 440. The second transmission system may involve wired or wireless signals. Wireless signals of the second transmission system may include for example radio signals or satellite communication. The supervisory system 440 may process the data to create conditioned data, process workflows (preferably relatively fast workflows), and/or generate alerts. The supervisory system may also perform control procedures. One way the supervisory system may perform control procedures is by sending signals to the remote terminal units 430 to prompt the remote terminal units 430 to control one or more sensors 415. For example, the supervisory system 440 may send a control signal to the remote terminal units 430 to change the frequency that a sensor 415 takes the measurements or may prompt the sensor 415 to take a different measurement. Upon receiving a control signal from the supervisory system 440, the remote terminal unit 430 would send a directive to the sensor 415 to effect the change. The supervisory system 440 may also send control signals to controllers for process equipment at the carbon sequestration site to change the configuration of process equipment, such as shutting in valves, for example, in response to an alert or choking back a flow or changing a pumping rate to control injection rate and/or pressure.

[0041] The supervisory system 440 may also display the data (conditioned or not), print out the data (conditioned or not) or archive the data (conditioned or not) in a

repository. Updates of onsite alerts may also be performed by the supervisory system.

[0042] The supervisory system 440 may send data (conditioned or not) to one or more data historians 445 (such as a computer system) via a third transmission system which may be wired or wireless. Wireless signals of the third transmission system may include for example radio signals, satellite communication or signals sent via the Internet. The data historian 445 may have access to the repository of the supervisory system on which data is stored. The data historian 445 may condition data. The data historian may store data on a data historian repository and may perform analysis of the data. The data historian and the supervisory system might be comprised of a single computer, although this would not be the preferred way of implementing the system. In addition, other (“secondary”) computing systems 450 may be given access to the data historian repository and may perform additional analysis of the data, such as relatively slow workflows. Experts 455 may be co-located with the data historian or supervisory system or may be remotely located. Experts remotely located from the supervisory system and/or the data historian may obtain access to the supervisory system and/or the data historian remotely, for example via web access 435, preferably through a system with security features.

[0043] The data historian 445 may also perform data mining and interpretation, review localization of microseismic events, compare new data with archived data or projected data, perform event detection, determine trends and thresholds for parameters of the supervisory system, and generate tasks and/or action items. The

data historian may send information to the supervisory system, such as conditioned data or task instructions or action items.

[0044] FIG. 6 depicts an embodiment of the present invention with a workflow more specifically addressing injection rate optimization and cap rock integrity control. Preferably at a well used for injecting the CO₂ underground (“injection well”) 500, measurements would be taken in real time by sensors such as wellhead pressure sensors, wellhead thermometers, bottom-hole pressure sensors, flowmeters, and phase composition sensors, and possibly one or more geophones for microseismic measurements. Other injection well sensors may also be used. One or more other wells at least not currently used for injection (“monitoring wells”) 510 would preferably have bottom-hole pressure sensors and geophones (microseismics) and may include other sensors. The measurements from the geophones and sensors in the injection well 500 and monitoring well 510 may be transmitted in real time to a remote terminal unit 520 via a first transmission system, which may be wired or wireless. Wireless signals of the first transmission system may include but not be limited to radio signals or mud pulses. The remote terminal unit may collect the data and forward the data to the supervisory system 530 via a second transmission system, which may be wired or wireless. Wireless signals of the second transmission system may include for example radio signals or satellite communication. The supervisory system 530 may process the data, process relatively fast workflows, generate alerts, and/or perform control procedures. The supervisory system 530 may perform sensor control, data conditioning and quality control on data received from remote

terminal units. The data (conditioned or not) may be displayed, printed out, saved or transmitted to the data historian 540, via a third transmission system, which may be wired or wireless. Updates of onsite alerts may be performed by the supervisory system 530 based on the data. An injection rate and pressure for the CO₂ would be limited by the need to preserve integrity of a caprock for the injection formation, so that the CO₂ is trapped beneath the caprock in the formation and would not be able to migrate to the surface. The combination of measurements and tasks listed above can be used to determine an optimized injection rate that will not adversely affect caprock integrity. The supervisory system 530 may calculate and display parameters in real time including average, minimum and maximum pressures at the wellhead and subsurface, frequency of microseismic events, injection rate and perform event detection. For pressure, temperature and microseismic events, the supervisory system could compare values received from sensors with expected trends and thresholds input from the data historian. The supervisory system 530 could be used to control pressure at a level below fracturation pressure, and injection rate below a determined maximum injection rate. The supervisory system 530 could flag alerts, generate tasks for either the data historian 540 or the remote terminal unit 520. The supervisory system 530 may send control signals to controllers for the process equipment to increase or decrease injection rate. The data historian may perform data quality control, data archiving, prepare flow and geomechanics models, perform calibrations, simulations, determine trends and thresholds for parameters of the supervisory system. The data historian 540 may also perform data mining

and interpretation, review localization of microseismic events, compare new data with archived data or projected data, perform event detection, determine trends and thresholds for parameters of the supervisory system, and generate tasks and/or action items.

[0045] FIG. 7 depicts an embodiment of the present invention, with a process more specifically focused on well equipment integrity monitoring. The injection well 600 sensors involved in this task may include wellhead and downhole pressure sensors, annular pressure sensors and temperature sensors at different depths, or continuous profile. Surface sensors 610 might include soil gas sensors at the well head. The real time measurements from the sensors in the injection well surface and from the surface may be sent to one or more remote terminal units 620 via a first transmission system, which may be wired or wireless. Wireless signals for the first transmission system may include but not be limited to radio signals or mud pulses. The remote terminal units 620 send signals containing measurement data via a second transmission system (which may be wired or wireless) to a supervisory system 630, which may engage in sensor control, data conditioning and quality control of data. Wireless signals of the second transmission system may include for example radio signals or satellite communication. The supervisory system 630 may process the data, process relatively fast workflows, generate alerts, and/or perform control procedures. The supervisory system 630 may perform sensor control, data conditioning and quality control on data received from remote terminal units. Conditioned data may be displayed, printed out, saved or transmitted elsewhere. The supervisory system 630 may calculate

and display parameters such as average, minimum and maximum annular pressure and a temperature profile in real time. The supervisory system 630 may send data to the data historian 640 via a third transmission system, which may be wired or wireless. The supervisory system 630 may perform event detection by comparing conditioned data with expected trends and defined thresholds, which might be provided by the data historian 640, for the annular pressure and temperature profile evolution, and to determine gas detected at the well head. The supervisory system 630 could also generate flag alerts and tasks for the data historian 640. Sporadically obtained data 650 might be sent to the supervisory system or directly to the data historian or both. Such sporadically obtained data 650 might include well integrity logs, such as caliper, sonic, ultrasonic, and/or electromagnetic logs, or soil gas sensors at the well head. The data historian 640 may perform data quality control, data archiving, create well flow models for calibration, simulations and determination of trends and thresholds for parameters to be sent to the supervisory system. The data historian 640 may perform data mining and interpretation, create temperature profile by inversion with flow model, compare data with archived data or projections, perform event detection, determine trends and thresholds for parameters for the supervisory system and may generate tasks and/or action items.

