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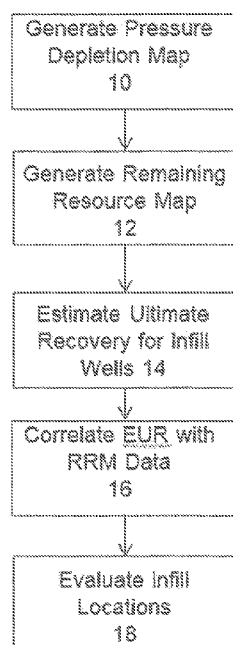
(54) **Title:** SYSTEM AND METHOD FOR REMAINING RESOURCE MAPPING

FIG. 1

(57) **Abstract:** A method for mapping remaining hydrocarbon resources in a subsurface reservoir, includes generating a pressure depletion map (10) of the subsurface reservoir based on a pressure depletion dataset representing a pressure change in at least one well over a time interval, obtaining a hydrocarbon pore thickness map of the subsurface reservoir based on a hydrocarbon pore thickness dataset representing hydrocarbon pore thickness substantially at a beginning of the time interval, using the pressure depletion map and the hydrocarbon pore thickness map, generating a remaining resource map (12) of the subsurface reservoir, for each of a plurality of infill wells located in the subsurface reservoir and operated during a portion of the time interval, determining an estimated ultimate recovery value (14), using each estimated ultimate recovery value with data from the remaining resource map for the locations of the infill wells to determine a correlation (16), and using the correlations and the remaining resource map, evaluating a location for a proposed infill well (18).



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).

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- *with international search report (Art. 21(3))*
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SYSTEM AND METHOD FOR REMAINING RESOURCE MAPPING

TECHNICAL FIELD

[0001] The present invention relates generally to mapping resources in a hydrocarbon reservoir and more particularly to the use of pressure data to estimate remaining resources in a producing reservoir.

BACKGROUND

[0002] As a reservoir undergoes resource production, it may be useful to estimate remaining resources in place in order to make decisions regarding future production decisions. Typically, remaining resources are estimated by generating a geologic model of the subsurface region. The model may be upscaled for use in a reservoir simulator. Then the reservoir simulator is run with reference to production data, pressure data and fluid property variability information, for example. Production information is predicted based on the simulator output and the predictions are compared to historical production information. Where the comparison is reasonable, resources may be determined based on the simulation. Where the difference between the prediction and actual production is too great, the model may be refined and re-run until acceptable results are obtained. Simulations of this type tend to have a high computing cost.

SUMMARY

[0003] A method for mapping remaining hydrocarbon resources in a subsurface reservoir, includes generating a pressure depletion map of the subsurface reservoir based on a pressure depletion dataset representing a pressure change in at least one well over a time interval, obtaining a hydrocarbon pore thickness map of the subsurface reservoir based on a hydrocarbon pore thickness dataset representing hydrocarbon pore thickness substantially at a beginning of the time interval, using the pressure depletion map and the hydrocarbon pore thickness map, generating a remaining resource map of the subsurface reservoir, for each of a plurality of infill wells located in the subsurface reservoir and operated during a portion of the time interval, determining an estimated ultimate recovery value, using each estimated ultimate recovery value with data from the remaining resource map for the locations of the infill wells to determine a correlation, and using the correlations and the remaining resource map, evaluating a location for a proposed infill well.

[0004] A system for implementing the foregoing method includes at least one processor and at least one associated memory and modules configured to execute a method including method for mapping remaining hydrocarbon resources in a subsurface reservoir, includes generating a pressure depletion map of the subsurface reservoir based on a pressure depletion dataset representing a pressure change in at least one well over a time interval, obtaining a hydrocarbon pore thickness map of the subsurface reservoir based on a hydrocarbon pore thickness dataset representing hydrocarbon pore thickness substantially at a beginning of the time interval, using the pressure depletion map and the hydrocarbon pore thickness map, generating a remaining resource map of the subsurface reservoir, for each of a plurality of infill wells located in the subsurface reservoir and operated during a portion of the time interval, determining an estimated ultimate recovery value, using each estimated ultimate recovery value with data from the remaining resource map for the locations of the infill wells to determine a correlation, and using the correlations and the remaining resource map, evaluating a location for a proposed infill well.

[0005] A non-transitory processor readable medium containing computer readable software instructions used to perform the foregoing method.

BRIEF DESCRIPTION OF DRAWINGS

[0006] Figure 1 is a flowchart illustrating steps performed in a method in accordance with an embodiment;

[0007] Figure 2 illustrates production rates of gas and oil as well as a pressure trend line over time in a reservoir;

[0008] Figures 3A and 3B illustrates high and low pressure gradient cases respectively for the region under study;

[0009] Figure 4 illustrates a ratio between initial pressure and pressure after a period of production for the region shown in Figure 3;

[0010] Figure 5 illustrates original hydrocarbon pore thickness for the region;

[0011] Figure 6 illustrates a remaining resources estimate generated based on the pressure ratio of Figure 4 and the hydrocarbon pore thickness of Figure 5;

[0012] Figures 7A and 7B illustrate high and low cases for remaining resources for the region;

[0013] Figure 8 illustrates production for a well before and after an adjacent infill production;

[0014] Figure 9 illustrates a well field showing contours of incremental reserve production based on infill response production plots;

[0015] Figure 10 illustrates a correlation between a remaining resource map (RRM) value and an average estimated ultimate recovery (EUR) for a group of infill wells; and

[0016] Figure 11 illustrates an embodiment of a use of the correlation diagram of Figure 10 for additional infill EUR estimates.

