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

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
19 February 2015 (19.02.2015)

WIPO | PCT

(10) **International Publication Number**
WO 2015/023970 A1

(51) **International Patent Classification**: ***G06F 19/00*** (2011.01)

(21) **International Application Number**: PCT/US2014/051320

(22) **International Filing Date**: 15 August 2014 (15.08.2014)

(25) **Filing Language**: English

(26) **Publication Language**: English

(30) **Priority Data**:
61/866,901 16 August 2013 (16.08.2013) US

(71) **Applicant**: **LANDMARK GRAPHICS CORPORATION** [US/US]; 2107 City West Blvd., Bldg. 2, Houston, TX 77042 (US).

(72) **Inventors**: **EWING, Michael, David**; 3976 Alcazar Drive, Castle Rock, CO 80109 (US). **IGARASHI, Sammi**; 855 S. Estes St, Lakewood, CO 80226 (US).

(74) **Agent**: **JENSEN, William, P.**; Crain, Caton & James, 1401 McKinney Street, Suite 1700, Houston, TX 77010 (US).

(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, 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, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, 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.

[Continued on next page]

(54) Title: CONVERTING RESERVE ESTIMATES IN A RESERVOIR MODEL TO A STANDARD FORMAT FOR DYNAMIC COMPARISON

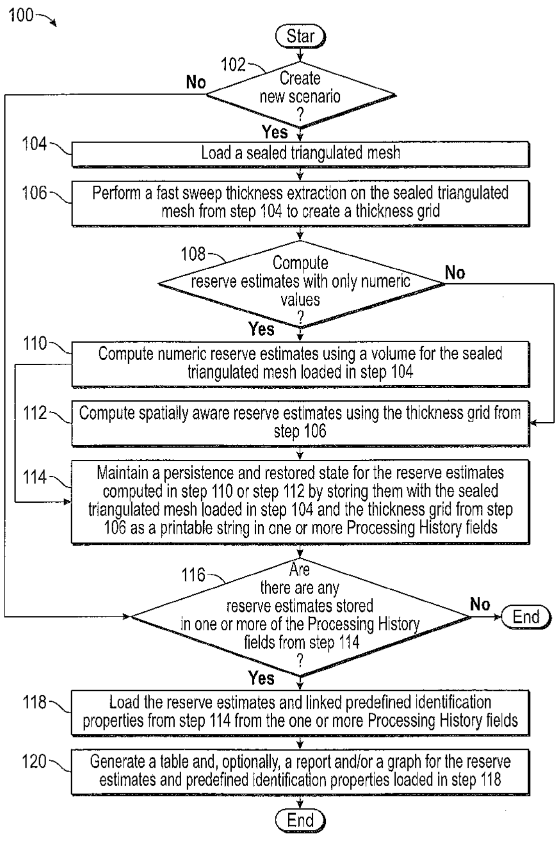


FIG. 1

(57) **Abstract**: Systems and methods for converting reserve estimates in a reservoir model to a standard format for dynamic comparison by storing them with a sealed triangulated mesh and a thickness grid as a printable string in one or more Processing History fields.

WO 2015/023970 A1

(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, 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))*

CONVERTING RESERVE ESTIMATES IN A RESERVOIR MODEL TO A STANDARD FORMAT FOR DYNAMIC COMPARISON

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The priority of U.S. Provisional Patent Application No. 61/866,901, filed August 16, 2013, is hereby claimed and the specification thereof is incorporated herein by reference.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

[0002] Not applicable.

FIELD OF THE DISCLOSURE

[0003] The present disclosure generally relates to systems and method for converting reserve estimates in a reservoir model to a standard format for dynamic comparison. More particularly, the present disclosure relates to converting reserve estimates in a reservoir model to a standard format for dynamic comparison by storing them with a sealed triangulated mesh and a thickness grid as a printable string in one or more Processing History fields.

BACKGROUND

[0004] Accurate reserve estimates are critical in the industry for proper risk assessment and providing these in a structural framework setting is unique. Traditional volumetric calculations are purely grid-based and define the volume between surfaces/horizons by computing and summarizing horizontal slices. The slicing technique does not accurately define geologic volumes especially with complex geometries such as fault blocks or salt bodies. In addition, it is challenging for the user to gain an accurate three-dimensional visual representation of the calculated volumes. Geocellular-based volume calculations also inadequately define volumes due to stair-stepped geometry representations.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The present disclosure is described below with references to the accompanying drawings in which like elements are referenced with like reference numerals, and in which:

[0006] **FIG. 1** is a flow diagram illustrating one embodiment of a method **100** for implementing the present disclosure.

[0007] **FIG. 2** is a flow diagram illustrating one embodiment of a method **200** for implementing step **106** in **FIG. 1**.

[0008] **FIG. 3** is a flow diagram illustrating one embodiment of a method **300** for implementing step **110** in **FIG. 1.**

[0009] **FIG. 4** is a flow diagram illustrating one embodiment of a method **400** for implementing step **112** in **FIG. 1**.

[0010] **FIG. 5** is a flow diagram illustrating one embodiment of a method **500** for implementing step **114** in **FIG. 1**.

[0011] **FIG. 6** is a flow diagram illustrating one embodiment of a method **600** for implementing step **120** in **FIG. 1**.

[0012] **FIG. 7** is a display illustrating exemplary predefined identification properties linked to a sealed triangulated mesh that is displayed at four different time intervals using the printable string stored in step **508** of **FIG. 5** and a 3D modeling engine.

[0013] **FIG. 8** is a display illustrating an exemplary tree table created in step **604** of **FIG. 6**.

[0014] **FIG. 9** is a display illustrating an exemplary HTML report created with a default XSL in step **614** of **FIG. 6**.

[0015] **FIG. 10** is a block diagram illustrating one embodiment of a computer system for implementing the present disclosure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0016] The present disclosure overcomes one or more deficiencies in the prior art by converting reserve estimates in a reservoir model to a standard format for dynamic comparison by storing them with a sealed triangulated mesh and a thickness grid as a printable string in one or more Processing History fields.

[0017] In one embodiment, the present disclosure includes a method for converting reserve estimates in a reservoir model to a standard format, which comprises: i) serializing the reserve estimates, a sealed triangulated mesh and a thickness grid, which each represents a reservoir model, into a byte array using a computer processor; ii) compressing the byte array; and iii) converting the compressed byte array into a printable string.

[0018] In another embodiment the present disclosure includes a non-transitory program carrier device tangibly carrying computer-executable instructions for converting reserve estimates in a reservoir model to a standard format, the instructions being executable to implement: i) serializing the reserve estimates, a sealed triangulated mesh and a thickness grid, which each represents a reservoir model, into a byte array; ii) compressing the byte array; and iii) converting the compressed byte array into a printable string.

[0019] In yet another embodiment, the present disclosure includes a non-transitory program carrier device tangibly carrying computer-executable instructions for converting reserve estimates in a reservoir model to a standard format, the instructions being executable to implement: i) serializing the reserve estimates, a sealed triangulated mesh and a thickness grid into a byte array; ii) compressing the byte array; iii) converting the compressed byte array into a printable string; and iv) converting the compressed byte array into the printable string using UTF-8/ASCII characters.

[0020] The subject matter of the present disclosure is described with specificity; however, the description itself is not intended to limit the scope of the disclosure. The subject matter thus, might also be embodied in other ways, to include different steps or combinations of steps similar to the ones described herein, in conjunction with other present or future technologies. Moreover, although the term “step” may be used herein to describe different elements of methods employed, the term should not be interpreted as implying any particular order among or between various steps herein disclosed unless otherwise expressly limited by the description to a particular order. While the present disclosure may be applied in the oil and gas industry, it is not limited thereto and may also be applied in other industries to achieve similar results.

Method Description

[0021] The present disclosure describes various approaches for computing gross rock volumes (GRV) and reserves while running multiple scenarios, keeping track of the calculation history and even restoring former volumes visually for time-lapse analyses. The present disclosure further offers a unique workflow for performing highly accurate GRV and reserve calculations in a dynamic structural framework setting.

[0022] This disclosure complements a new direction in 3D modeling where sealed triangulated mesh spaces, also referred to as called compartments, are modeled instead of just the geological objects (e.g. surfaces, faults, geoshells, fluid contacts). These compartments are auto-grouped into different geologic categories such as stratigraphic layers, fault blocks, fluid layers and geoshells, or they may be grouped manually into custom reservoirs, to help identify the exact

GRV and/or reserve calculations. The modeled volumes may be visualized in all views by color and/or lithology fills.

[0023] This disclosure thus, provides a number of techniques that work by combining closed triangulated mesh compartments. The volumes of all the individual triangulated mesh bodies comprising compartments are obtained through a direct polyhedral volume calculation and are added together to produce a GRV for the interior space of each compartment. This value can then be used in numerical reserve estimates or in a new feature that uses extracted thickness values to perform grid-based reserve estimates.