[0046] FIG. 8 depicts a preferred embodiment of the invention with a process focused on reservoir integrity and migration of or detection of leakage. Injection well sensors 700 involved in this process may include pressure and temperature measurements both from the reservoir and in the overburden. Other injection well sensors may

take microseismic measurements from geophones or chemical measurements. Surface real time sensors 710 may include permanent gas analyzers at the surface and on an atmospheric tower, as well as accumulation chambers to determine gas include flux at the surface. The real time measurements may be sent to one or more remote terminal units 720 via a first transmission system, which may be wired or wireless. Wireless signals for the first transmission system may include but not be limited to radio signals or mud pulses.

[0047] The remote terminal units 720 send signals containing measurement data via a second transmission system (which may be wired or wireless) to a supervisory system 730 which may engage in sensor control, data conditioning and quality control of data. Wireless signals of the second transmission system may include for example radio signals or satellite communication. Conditioned data may be displayed, printed out, saved or transmitted elsewhere. The supervisory system 730 may send data via a third transmission system (which may be wired or wireless) to a data historian 740. The supervisory system 730 may calculate and display parameters such as average, minimum and maximum pressure and frequency of microseismic events in real time. The supervisory system 730 may perform event detection for pressure, temperature and microseismic events by comparing data to expected trends and/or defined thresholds from the data historian 740. For determine whether CO₂ is present in the overburden or at the surface the supervisory system 730 may compare of data measurements to trends from the data historian 740. The supervisory system 730 could also flag alerts and generate tasks for the data historian 740. Sporadically obtained data 760

might be sent to the supervisory system 730 or directly to the data historian 740 or both. Such sporadically obtained data 760 might include well logs, chemical sampling (such as aquifer, air, soils), portable gas analyzer, seismic data, and accumulation chambers. The data historian 740 may perform data quality control, data archiving, create overburden models with aquifers descriptions and a geomechanics model. The data historian 740 could ascertain atmospheric dispersion using calibrations, simulations and determinations of trends and thresholds for parameters from the supervisory system 730. The data historian 740 could perform data mining and interpretation and microseismics: localization of microseismic events. The data historian 740 could review atmospheric measurements to determine inversion and localization of the leakage. The data historian 740 could compare data received to archived data. The data historian could perform event detection, determine trends and thresholds for parameters of the supervisory system. The data historian 740 may generate tasks and/or action items. The data historian 740 may identify potential zones of leakage for the deployment of other sensors or may indicate other action to be taken. The data collected could also be used for other processes such as creating alerts 750 such as well integrity alerts and HSE monitoring alerts.

[0048] FIG. 9 depicts a preferred embodiment of the invention with a process focused on monitoring CO₂ and determining the amount of CO₂ stored. Injection well sensors 800 involved in this process may include flowmeter, sensors for wellhead pressure and temperature measurements, gas stream composition sensors, and bottomhole pressure and temperature sensors. Surface real time sensors 810 may

include permanent gas analyzers at the surface and on atmospheric tower, and one or more accumulation chambers (to determine gas flux at the surface). The real time measurements may be sent to one or more remote terminal units 820 via a first transmission system, which may be wired or wireless. Wireless signals for the first transmission system may include but not be limited to radio signals or mud pulses.

[0049] The remote terminal units 820 send signals containing measurement data via a second transmission system (which may be wired or wireless) to a supervisory system 830 which may engage in sensor control, data conditioning and quality control of data. Wireless signals of the second transmission system may include for example radio signals or satellite communication. Conditioned data may be displayed, printed out, saved or transmitted elsewhere. Using the data, the supervisory system 830 may calculate and display in real time injected mass of CO₂, fraction of contaminants, cumulative quantity of CO₂ leaked and total mass of CO₂ stored. In case a leakage is detected from the process described with respect to FIG. 8 above, the supervisory system 830 could flag alerts, generate tasks for the data historian such as quantification of leakage. The supervisory system may send data via a third transmission system (which may be wired or wireless) to a data historian 840. Sporadically obtained data 860 might be sent to the supervisory system 830 or directly to the data historian 840 or both. Such sporadically obtained data 860 might include chemical sampling (aquifer, air, soils) and a data from a portable gas analyzer and accumulation chambers. The data historian 840 may perform data quality control, data archiving. The data

historian 840 may create an aquifers model, which may include an atmospheric dispersion model and a well flow model, which might have calibration and simulation functions. The data historian 840 may perform data mining and interpretation, may compare obtained data with archived data. The data historian 840 could create a statistical model to extrapolate local measurements and estimate the quantity of CO₂ leaked. Other processes or workflows 850 which could be performed with data from these sensors include a well injectivity workflow for providing an optimized injection rate and reservoir integrity and migration /leakage detection.

[0050] The workflow described with respect to FIG. 9 could also be used for optimizing a enhanced recovery operation for hydrocarbons using CO₂ injection if one also measures gas and other fluids produced.

[0051] FIG. 10 depicts a preferred embodiment of the invention with respect to a preferred embodiment of the invention with a process focused on health, safety and environmental (“HSE”) monitoring, including impact of CO₂ leakage on freshwater aquifers, soil and atmosphere. Monitoring wells may be shallow for this process and monitoring well sensors 900 involved in this process may include pressure, temperature and conductivity sensors in freshwater aquifers and chemical sensors in fresh water aquifers which may be permanent. Surface real time sensors 910 may gas analyzers, which may be permanently placed, at the surface and on atmospheric tower. The real time measurements may be sent to one or more remote terminal units 920 via a first transmission system, which may be wired or wireless. Wireless signals for the first transmission system may

include but not be limited to radio signals or mud pulses. The remote terminal units 920 send signals containing measurement data via a second transmission system (which may be wired or wireless) to a supervisory system 930 which may engage in sensor control, data conditioning and quality control of data. Wireless signals of the second transmission system may include for example radio signals or satellite communication. Conditioned data may be displayed, printed out, saved or transmitted elsewhere. The supervisory system 930 may engage in event detection concerning the concentration of CO₂ in the atmosphere or relating to a threshold determined by the data historian, or relating to anomalous changes in any of the pressure, temperature, conductivity, pH, pCO₂ in an aquifer. The supervisory system 930 may also flag alerts and generate tasks for the data historian. Sporadically obtained data 960 might be sent to the supervisory system 930 or directly to the data historian 940 or both. Such sporadically obtained data 960 might include results of chemical sampling (aquifer, air, soils) or of a portable gas analyzer. The data historian 940 may perform data quality control and data archiving. The data historian may 940 create aquifer models, contamination models, and atmospheric dispersion models by using determination of detection thresholds and determination of the need for complementary measurements and design for the deployment of new sensors. The data historian may 940 perform data mining and interpretation, may perform a comparison of data received with archived data or with projections. The data historian 940 may perform event detection by comparing measurements with threshold of species as defined by regulation (water purity, air purity, and soil purity). The data historian

940 may generate tasks or create action items regarding identification of potential zones of leakage for the deployment of other sensors. The process described with respect to FIG. 10 could be performed in conjunction with other workflows 850, such as the reservoir integrity and migration /leakage detection process of FIG. 8.

[0052] Although the foregoing is provided for purposes of illustrating, explaining and describing certain embodiments of the invention in particular detail, modifications and adaptations to the described methods, systems and other embodiments will be apparent to those skilled in the art and may be made without departing from the scope or spirit of the invention.

CLAIMS

What is claimed is:

1. A method of sequestering CO₂ comprising:
 - a. collecting carbon dioxide and preparing the carbon dioxide for sequestration;
 - b. selecting a storage site;
 - c. obtaining permits for using the storage site for sequestration;
 - d. preparing the storage site;
 - e. transporting the carbon dioxide to the storage site, measuring the carbon dioxide as desirable; and
 - f. placing and monitoring CO₂, using a real time monitoring, analysis and optimization system.
2. The method of claim 1, further comprising:
 - a. detecting a problem situation in the carbon sequestration by using the real time monitoring, analysis and optimization system and taking one or more actions to improve the problem situation.
3. A method for real time monitoring, analysis and optimization of a carbon sequestration operation including injection of carbon dioxide into an underground reservoir via an at least one injection well comprising:
 - a. measurement taking of a at least one first real time measurement data by at least one first sensor in the at least one injection well;
 - b. measurement taking of a at least one second real time measurement data by at least one second sensor in at least one second location;

- c. transmitting by the at least one first sensor of the at least one first real time measurement data and transmitting by the at least one second sensor of the at least one second real time measurement data via a first transmission system to at least one remote terminal unit which collects measurement data;
 - d. transmitting by the at least one remote terminal unit of the collected measurement data via a second transmission system to a supervisory system;
 - e. transmitting by the supervisory system of the measurement data via a third transmission system to a data historian; and
 - f. wherein one or more of the transmitting steps is performed in real time.
4. The method of claim 3, wherein the at least one second location is an at least one monitoring well.
5. The method of claim 3, wherein the at least one second location is at the surface.
6. The method of claim 4, further comprising:
- a. measurement taking by at least one third sensor of at least one third real time measurement data at a location at the surface;
 - b. and transmitting by the at least one third sensor of the at least one third real time measurement data via the first transmission system to the at least one remote terminal unit which collects measurement data.
7. The method of claim 3, wherein one or more of the transmission systems is wireless.
8. The method of claim 3, further comprising: sporadic measurement taking of sporadic measurement data by the at least one first sensor in the at least one injection well and transmitting by the at least one first sensor of the sporadic measurement data via the first transmission system to the at least one remote terminal unit and transmitting of the

- sporadic measurement data by the at least one remote terminal unit via the second transmission system to the supervisory system.
9. The method of claim 3, further comprising processing of the measurement data by the supervisory system.
 10. The method of claim 9, wherein processing of the measurement data by the supervisory system includes creating conditioned data, processing workflows and generating alerts.
 11. The method of claim 9, further comprising performing one or more control procedures on the carbon sequestration process by the supervisory system.
 12. The method of claim 10, further comprising displaying by the supervisory system and archiving the conditioned data by the supervisory system in a repository.
 13. The method of claim 9 further comprising providing access to the data historian for secondary systems.
 14. The method of claim 3, further providing processing of the measurement data by the data historian.
 15. The method of claim 14 wherein processing of the measurement data by the data historian includes conditioning data, analyzing the data, and performing data mining and interpretation.
 16. The method of claim 14 wherein processing of the measurement data by the data historian includes reviewing localization of microseismic events, performing event detection, determining trends and thresholds for parameters of the supervisory system, and generating tasks.
 17. The method of claim 14 further comprising transmission from the data historian to the supervisory system of information comprising task instructions.

18. The method of claim 3 or 4 further comprising determining for the carbon dioxide an optimized injection rate that will not adversely affect caprock integrity of the reservoir into which the carbon dioxide is injected.
19. The method of claim 10 wherein there are a plurality of first sensors taking a plurality of first data measurements, a plurality of second sensors taking a plurality of second data measurements and the supervisory system uses the processed data from the first data measurements and the second data measurements to ascertain well equipment integrity.
20. The method of claim 9 wherein there are a plurality of first sensors taking a plurality of first data measurements, a plurality of second sensors taking a plurality of second data measurements and the supervisory system uses the processed data from the first data measurements and the second data measurements to ascertain reservoir integrity.
21. The method of claim 9 wherein there are a plurality of first sensors taking a plurality of first data measurements, a plurality of second sensors taking a plurality of second data measurements and the supervisory system uses the processed data from the first data measurements and the second data measurements to ascertain the amount of carbon dioxide sequestered.
22. The method of claim 3 wherein carbon sequestration operation is part of an enhanced recovery operation for hydrocarbons and further comprises measuring the fluids produced by at least one production well.
23. The method of claim 9 wherein there are a plurality of first sensors taking a plurality of first data measurements, a plurality of second sensors taking a plurality of second data measurements and the supervisory system uses the processed data from the first data measurements and the second data measurements to ascertain health, safety and environmental compliance of the carbon sequestration operation.