[0024] At all stages of the analysis, the actual sealed space being analyzed is visible. A subset of the sealed model is isolated and preserved for both analysis and later viewing, making it easy to visualize what was computed and how it changes through time. All thickness and reserve calculations can also be viewed as 3D grids and used to generate varying scenarios both visually and numerically at any stage in the reserve estimation process.

[0025] Referring now to **FIG. 1**, a flow diagram of one embodiment of a method **100** for implementing the present disclosure is illustrated.

[0026] In step **102**, the method **100** determines if a new scenario should be created using the client interface and/or the video interface described in reference to **FIG. 10**. If a new scenario should not be created, then the method **100** proceeds to step **116**. Otherwise, the method **100** proceeds to step **104**.

[0027] In step **104**, a sealed triangulated mesh is loaded. The sealed triangulated mesh includes a volume that is computed in the unit system of any well-known 3D modeling engine using techniques well known in the art such as Stoke's Theorem.

[0028] In step **106**, fast sweep thickness extraction is performed on the sealed triangulated mesh from step **104** to create a thickness grid. One embodiment of a method for performing this step is described further in reference to **FIG. 2**.

[0029] In step **108**, the method **100** determines if reserve estimates should be computed with only numeric values using the client interface and/or the video interface described in reference to **FIG. 10**. If reserve calculations should not be computed with only numeric values, then the method **100** proceeds to step **112**. Otherwise, the method **100** proceeds to step **110**.

[0030] In step **110**, numeric reserve estimates are computed using the volume for the sealed triangulated mesh loaded in step **104** and the method **100** proceeds to step **114**. One embodiment of a method for performing this step is described further in reference to **FIG. 3**.

[0031] In step **112**, spatially aware reserve estimates are computed using the thickness grid from step **106**. One embodiment of a method for performing this step is described further in reference to **FIG. 4**.

[0032] In step **114**, a persistence and restored state are maintained for the reserve estimates computed in step **110** or step **112** by storing them with the sealed triangulated mesh loaded in step **104** and the thickness grid from step **106** as a printable string in one or more Processing History fields. One embodiment of a method for performing this step is described further in reference to **FIG. 5**.

[0033] In step **116**, the method **100** determines if there are any reserve estimates stored in one or more of the Processing History fields from step **114**. If there are no reserve estimates stored in the one or more Processing History fields, then the method **100** ends. Otherwise, the method **100** proceeds to step **118**.

[0034] In step **118**, the reserve estimates and linked predefined identification properties from step **114** are loaded from the one or more Processing History fields.

[0035] In step **120**, a table and, optionally, a report and/or a graph are generated for the reserve estimates and predefined identification properties loaded in step **118**. One embodiment of a method for performing this step is described further in reference to **FIG. 6.**

Fast Sweep Thickness Extraction

[0036] Referring now to **FIG. 2**, a flow diagram illustrating one embodiment of a method **200** for implementing step **106** in **FIG. 1** is illustrated. The method **200** performs a fast sweep thickness extraction on the sealed triangulated mesh from step **104** to create a thickness grid. The thickness grid may be multiplied by a constant value or by one or more other grids with laterally-varying attributes to produce reserve estimates.

[0037] In step **202**, the sealed triangulated mesh from step **104** is loaded.

[0038] In step **204**, a predefined slice interval and a predefined thickness interval are loaded.

[0039] In step **206**, a plurality of polylines is created by intersecting a vertical plane with the sealed triangulated mesh from step **202** at the predefined slice interval from step **204** along an x-dimension in spatial extents for the sealed triangulated mesh using contouring techniques that are well known in the art. Each polyline includes a first point and a last point.

[0040] In step **208**, a plurality of polygons is created by connecting the first point and the last point of each polyline in a respective vertical plane. Each polygon in the plurality of polygons lies in a respective vertical plane defined by the intersection of the vertical plane with the sealed triangulated mesh at the predefined slice interval.

[0041] In step **210**, each polygon in the plurality of polygons from step **208** is aligned perpendicular to the respective vertical plane.

[0042] In step **212**, a grid is created having an equal number of rows and columns, spatial extents that match the spatial extents of the sealed triangulated mesh from step **202**, a grid x-dimension cell size equal to the predefined slice interval from step **204** and a grid y-dimension cell size equal to the predefined thickness interval from step **204**. Each grid node is initialized with a value of zero. The grid, for example, may have 1000 rows and 1000 columns for computing efficiency and broad application coverage. The grid is preferably positioned above the sealed triangulate mesh from step **202**.

[0043] In step **214**, a plurality of thickness values are computed using techniques well-known in the art and each aligned polygon at the predefined thickness interval from step **204**.

[0044] In step **216**, a thickness grid is created by assigning each thickness value in the plurality of thickness values computed in step **214** to a respective grid node on the grid created in step **212** using the predefined slice interval from step **204** and the predefined thickness interval from step **204**. The predefined slice interval and the predefined thickness interval are used to assign each thickness value to a respective grid node by assigning each thickness value corresponding to a respective vertical plane at the predefined slice interval and predefined thickness interval to a respective grid node on the grid at an x-dimension corresponding to the respective vertical plane at the predefined slice interval and at a y-dimension corresponding to the predefined thickness interval. The thickness grid is returned to step **106** in **FIG. 1**.

Numeric Reserve Estimates

[0045] Referring now to **FIG. 3**, a flow diagram of one embodiment of a method **300** for implementing step **110** in **FIG. 1** is illustrated. The method **300** computes numeric reserve estimates using the volume for the sealed triangulated mesh loaded in step **104.**

[0046] In step **302,** the volume for the sealed triangulated mesh from step **104** is loaded.

[0047] In step **304**, Original Oil In Place (OOIP) is calculated by multiplying the volume loaded in step **302** and a predefined percent value for Net to Gross Ratio (NTG Ratio), porosity, and hydrocarbon saturation.

[0048] In step **306**, Stock Tank Original Oil In Place (STOOIP) is calculated by dividing the OOIP calculated in step **304** by a predefined Formation Volume Factor (FVF).

[0049] In step **308**, Recoverable Hydrocarbon Reserves (RHCR) is calculated by multiplying the STOOIP calculated in step **306** and a predefined recovery factor. The numeric reserve estimates (RHCR) are returned to step **110** in **FIG. 1**.

Spatially Aware Reserve Estimates

[0050] Referring now to **FIG. 4**, a flow diagram of one embodiment of a method **400** for implementing step **112** in **FIG. 1** is illustrated. The method **400** computes spatially aware reserve estimates using the thickness grid from step **106.** A defining feature of the method **400** is the ability to match the thickness grid and an attribute grid. The thickness grid represents the aggregate vertical thickness of a compartment at each grid node. The method **400** enables the thickness grid to be multiplied by one or more grids of laterally-varying attributes to produce a unified grid. Gross volumes may then be derived from gross thickness grids and net volumes may be acquired from the unified grids.

[0051] In step **402,** an attribute grid, a constant value, a predefined FVF, and a predefined recovery factor are loaded. The attribute grid includes an attribute grid node at each intersection of the attribute grid representing a plurality of attribute grid nodes, wherein each attribute grid node has an attribute value. The attribute grid thus, may represent attributes such as porosity or permeability, for example.

[0052] In step **404**, the attribute grid from step **402** is resampled using resampling techniques well known in the art such as bicubic interpolation to match the attribute grid and the thickness grid from step **106** so that the attribute grid includes an attribute grid node at each location of a thickness grid node. As a result, some of the attribute grid nodes may have an attribute value that is null when the attribute grid and the thickness grid are not the same size.

[0053] In step **406**, a unified grid is created by multiplying the thickness value of each grid node on the thickness grid from step **106** and the attribute value of each respective resampled attribute grid node from step **404**. The unified grid thus, includes a unified grid node at each location of an attribute grid node representing a plurality of unified grid nodes, wherein each unified grid node has a value that is the product of the thickness value of a thickness grid node at the same location and the attribute value of a respective resampled attribute grid node at the same location. The value of a unified grid node is invalid if the thickness value of a thickness grid node is at the same location is multiplied by a null attribute value of a respective resampled attribute grid node at the same location. The unified grid also defines a plurality of cells, wherein each cell includes four sides and a center.

[0054] In step **408**, the method **400** determines if the value of each unified grid node is valid. If the value of each unified grid node is valid, then the method proceeds to step **418**. Otherwise, the method proceeds to step **410**.

[0055] In step **410**, the method **400** determines whether to replace each invalid value for a respective unified grid node with the constant value from step **402** using the client interface and/or the video interface described in reference to **FIG. 10**. If each invalid value for a respective unified grid node should not be replaced with the constant value, then the method **400** proceeds to step **414**. Otherwise, then the method **400** proceeds to step **412**.

[0056] In step **412**, the unified grid created in step **406** is converted to an OOIP grid by replacing each invalid value for a respective unified grid node with the constant value from step

402. The OOIP grid thus, includes an OOIP grid node at each location of a respective unified grid node representing a plurality of OOIP grid nodes, wherein each OOIP grid node has a value that is the same value as the valid value of the respective unified grid node or the constant value. The OOIP grid defines a plurality of cells, wherein each cell includes four sides and a center. The method **400** then proceeds to step **418**.