24. The method as in claim 23 wherein the supervisory system engages in event detection.
25. A system for real time monitoring and optimizing CO₂ sequestration comprising:
 - a. at least one first sensor in an at least one injection well for taking an at least a first real time measurement to obtain first measurement data;
 - b. at least one second sensor in an at least one second location for taking an at least a second real time measurement to obtain second measurement data;
 - c. a transmission system used by the at least one first sensor to send the first measurement data and by the at least one second sensor to send the second measurement data to at least one remote terminal unit;
 - d. a second transmission system used by the remote terminal unit to send collected data to a supervisory system; and
 - e. a third transmission system used by the supervisory system and a data historian to exchange data, wherein the supervisory system processes the data and the data historian performs analysis with the processed data.
26. A system in accordance with claim 25 wherein the second transmission system is configured to be used by the supervisory system to send signals to the remote terminal unit to make changes in the measurements taken by one or more sensors.
27. A system in accordance with claim 25 wherein the supervisory system responds to an alert prompted by analysis of the data to send one or more signals to a controller of process equipment at the carbon sequestration site for the controller to change the configuration of process equipment change operations in the injection well.
28. A system in accordance with claim 25 wherein the data historian uses data received from the supervisory system to create simulation models.

29. A system in accordance with claim 25 wherein the data historian performs data quality control.
30. A system in accordance with claim 25 wherein the data historian performs data archiving.
31. A system in accordance with claim 25 wherein the supervisory system performs sensor control.
32. A system in accordance with claim 25 wherein the supervisory system performs data conditioning on data received from the remote terminal unit.
33. A system in accordance with claim 25 wherein the supervisory system performs quality control on data received from the remote terminal unit to create conditioned data.
34. A system in accordance with claim 25 further comprising a display wherein the supervisory system displays conditioned data.
35. A system in accordance with claim 25 wherein the supervisory system updates onsite alerts based on the conditioned data.
36. A system in accordance with claim 25 wherein at least one second sensor is in a monitoring well.
37. A system in accordance with claim 25 wherein at least one second sensor is positioned on the surface of the location.
38. A system in accordance with claim 36 further comprising at least one third sensor positioned on the surface of the location to take at least one third real time measurement data for transmission to the remote terminal.
39. A system in accordance with claim 25 wherein the first real time measurement data is of bottomhole pressure.

40. A system in accordance with claim 25 where there are a plurality of first sensors at a first location and among the first real time measurements taken are bottomhole pressure and bottomhole temperature.
41. A method of controlling a carbon sequestration operation comprising the steps of:
- a. collecting data from one or more sensors deployed at the carbon sequestration site;
 - b. transmitting the data from the sensors to a remote terminal unit;
 - c. transmitting the data from the remote terminal unit to a supervisory system;
 - d. processing the data by the supervisory unit;
 - e. transmitting the processed data from the supervisory system to a data historian;
 - f. analyzing the processed data using the data historian to diagnose an imperfection in the carbon sequestration process
 - g. implementing one or more improvements addressing the diagnosed imperfection through instruction signals sent from the supervisory system to the remote terminal unit.
42. A system for real time monitoring and optimizing the enhanced recovery of hydrocarbons produced through one or more production wells in an oilfield by using carbon dioxide injection comprising:
- a. at least one first sensor in an at least one carbon dioxide injection well for taking an at least a first real time measurement to obtain first measurement data;
 - b. at least one second sensor in an at least one second location for taking an at least a second real time measurement to obtain second measurement data;

- c. a transmission system used by the at least one first sensor to send the first measurement data and by the at least one second sensor to send the second measurement data to at least one remote terminal unit;
- d. a second transmission system used by the remote terminal unit to send collected data to a supervisory system;
- e. a third transmission system used by the supervisory system and a data historian to exchange data, wherein the supervisory system processes the data and the data historian performs analysis with the processed data; and
- f. a produced fluid measurement system for obtaining measurements gas and other fluids produced by the one or more production wells and a fourth transmission system for transmitting the fluid measurements to the supervisory system.