[0057] In step **414**, an average value for each unified grid node with an invalid value is calculated by dividing the sum of the attribute values for the resampled attribute grid nodes from step **404** by the total number of resampled attribute grid nodes from step **404**.

[0058] In step **416**, the unified grid created in step **406** is converted to an OOIP grid by replacing each invalid value for a respective unified grid node with the average value calculated in step **414**. The OOIP grid thus, includes an OOIP grid node at each location of a respective unified grid node representing a plurality of OOIP grid nodes, wherein each OOIP grid node has a value that is the same value as the valid value of the respective unified grid node or the average value. The OOIP grid defines a plurality of cells, wherein each cell includes four sides and a center.

[0059] In step **418**, each cell of the unified grid from step **406,** or each cell of the OOIP grid from step **412** or step **416,** is divided into four triangles. Each of the four triangles for each cell includes a vertex at the center of the respective cell and two vertices that form one of the four sides of the respective cell. Each vertex includes an x, y, z value.

[0060] In step **420**, a truncated prism having a volume is created for each set of four triangles from step **418** by connecting each vertex for a respective triangle to a plane including only the x value and the y value of the respective vertex at z=0.

[0061] In step **422**, OOIP is calculated as the sum of the volumes of the truncated prisms created in step **420**.

[0062] In step **424**, STOOIP is calculated by dividing the OOIP calculated in step **422** by the FVF from step **402**.

[0063] In step **428**, RHCR is calculated by multiplying the STOOIP calculated in step **424** by the recovery factor from step **402**. The spatially aware reserve estimates (RHCR) are returned to step **112** in **FIG. 1**.

Persistence and Restored State

[0064] Referring now to **FIG. 5**, a flow diagram of one embodiment of a method **500** for implementing step **114** in **FIG. 1** is illustrated. The method **500** maintains persistence and restored state for the reserve estimates computed in step **110** or step **112** by storing them with the sealed triangulated mesh loaded in step **104** and the thickness grid from step **106** as a printable string in one or more Processing History fields. In this manner, the reserve estimates are permanently saved with identification, interpreter, date and parameters used. Each saved result of any reserve estimate is linked to relevant predefined identification properties By saving the sealed triangulated mesh, thickness grid and reserve estimates in the Processing History fields, the structure can be recovered, visualized again, and used as a basis for additional analysis even as the structure changes over time.

[0065] In step **502**, the sealed triangulated mesh from step **104**, the thickness grid from step **106** and the reserve estimates computed in step **110** or step **112** are serialized into a byte array using techniques well known in the art.

[0066] In step **504**, the serialized byte array from step **502** is compressed using techniques well known in the art.

[0067] In step **506**, the compressed byte array from step **504** is converted into a printable string using UTF-8/ ASCII characters to make it compatible with standard Processing History fields.

[0068] In step **508**, the printable string from step **506** is stored in one or more of the Processing History fields with a link to the 3D modeling engine and relevant predefined identification properties that uniquely describe the reserve estimates represented by the printable string. The printable string and predefined identification properties are returned to step **114** in **FIG. 1**. In **FIG. 7,** a display **700** illustrates exemplary predefined identification properties linked to a sealed triangulated mesh **702**, **704**, **706**, **708** that is displayed at four different time intervals using the 3D modeling engine. In this manner, the reservoir model at a predetermined time may be dynamically compared to the reservoir model at another predetermined time to improve the reserve estimates in the reservoir model.

Display and Reporting

[0069] Referring now to **FIG. 6**, a flow diagram of one embodiment of a method **600** for implementing step **120** in **FIG. 1** is illustrated. The method **600** generates a table and, optionally, a report and/or a graph for the reserve estimates and the predefined identification properties loaded in step **118.** The report provides abstracted control over the layout and the possibility for additional custom defined layouts in the future.

[0070] In step **602**, the sealed triangulated mesh from step **104**, the reserve estimates and the predefined identification properties from step **118** are loaded.

[0071] In step **604**, a tree table is created by linking the sealed triangulated mesh and each respective reserve estimate using the predefined identification properties. In **FIG. 8**, a display **800** illustrates an exemplary tree table wherein each reserve estimate is represented by the volume/units columns and includes the type of calculation, its date and the interpreter.

[0072] In step **606**, the method **600** determines if an advanced report should be created using the client interface and/or the video interface described in reference to **FIG. 10**. If an advanced report should not be created, then the method **600** proceeds to step **616**. Otherwise, the method proceeds to step **608**.

[0073] In step **608**, the method **600** determines if there is a predefined extensible style-sheet language (XSL) using the client interface and/or the video interface described in reference to **FIG. 10**. If there is not a predefined XSL, then the method **600** proceeds to step **612**. Otherwise, the method **600** proceeds to step **610**.

[0074] In step **610**, the predefined XSL is loaded and interpreted and the method **600** then proceeds to step **614**.

[0075] In step **612**, a default XSL is loaded and interpreted.

[0076] In step **614**, a hyper-text markup language (HTML) report is created by processing the tree table from step **604** with the XSL loaded in step **610** or step **612**. In **FIG. 9,** a display **900** illustrates an exemplary HTML report created with the default XSL from step **612** wherein the individual parameters of each reserve estimate are shown such as the calculation name values for each parameter distinguished by each column.

[0077] In step **616**, the method **600** determines if there are predefined parameters for a graph using the client interface and/or the video interface described in reference to **FIG. 10**. If there are no predefined parameters for a graph, then the method **600** returns the table and, if available, the report to step **120** in **FIG. 1.** Otherwise, the method proceeds to step **618**.

[0078] In step **618**, a graph is formatted using predefined parameters and the tree table from step **604**. The table and, if available, the report and/or the graph are returned to step **120** in **FIG. 1**.

System Description

[0079] The present disclosure may be implemented through a computer-executable program of instructions, such as program modules, generally referred to as software applications or application programs executed by a computer. The software may include, for example, routines, programs, objects, components and data structures that perform particular tasks or implement particular abstract data types. The software forms an interface to allow a computer to react according to a source of input. DecisionSpace® Geosciences, which is a commercial software application marketed by Landmark Graphics Corporation, may be used as an interface application to implement the present disclosure. The software may also cooperate with other code segments to initiate a variety of tasks in response to data received in conjunction with the source of the received data. The software may be stored and/or carried on any variety of memory such as CD-ROM, magnetic disk, bubble memory and semiconductor memory (*e.g.*, various types of RAM or ROM). Furthermore, the software and its results may be transmitted over a variety of carrier media such as optical fiber, metallic wire and/or through any of a variety of networks, such as the Internet.

[0080] Moreover, those skilled in the art will appreciate that the disclosure may be practiced with a variety of computer-system configurations, including hand-held devices, multiprocessor systems, microprocessor-based or programmable-consumer electronics, minicomputers, mainframe computers, and the like. Any number of computer-systems and computer networks are acceptable for use with the present disclosure. The disclosure may be practiced in distributed-computing environments where tasks are performed by remote-processing devices that are linked through a communications network. In a distributed-computing environment, program modules may be located in both local and remote computer-storage media including memory storage devices. The present disclosure may therefore, be implemented in connection with various hardware, software or a combination thereof, in a computer system or other processing system.

[0081] Referring now to **FIG. 10**, a block diagram illustrates one embodiment of a system for implementing the present disclosure on a computer. The system includes a computing unit, sometimes referred to as a computing system, which contains memory, application programs, a client interface, a video interface, and a processing unit. The computing unit is only one example of a suitable computing environment and is not intended to suggest any limitation as to the scope of use or functionality of the disclosure.

[0082] The memory primarily stores the application programs, which may also be described as program modules containing computer-executable instructions, executed by the computing unit for implementing the present disclosure described herein and illustrated in **FIGS. 1-9**. The memory therefore, includes a visual volumetrics module, which enables steps **106, 110, 112 and 120** described in reference to **FIG. 1**. The visual volumetrics module may integrate functionality from the remaining application programs illustrated in **FIG. 10**. In particular, DecisionSpace® Geosciences may be used as an interface application to perform steps **102**, **108**, **116** in **FIG. 1** while steps **104** and **118** may be performed using the database. Although DecisionSpace® Geosciences may be used as an interface application, other interface applications may be used, instead, or the visual volumetrics module may be used as a stand-alone application.

[0083] Although the computing unit is shown as having a generalized memory, the computing unit typically includes a variety of computer readable media. By way of example, and not limitation, computer readable media may comprise computer storage media and communication media. The computing system memory may include computer storage media in the form of volatile and/or nonvolatile memory such as a read only memory (ROM) and random access memory (RAM). A basic input/output system (BIOS), containing the basic routines that help to transfer information between elements within the computing unit, such as during start-up, is typically stored in ROM. The RAM typically contains data and/or program modules that are immediately accessible to, and/or presently being operated on, the processing unit. By way of example, and not limitation, the computing unit includes an operating system, application programs, other program modules, and program data.

[0084] The components shown in the memory may also be included in other removable/nonremovable, volatile/nonvolatile computer storage media or they may be implemented in the computing unit through an application program interface ("API") or cloud computing, which may reside on a separate computing unit connected through a computer system or network. For example only, a hard disk drive may read from or write to nonremovable, nonvolatile magnetic media, a magnetic disk drive may read from or write to a removable, nonvolatile magnetic disk, and an optical disk drive may read from or write to a removable, nonvolatile optical disk such as a CD ROM or other optical media. Other removable/non-removable, volatile/nonvolatile computer storage media that can be used in the exemplary operating environment may include, but are not limited to, magnetic tape cassettes, flash memory cards, digital versatile disks, digital video tape, solid state RAM, solid state ROM, and the like. The drives and their associated computer storage media discussed above provide storage of computer readable instructions, data structures, program modules and other data for the computing unit.

[0085] A client may enter commands and information into the computing unit through the client interface, which may be input devices such as a keyboard and pointing device, commonly referred to as a mouse, trackball or touch pad. Input devices may include a microphone, joystick, satellite dish, scanner, or the like. These and other input devices are often connected to the processing unit through the client interface that is coupled to a system bus, but may be connected by other interface and bus structures, such as a parallel port or a universal serial bus (USB).

[0086] A monitor or other type of display device may be connected to the system bus via an interface, such as a video interface. A graphical user interface ("GUI") may also be used with the video interface to receive instructions from the client interface and transmit instructions to the processing unit. In addition to the monitor, computers may also include other peripheral output devices such as speakers and printer, which may be connected through an output peripheral interface.

[0087] Although many other internal components of the computing unit are not shown, those of ordinary skill in the art will appreciate that such components and their interconnection are well known.

[0088] While the present disclosure has been described in connection with presently preferred embodiments, it will be understood by those skilled in the art that it is not intended to limit the disclosure to those embodiments. It is therefore, contemplated that various alternative embodiments and modifications may be made to the disclosed embodiments without departing from the spirit and scope of the disclosure defined by the appended claims and equivalents thereof.

CLAIMS

1. A method for converting reserve estimates in a reservoir model to a standard format, which comprises:

serializing the reserve estimates, a sealed triangulated mesh and a thickness grid, which each represents a reservoir model, into a byte array using a computer processor;

compressing the byte array; and

converting the compressed byte array into a printable string.

2. The method of claim 1, wherein the compressed byte array is converted into the printable string using UTF-8/ASCII characters.

3. The method of claim 2, further comprising storing the printable string in Processing History fields with a link to a 3D modeling engine and predefined identification properties describing the reserve estimates.

4. The method of claim 1, further comprising dynamically comparing a printable string representing the reservoir model at a predetermined time and another printable string representing the reservoir model at another predetermined time to improve the reserve estimates in the reservoir model.

5. The method of claim 3, wherein the predetermined identification properties include a time stamp for the creation and each update of the reserve estimates, and a last update user identification.

6. The method of claim 1, further comprising displaying at least one of a table, a report and a graph for the reserve estimates and the predefined identification properties using the printable string.

7. The method of claim 6, further comprising displaying the sealed triangulated mesh and the thickness grid with the display of the at least one of the table, the report and the graph.

8. A non-transitory program carrier device tangibly carrying computer-executable instructions for converting reserve estimates in a reservoir model to a standard format, the instructions being executable to implement:

serializing the reserve estimates, a sealed triangulated mesh and a thickness grid, which each represents a reservoir model, into a byte array;

compressing the byte array; and

converting the compressed byte array into a printable string.

9. The program carrier device of claim 8, wherein the compressed byte array is converted into the printable string using UTF-8/ASCII characters.

10. The program carrier device of claim 9, further comprising storing the printable string in Processing History fields with a link to a 3D modeling engine and predefined identification properties describing the reserve estimates.

11. The program carrier device of claim 8, further comprising dynamically comparing a printable string representing the reservoir model at a predetermined time and another printable string representing the reservoir model at another predetermined time to improve the reserve estimates in the reservoir model.

12. The program carrier device of claim 10, wherein the predetermined identification properties include a time stamp for the creation and each update of the reserve estimates, and a last update user identification.

13. The program carrier device of claim 8, further comprising displaying at least one of a table, a report and a graph for the reserve estimates and the predefined identification properties using the printable string.

14. The program carrier device of claim 13, further comprising displaying the sealed triangulated mesh and the thickness grid with the display of the at least one of the table, the report and the graph.

15. A non-transitory program carrier device tangibly carrying computer-executable instructions for converting reserve estimates in a reservoir model to a standard format, the instructions being executable to implement:

serializing the reserve estimates, a sealed triangulated mesh and a thickness grid into a byte array;

compressing the byte array;

converting the compressed byte array into a printable string; and converting the compressed byte array into the printable string using UTF-8/ASCII characters.

16. The program carrier device of claim 15, further comprising storing the printable string in Processing History fields with a link to a 3D modeling engine and predefined identification properties describing the reserve estimates.

17. The program carrier device of claim 15, further comprising dynamically comparing a printable string representing the reservoir model at a predetermined time and another printable string representing the reservoir model at another predetermined time to improve the reserve estimates in the reservoir model.

18. The program carrier device of claim 16, wherein the predetermined identification properties include a time stamp for the creation and each update of the reserve estimates, and a last update user identification.

19. The program carrier device of claim 15, further comprising displaying at least one of a table, a report and a graph for the reserve estimates and the predefined identification properties using the printable string.

20. The program carrier device of claim 19, further comprising displaying the sealed triangulated mesh and the thickness grid with the display of the at least one of the table, the report and the graph.