FIG.2

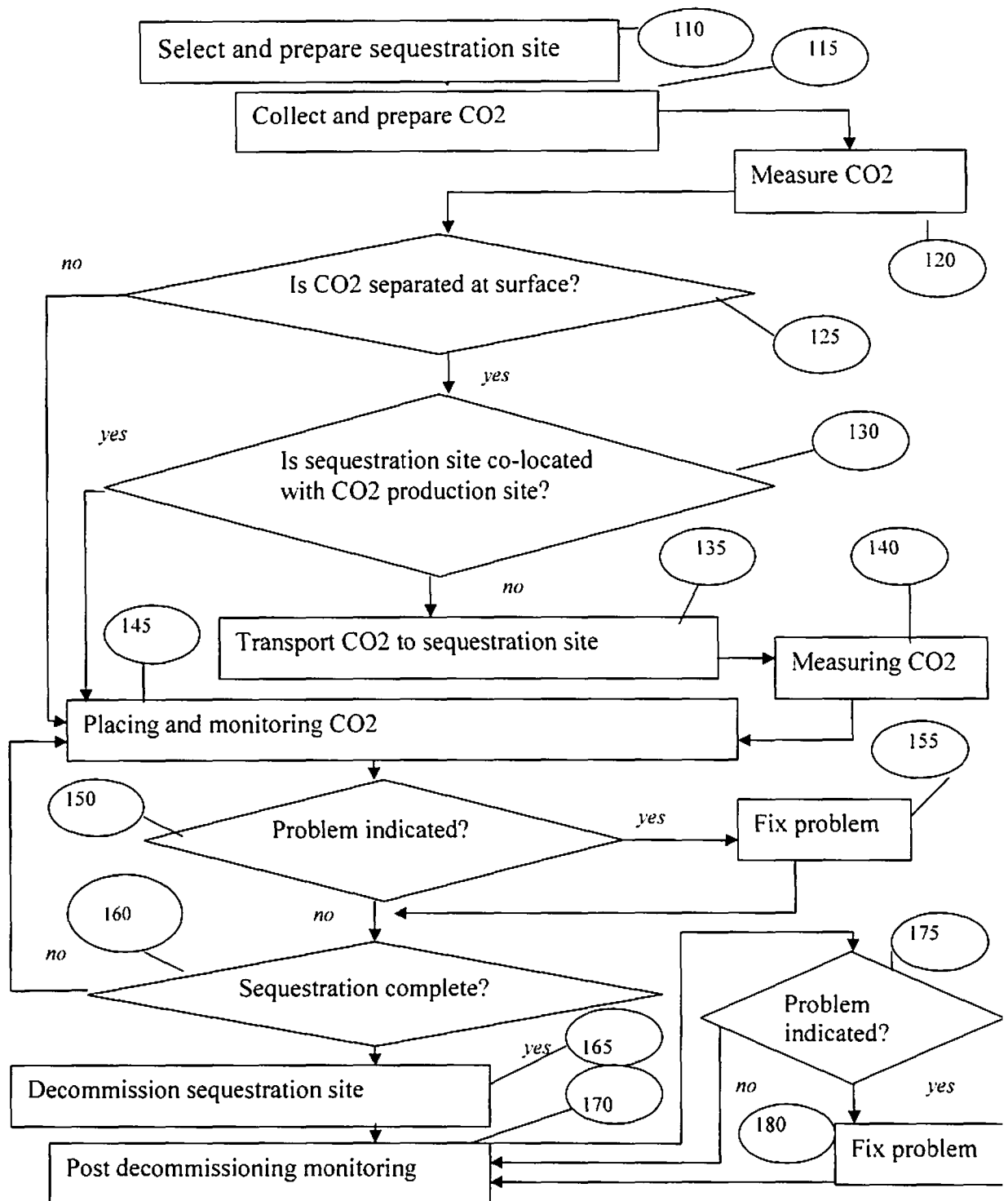


FIG. 3

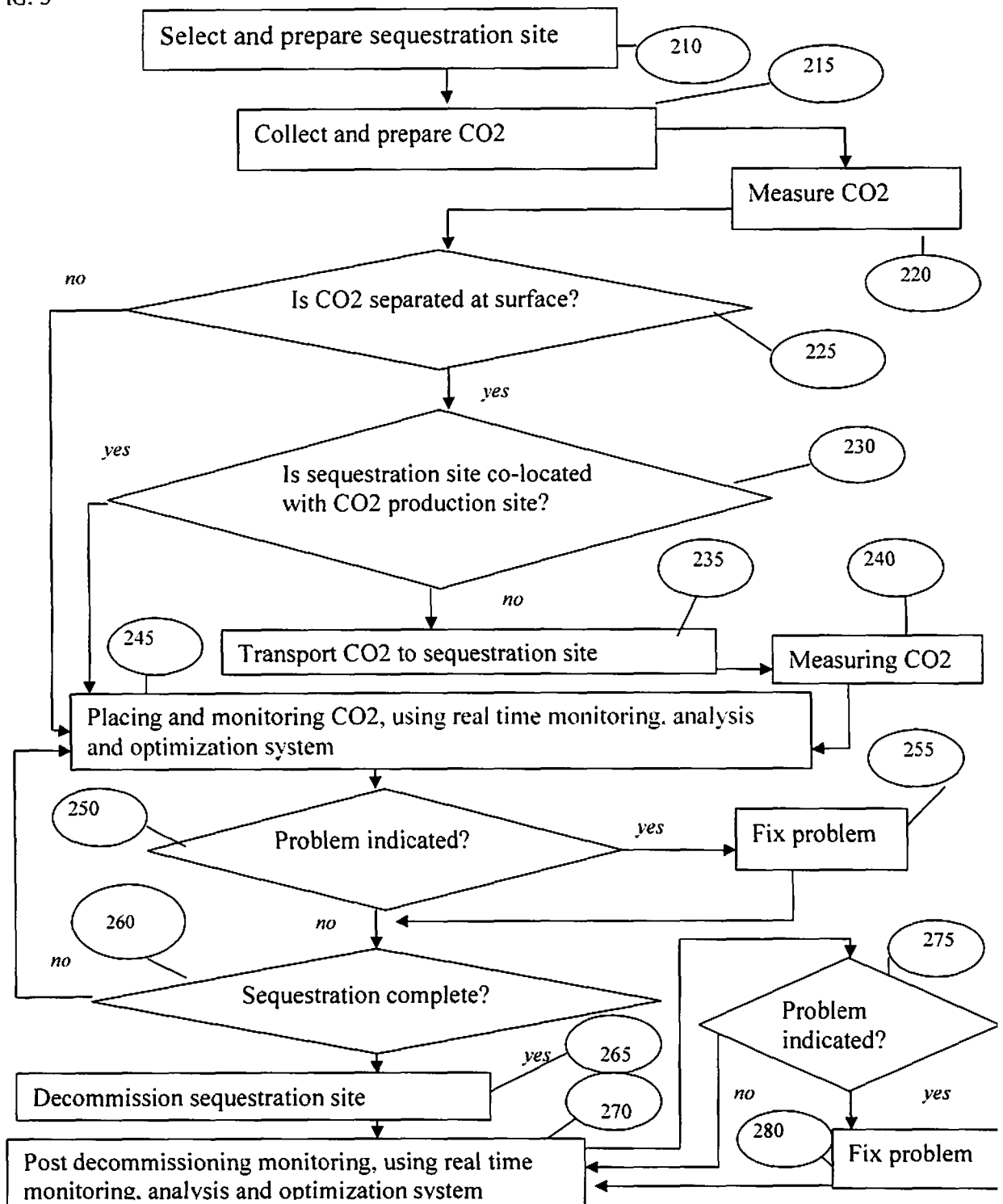