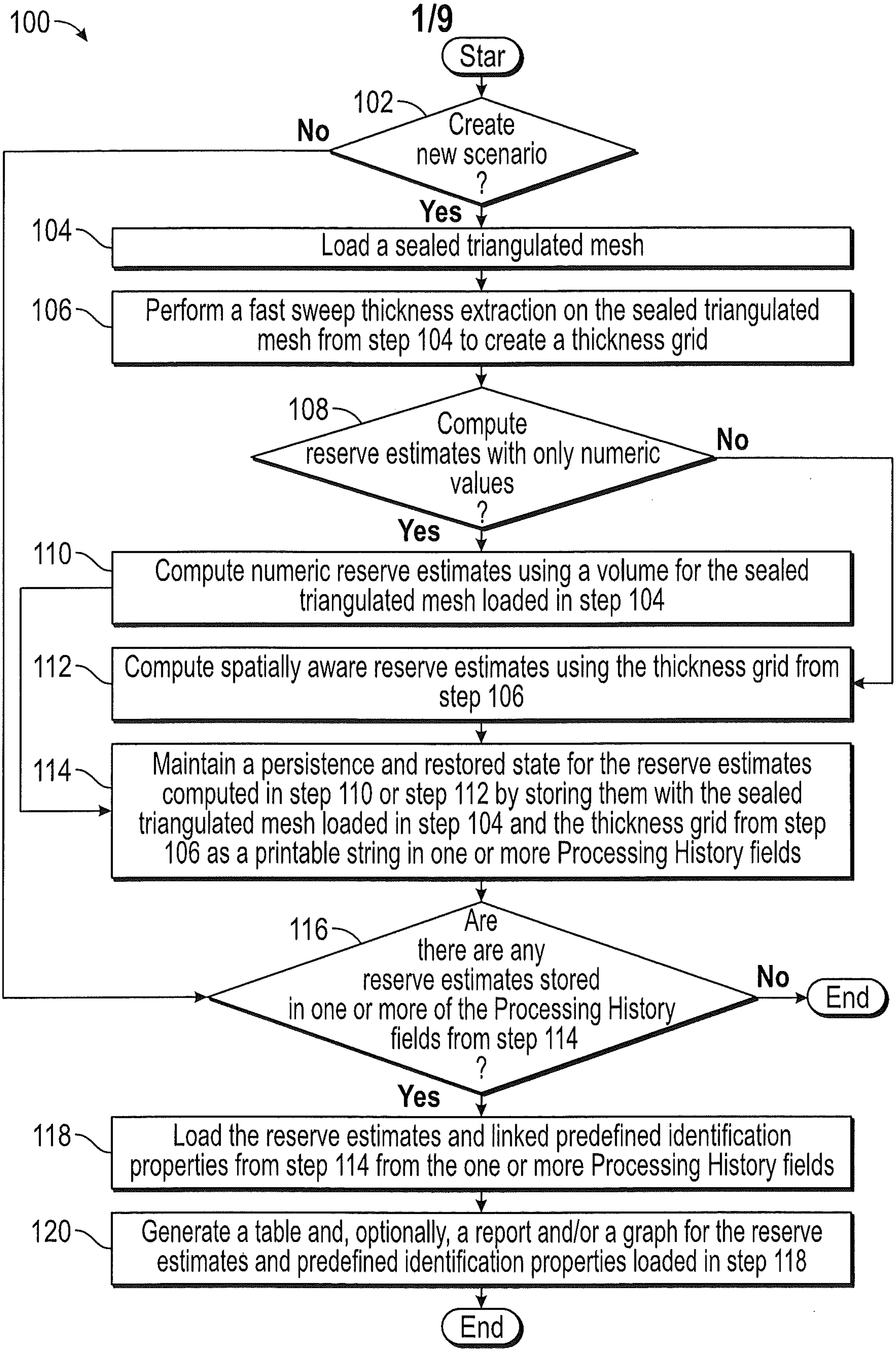

100
Star
102
Create new scenario ?
No
Yes
104
Load a sealed triangulated mesh
106
Perform a fast sweep thickness extraction on the sealed triangulated mesh from step 104 to create a thickness grid
108
Compute reserve estimates with only numeric values ?
No
Yes
110
Compute numeric reserve estimates using a volume for the sealed triangulated mesh loaded in step 104
112
Compute spatially aware reserve estimates using the thickness grid from step 106
114
Maintain a persistence and restored state for the reserve estimates computed in step 110 or step 112 by storing them with the sealed triangulated mesh loaded in step 104 and the thickness grid from step 106 as a printable string in one or more Processing History fields
116
Are there are any reserve estimates stored in one or more of the Processing History fields from step 114 ?
No
End
Yes
118
Load the reserve estimates and linked predefined identification properties from step 114 from the one or more Processing History fields
120
Generate a table and, optionally, a report and/or a graph for the reserve estimates and predefined identification properties loaded in step 118
End

FIG. 1

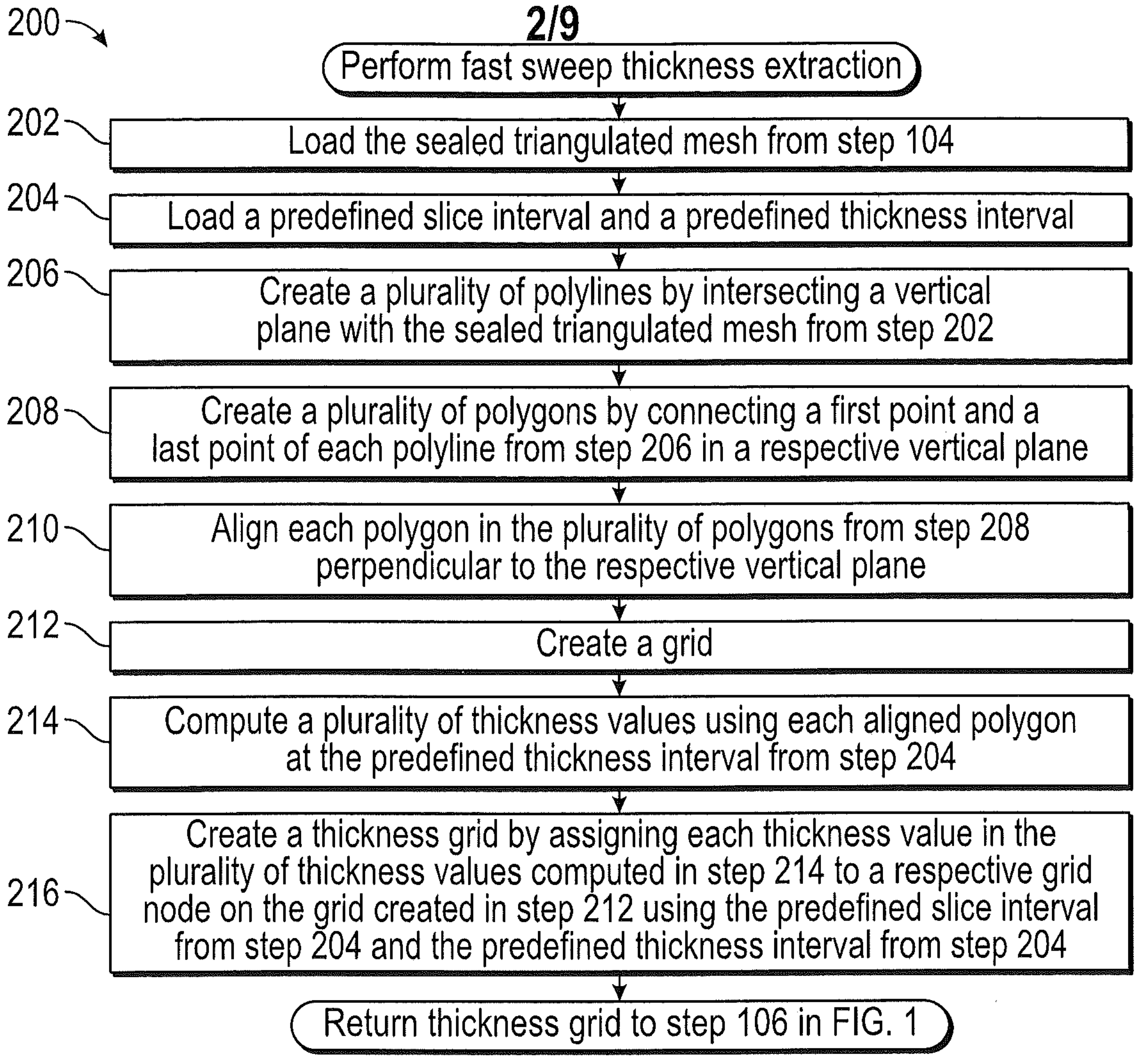

200
Perform fast sweep thickness extraction
202
Load the sealed triangulated mesh from step 104
204
Load a predefined slice interval and a predefined thickness interval
206
Create a plurality of polylines by intersecting a vertical plane with the sealed triangulated mesh from step 202
208
Create a plurality of polygons by connecting a first point and a last point of each polyline from step 206 in a respective vertical plane
210
Align each polygon in the plurality of polygons from step 208 perpendicular to the respective vertical plane
212
Create a grid
214
Compute a plurality of thickness values using each aligned polygon at the predefined thickness interval from step 204
216
Create a thickness grid by assigning each thickness value in the plurality of thickness values computed in step 214 to a respective grid node on the grid created in step 212 using the predefined slice interval from step 204 and the predefined thickness interval from step 204
Return thickness grid to step 106 in FIG. 1

FIG. 2

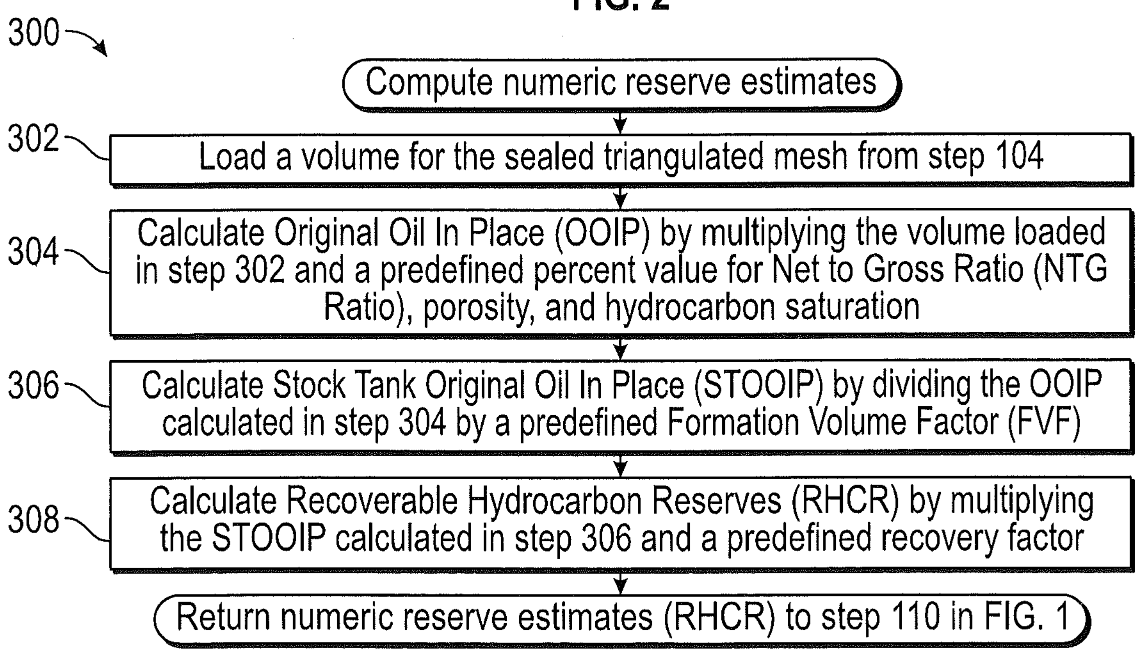

300
Compute numeric reserve estimates
302
Load a volume for the sealed triangulated mesh from step 104
304
Calculate Original Oil In Place (OOIP) by multiplying the volume loaded in step 302 and a predefined percent value for Net to Gross Ratio (NTG Ratio), porosity, and hydrocarbon saturation
306
Calculate Stock Tank Original Oil In Place (STOOIP) by dividing the OOIP calculated in step 304 by a predefined Formation Volume Factor (FVF)
308
Calculate Recoverable Hydrocarbon Reserves (RHCR) by multiplying the STOOIP calculated in step 306 and a predefined recovery factor
Return numeric reserve estimates (RHCR) to step 110 in FIG. 1

FIG. 3

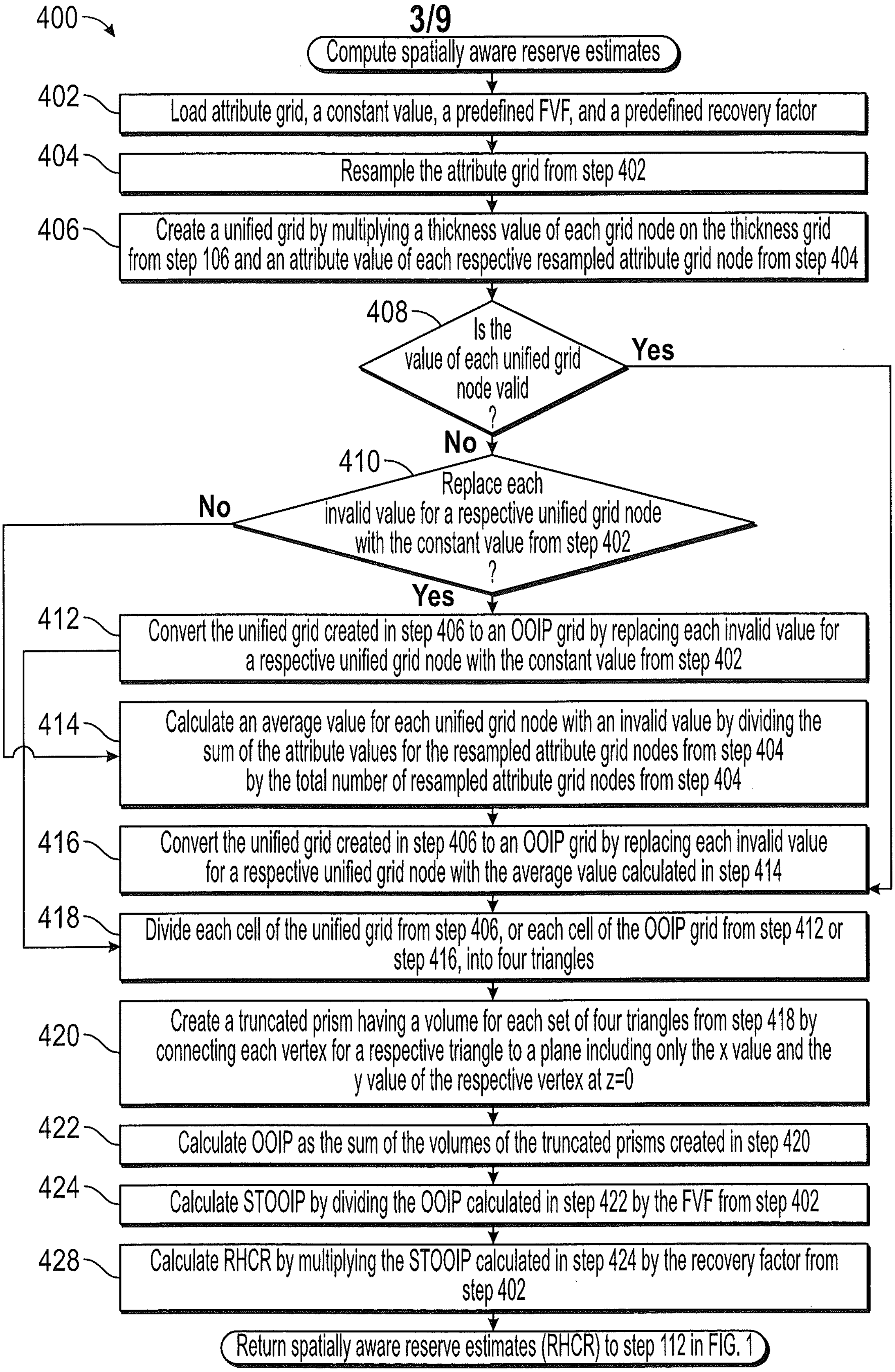

400
Compute spatially aware reserve estimates
402
Load attribute grid, a constant value, a predefined FVF, and a predefined recovery factor
404
Resample the attribute grid from step 402
406
Create a unified grid by multiplying a thickness value of each grid node on the thickness grid from step 106 and an attribute value of each respective resampled attribute grid node from step 404
408
Is the value of each unified grid node valid ?
Yes
No
410
Replace each invalid value for a respective unified grid node with the constant value from step 402 ?
No
Yes
412
Convert the unified grid created in step 406 to an OOIP grid by replacing each invalid value for a respective unified grid node with the constant value from step 402
414
Calculate an average value for each unified grid node with an invalid value by dividing the sum of the attribute values for the resampled attribute grid nodes from step 404 by the total number of resampled attribute grid nodes from step 404
416
Convert the unified grid created in step 406 to an OOIP grid by replacing each invalid value for a respective unified grid node with the average value calculated in step 414
418
Divide each cell of the unified grid from step 406, or each cell of the OOIP grid from step 412 or step 416, into four triangles
420
Create a truncated prism having a volume for each set of four triangles from step 418 by connecting each vertex for a respective triangle to a plane including only the x value and the y value of the respective vertex at z=0
422
Calculate OOIP as the sum of the volumes of the truncated prisms created in step 420
424
Calculate STOOIP by dividing the OOIP calculated in step 422 by the FVF from step 402
428
Calculate RHCR by multiplying the STOOIP calculated in step 424 by the recovery factor from step 402
Return spatially aware reserve estimates (RHCR) to step 112 in FIG. 1