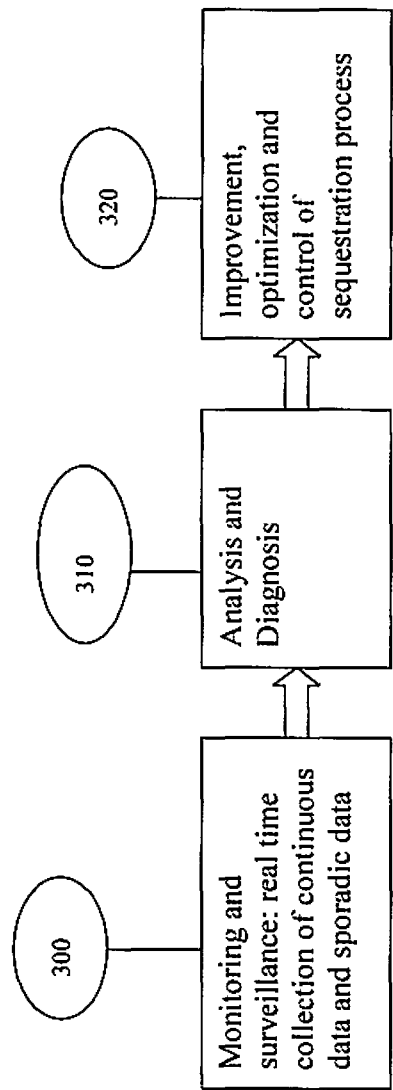
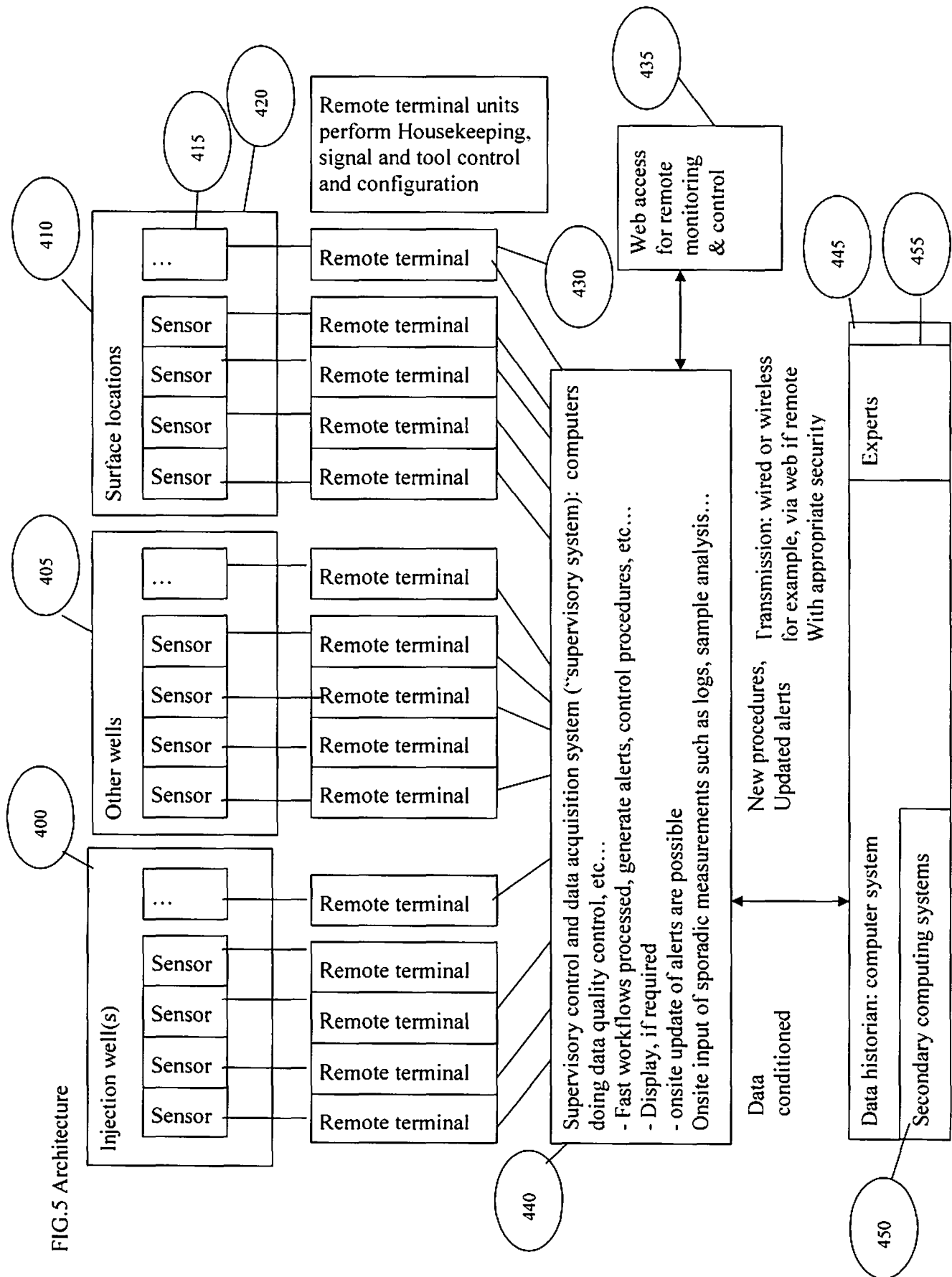
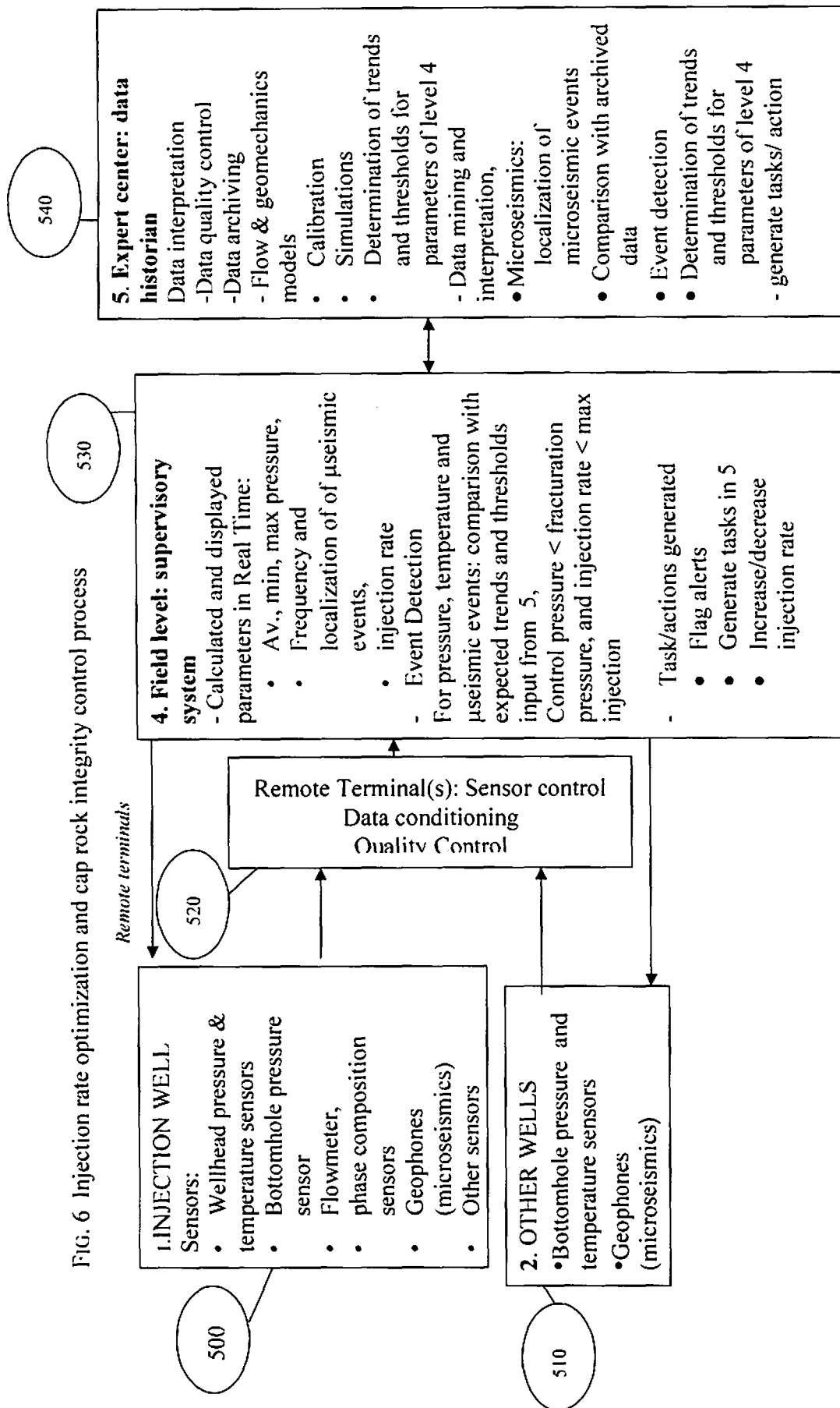


FIG. 4







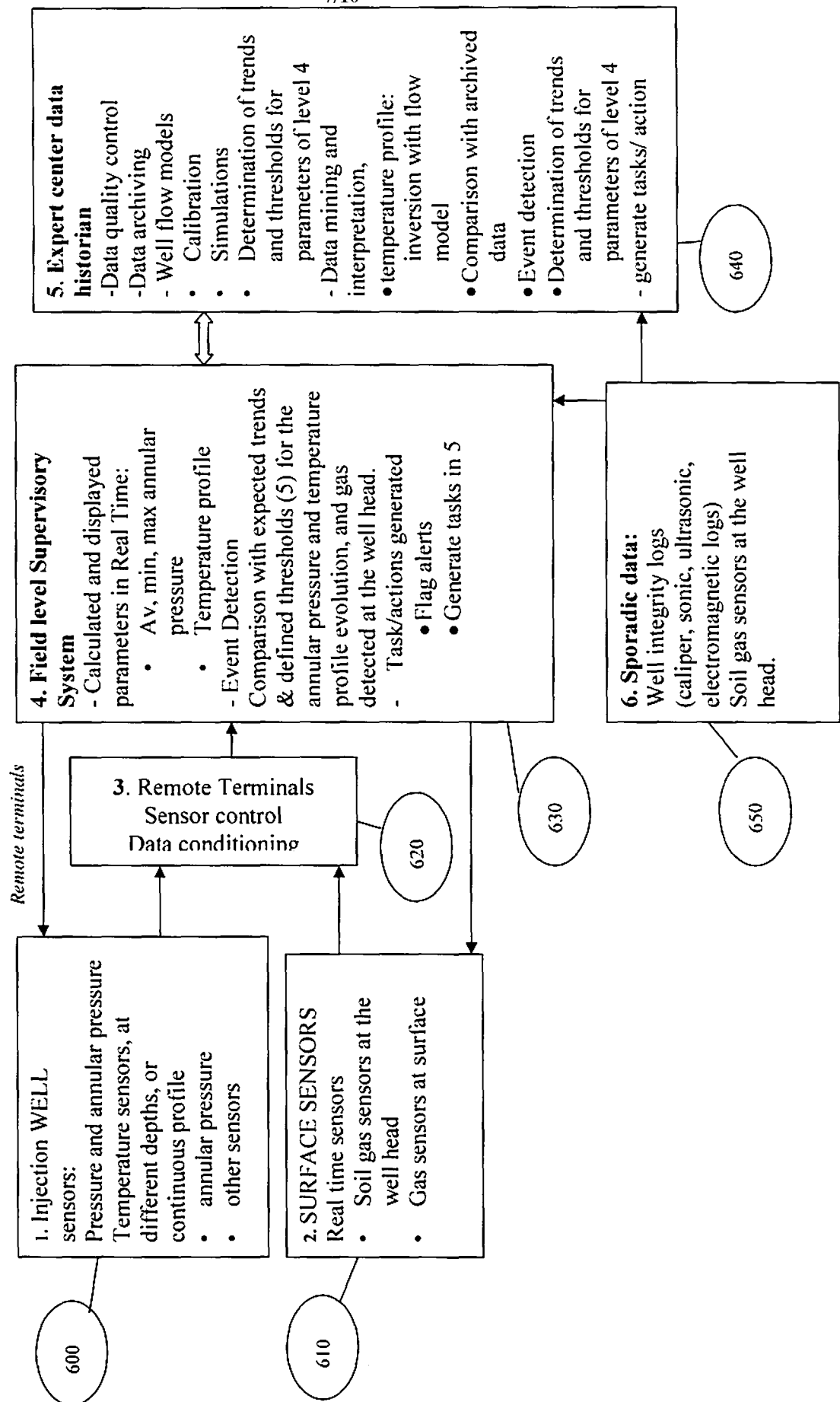


FIG. 7 Well Integrity Monitoring Process

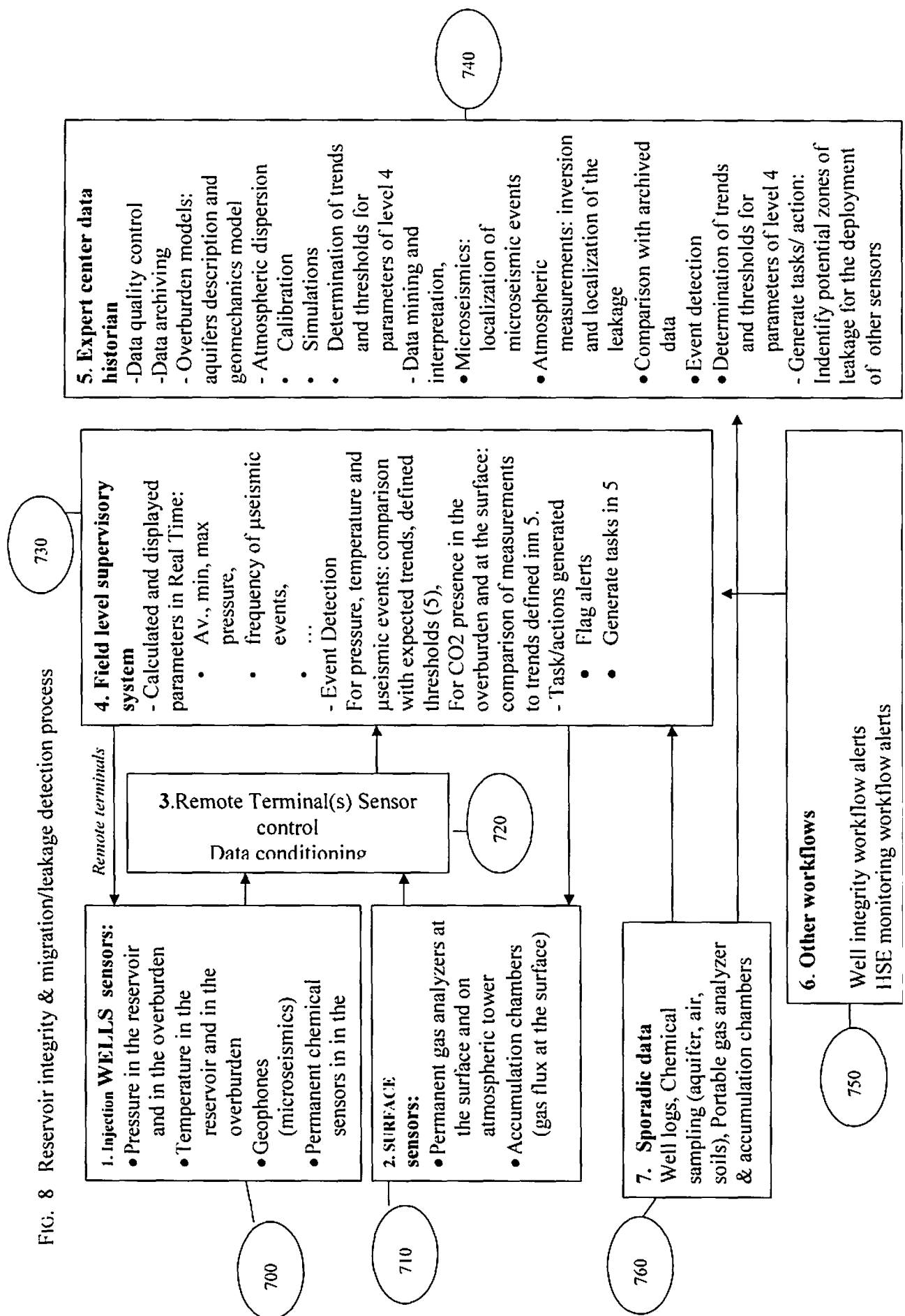