FIG. 4

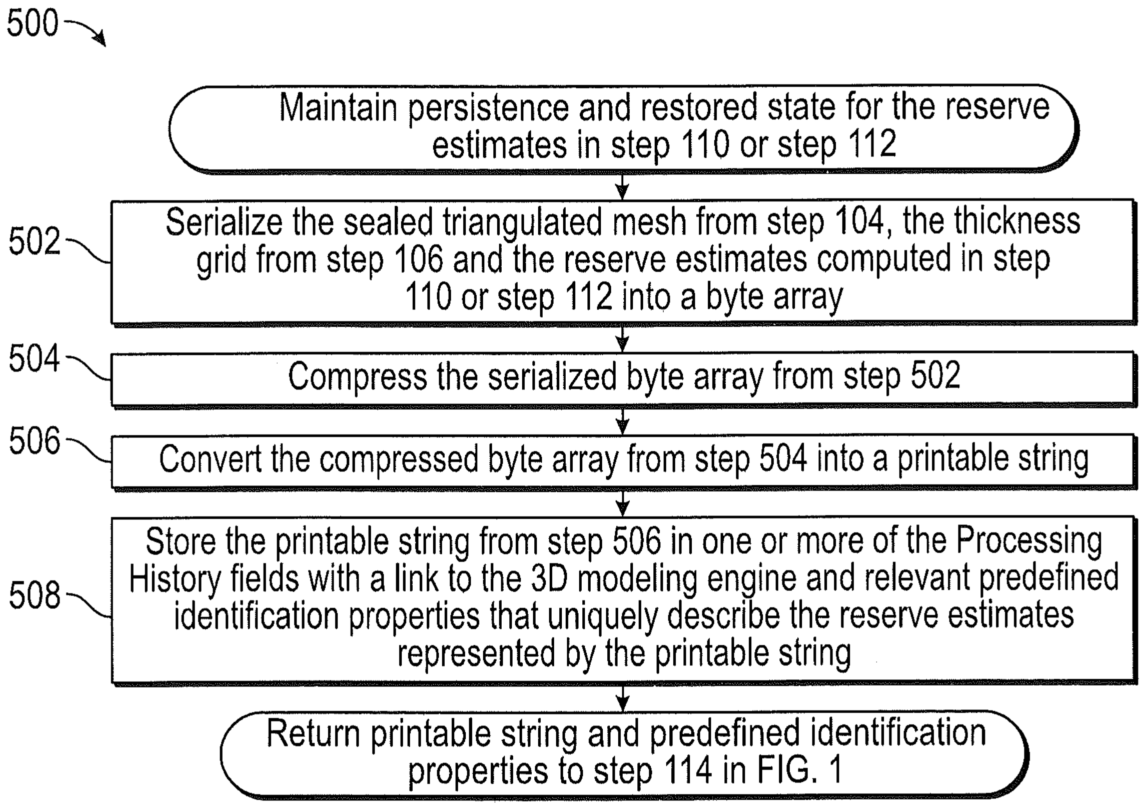
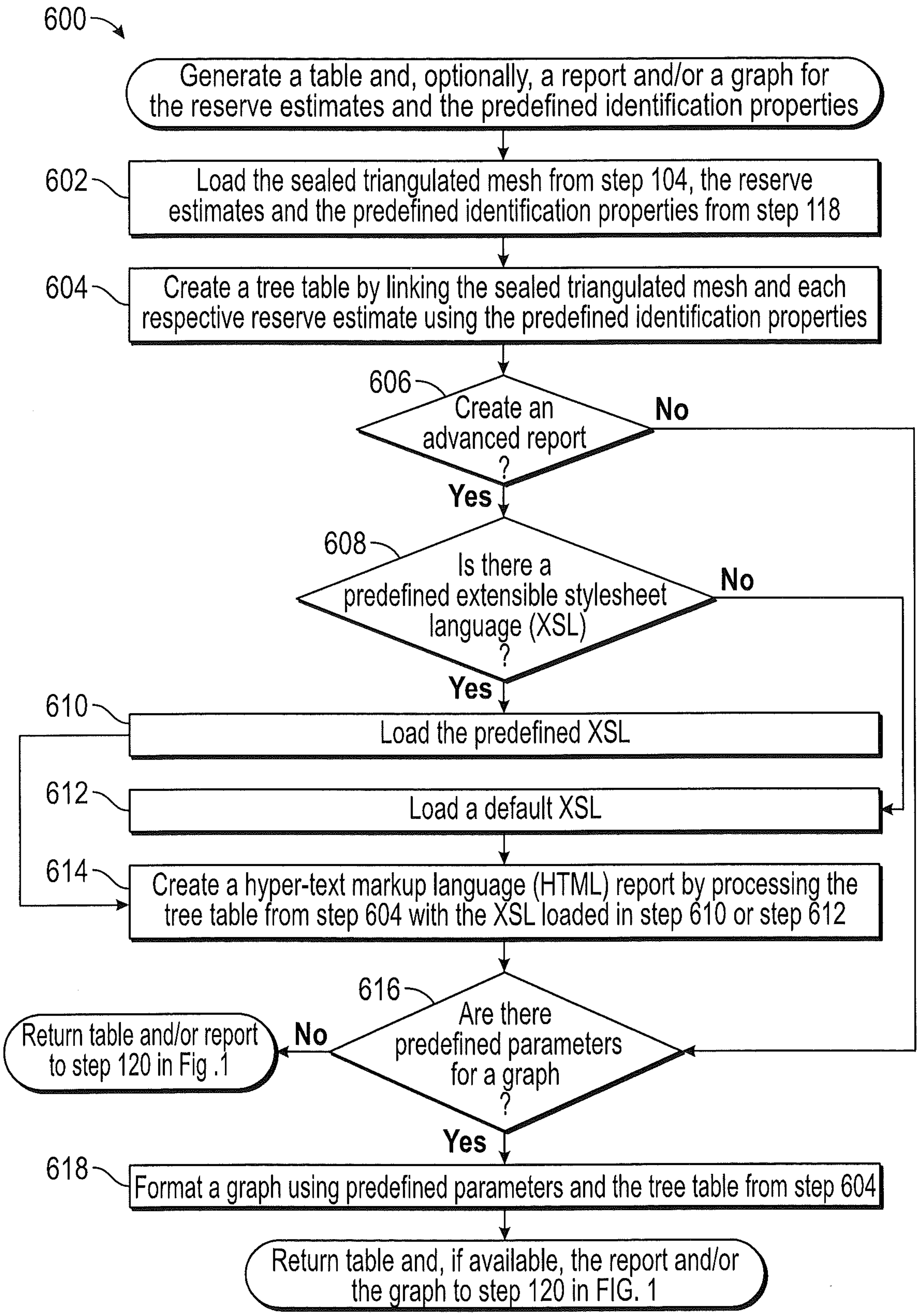

500
Maintain persistence and restored state for the reserve estimates in step 110 or step 112
502
Serialize the sealed triangulated mesh from step 104, the thickness grid from step 106 and the reserve estimates computed in step 110 or step 112 into a byte array
504
Compress the serialized byte array from step 502
506
Convert the compressed byte array from step 504 into a printable string
508
Store the printable string from step 506 in one or more of the Processing History fields with a link to the 3D modeling engine and relevant predefined identification properties that uniquely describe the reserve estimates represented by the printable string
Return printable string and predefined identification properties to step 114 in FIG. 1

FIG. 5



600
Generate a table and, optionally, a report and/or a graph for the reserve estimates and the predefined identification properties
602
Load the sealed triangulated mesh from step 104, the reserve estimates and the predefined identification properties from step 118
604
Create a tree table by linking the sealed triangulated mesh and each respective reserve estimate using the predefined identification properties
606
Create an advanced report ?
No
Yes
608
Is there a predefined extensible stylesheet language (XSL) ?
No
Yes
610
Load the predefined XSL
612
Load a default XSL
614
Create a hyper-text markup language (HTML) report by processing the tree table from step 604 with the XSL loaded in step 610 or step 612
616
Are there predefined parameters for a graph ?
No
Return table and/or report to step 120 in Fig .1
Yes
618
Format a graph using predefined parameters and the tree table from step 604
Return table and, if available, the report and/or the graph to step 120 in FIG. 1

FIG. 6

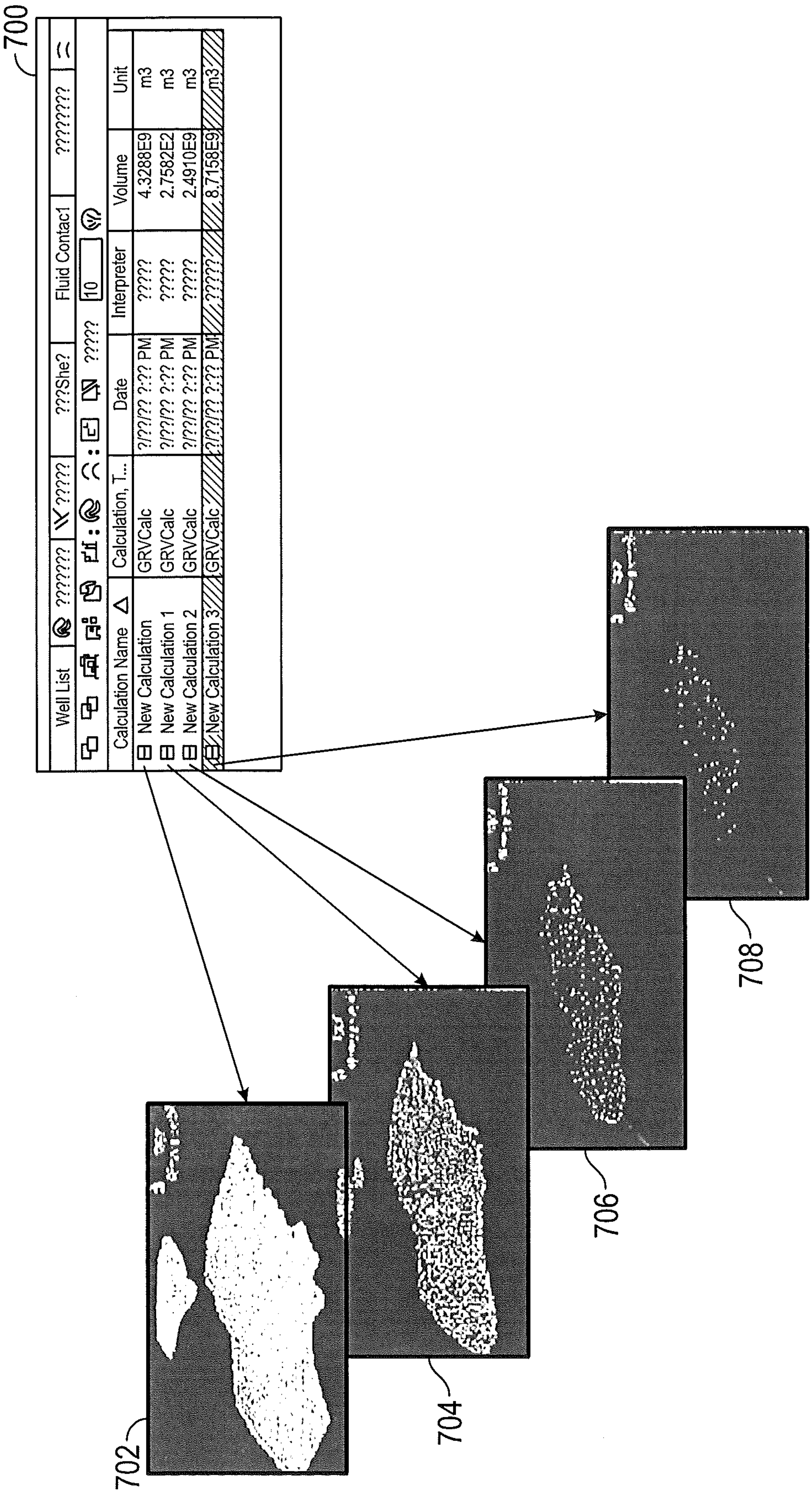

700
Well List
???????
?????
???She?
Fluid Contac1
????????
?????
10
Calculation Name
Calculation, T...
Date
Interpreter
Volume
Unit
New Calculation
New Calculation 1
New Calculation 2
New Calculation 3
GRVCalc
?/??/?? ?:?? PM
?????
4.3288E9
2.7582E2
2.4910E9
8.7158E9
m3
702
704
706
708