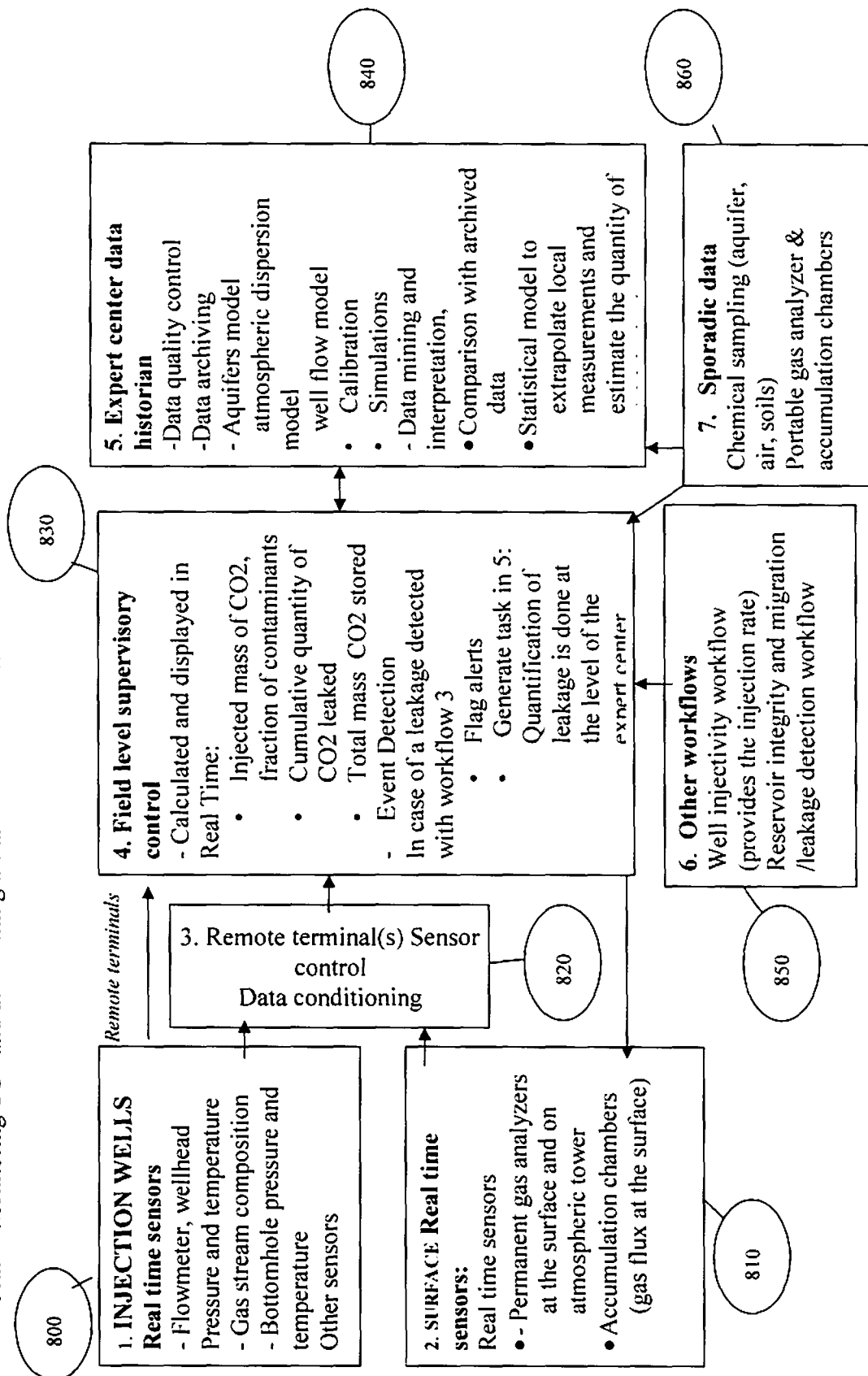
FIG. 9 Monitoring CO₂ and determining the amount of CO₂ stored

FIG. 10 Health Safety and environment monitoring