FIG. 7

800

Calculation Name ▽	Calculation, T...	Date	Interpreter	Volume	Unit
⊟ Min Contact	GRVCalc	5/15/13 9:30 AM	01STA	1.2035E10	ft3
⊟ OOIP	OOIPCalc	5/15/13 9:31 AM	01STA	2.1435E6	bbl
⊟ STOOIP	STOOIPCalc	5/15/13 9:31AM	01STA	5.3587E6	bbl
RHCR	RHCRCalc	5/15/13 9:31 AM	01STA	2.1435E6	bbl
⊟ Max Contact	GRVCalc	5/14/13 4:08 PM	01STA	3.4079E8	m3
⊟ OOIP	OOIPCalc	5/14/13 4:25 PM	01STA	1.2004E8	bbl
⊟ STOOIP	STOOIPCalc	5/14/13 4:25 PM	01STA	7.0609E7	bbl
0.4 R	RHCRCalc	5/14/13 4:25 PM	01STA	2.8244E7	bbl
0.2 R	RHCRCalc	5/15/13 9:21 AM	01STA	1.4122E7	bbl
⊟ OOIP	OOIPCalc	5/15/13 9:30 AM	01STA	6.8158E5	m3
⊟ STOOIP	STOOIPCalc	5/15/13 9:30 AM	01STA	4.8684E5	m3
RHCR	RHCRCalc	5/15/13 9:30 AM	01STA	2.4342E5	m3
⊟ Min	OOIPCalc	5/15/13 9:27 AM	01STA	2.1435E6	bbl
⊟ Low	STOOIPCalc	5/15/13 9:27 AM	01STA	4.287E6	bbl
0.7 R	RHCRCalc	5/15/13 9:29 AM	01STA	3.0009E6	bbl
0.2 R	RHCRCalc	5/15/13 9:27 AM	01STA	8.574E5	bbl
⊟ High	STOOIPCalc	5/15/13 9:28 AM	01STA	1.2609E6	bbl
0.8 R	RHCRCalc	5/15/13 9:28 AM	01STA	1.0087E6	bbl
0.3 R	RHCRCalc	5/15/13 9:28 AM	01STA	3.7826E5	bbl

FIG. 8

900

Calculation Name	Compartment GRV	Net to Gross	Porosity	HC Saturation	OOIP	Form Vol Factor	STOOIP	Recovery Factor	RHCR	Dat
Max Contact	3.4079E8 m3									2013-0 16:08:
OOIR	3.4079E8 m3	0.10	0.10	0.20	6.8158E5 m3					2013-0 09:30:
STOOIP	3.4079E8 m3	0.10	0.10	0.20	6.8158E5 m3	1.40	4.8684E5 m3			2013-0 09:30:
RHCR	3.4079E8 m3	0.10	0.10	0.20	6.8158E5 m3	1.40	4.8684E5 m3	0.50	2.4342E5 m3	2013-0 09:30:
Min	3.4079E8 m3	0.10	0.10	0.10	2.1435E6 bbl					2013-0 09:27:
Low	3.4079E8 m3	0.10	0.10	0.10	2.1435E6 bbl	0.50	4.287E6 bbl			2013-0 09:27:
0.7 R	3.4079E8 m3	0.10	0.10	0.10	2.1435E6 bbl	0.50	4.287E6 bbl	0.70	3.0009E6 bbl	2013-0 09:27:
0.2 R	3.4079E8 m3	0.10	0.10	0.10	2.1435E6 bbl	0.50	4.287E6 bbl	0.20	8.574E5 bbl	2013-0 09:27:
High	3.4079E8 m3	0.10	0.10	0.10	2.1435E6 bbl	1.70	1.2609E6 bbl			2013-0 09:27:
0.8 R	3.4079E8 m3	0.10	0.10	0.10	2.1435E6 bbl	1.70	1.2609E6 bbl	0.80	1.0007E6 bbl	2013-0 09:27:

FIG. 9

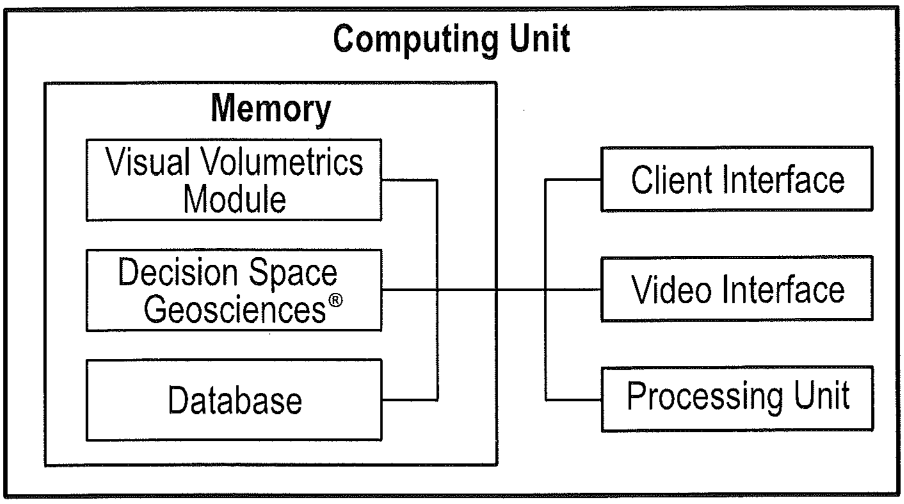

Computing Unit
Memory
Visual Volumetrics Module
Decision Space Geosciences®
Database
Client Interface
Video Interface
Processing Unit

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/051320

A. CLASSIFICATION OF SUBJECT MATTER

G06F 19/00(2011.01)i

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)
G06F; G06Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords : reservior, modeling, simulate

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	KR 10-2011-0034743 A (KOREA INSTITUTE OF GEOSCIENCE AND MINERAL RESOURCES) 06 April 2011 See abstract, claim 1, paragraphs [0034-0052], figures 1-3.	1-20
A	US 7739089 B2 (OMER M. GURPINAR et al.) 15 June 2010 See abstract, claims 1, 11, 23, column 28 line 54-column 31 line 5, figure 7	1-20
A	US 2013-0124169 A1 (WON-MO SUNG) 16 May 2013 See abstract, figure 4, claim 1, paragraphs [0037-0039].	1-20

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

☒ See patent family annex.

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

Date of the actual completion of the international search	Date of mailing of the international search report
17 November 2014 (17.11.2014)	**17 November 2014 (17.11.2014)**

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City, 302-701, Republic of Korea
Facsimile No. +82-42-472-7140

Authorized officer
KIM, Dong Sung
Telephone No. +82-42-481-8519

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
KR 10-2011-0034743 A	06/04/2011	None	
US 7739089 B2	15/06/2010	AT 324327 T	15/05/2006
		AU 2001-35010 A1	03/09/2001
		BR 0108571 A	13/05/2003
		CA 2400796 A1	30/08/2001
		CA 2602280 A1	30/08/2001
		CA 2605860 A1	30/08/2001
		CN 101221634 A	16/07/2008
		CN 1419677 A0	21/05/2003
		DE 60119087 D1	01/06/2006
		EP 1263653 A2	11/12/2002
		EP 1263653 A4	15/09/2004
		EP 1263653 B1	26/04/2006
		EP 1679424 A2	12/07/2006
		EP 1679424 A3	30/08/2006
		EP 1684096 A2	26/07/2006
		EP 1684096 A3	30/08/2006
		EP 1691031 A2	16/08/2006
		EP 1691031 A3	30/08/2006
		EP 1691032 A2	16/08/2006
		EP 1691032 A3	30/08/2006
		EP 1701001 A1	13/09/2006
		JP 04593051 B2	08/12/2010
		JP 2003-524245 A	12/08/2003
		KR 10-0756684 B1	07/09/2007
		KR 2003-0014357 A	17/02/2003
		NO 333783 B1	16/09/2013
		RU 2002122397 A	20/01/2004
		RU 2281384 C2	10/08/2006
		SG 127743 A1	29/12/2006
		US 2005-0149307 A1	07/07/2005
		US 2007-0156377 A1	05/07/2007
		US 2008-0288226 A1	20/11/2008
		US 6980940 B1	27/12/2005
		US 7478024 B2	13/01/2009
		US 7953585 B2	31/05/2011
		WO 01-62603 A2	30/08/2001
		WO 01-62603 A3	30/05/2002
US 2013-0124169 A1	16/05/2013	KR 10-1169867 B1	03/08/2012
		KR 2011-0138088 A	26/12/2011
		US 8798970 B2	05/08/2014
		WO 2011-159109 A2	22/12/2011
		WO 2011-159109 A3	19/04/2012