DETAILED DESCRIPTION

[0017] Embodiments include methods for estimating remaining resources using measured reservoir pressure in combination with initial hydrocarbon thickness data in accordance with a flowchart as illustrated in Figure 1. Initial hydrocarbon thickness data is represented with a map of original gas net pay or net gas hydrocarbon pore thickness (gas HPT) with HPT representing the product of true vertical thickness net sand with porosity (fraction) and gas saturation (fraction). Estimates of the pressure throughout the field can be generated based on well surveillance measurements, and the pressure field may be estimated as ranges having high estimates and low estimates for each position in the field. Examples of well surveillance measurements may include, without limitation, shut-in bottom hole reservoir pressure and fluid production tests. As an example, the pressures across the reservoir may be expressed as a grid, and a set of grids having high and low estimates can be generated, and may be used to generate a map 10.

[0018] Similarly, initial gas hydrocarbon pore thickness grids may be generated based on seismic imaging and/or well monitoring data. In this regard, the HPT map may be part of an ensemble of different maps which represent different assumptions regarding the initial reservoir state. As will be appreciated, the actual acquisition of seismic data, along with various processing techniques, may be performed by a third-party vendor, such that obtaining data should be understood to encompass direct acquisition as well as retrieval or receipt of data from a storage medium or database. The hydrocarbon thickness grids may then be multiplied by the pressure grids to create grids that are representative of ranges of remaining

resources across the reservoir 12. The high and low cases may also be used to generate average cases.

[0019] For each of a number of infill wells, an EUR is produced 14. This estimate can be performed in any conventional manner, such as decline curve analysis techniques. Examples of such techniques include exponential or hyperbolic trend analysis on rate versus time plots.

[0020] In an embodiment, the estimated remaining resource map may be generated for any given time using historical pressure values. In this approach, a pressure map generated by using pressure values from a time prior to drilling a selected infill well, or wells, combined with the original HPT map are used to develop a correlation factor 16 between remaining resource value from the grid and estimated ultimate recovery for the infill well. Where the correlation factor is high, the remaining resource estimate can be considered to be an accurate estimate.

[0021] The resulting remaining resource estimates can then be used to determine which areas in the reservoir are likely to be good candidates for infill or injection well drilling 18. Furthermore, estimates of incremental production vs. accelerated production due to infill well drilling may be produced, and those estimates can further inform decisions relating to further field development activities.

[0022] Each of the foregoing steps is discussed in greater detail below.

[0023] Figure 2 illustrates diagnostic information relating to a particular well in the region of interest. As shown in the figure, rates of extraction for oil and gas versus time may be determined. Likewise, shut in bottom hole pressure (SIBHP) measurements may be taken for each well, and high and low case trend lines may be generated based on those measurements. Over time, both the reservoir bottom hole pressure (BHP) and extraction rates fall as the region becomes depleted.

[0024] Figures 3A and 3B are pressure gradient maps, produced based on a number of measurements of the type illustrated in Figure 2. That is, BHP is measured for several wells in the reservoir, through any of a variety of techniques to measure shut-in BHP, including pressure bombs or gauges, or other surveillance measurements such as Modular Dynamic Testers (MDTs). Once the measurements are obtained at the wellbore, pressures throughout the reservoir are estimated by interpolation and extrapolation. In particular, pressure at the

boundary of the region under study may have to be extrapolated from the observed gradients as in the illustrated case there are no wells to provide data at the edges of the region. High and low estimates for boundary pressure results in high (as illustrated in Figure 3A) and low (Figure 3B) gradients throughout the region.

[0025] Once the pressure maps are generated for any given time period, they may be compared to an initial pressure map to produce a pressure depletion map, which may be illustrated as a ratio as illustrated in Figure 4. As will be appreciated, pressure ratio maps may be based on an average current pressure, or on high or low estimates of pressure, or an ensemble of pressure ratio maps may be created. Regions 20 (outlined in white) are pressure-depleted as a result of the production activities in the reservoir.

[0026] An initial hydrocarbon pore thickness map is shown in Figure 5. For reference, the depleted regions 20 from Figure 4 are outlined. As will be appreciated, the initial HPT map should represent data taken at substantially the same time as the beginning of the time period over which the pressure depletion is measured. Which is the initial state of the reservoir just prior to commencement of production of hydrocarbons.

[0027] Using the initial HPT of Figure 5 and the pressure ratio of Figure 4, using a grid to grid multiplication, a remaining resource map is generated as illustrated in Figure 6. The pressure ratio reflects an estimate of how much hydrocarbon has been removed, while the initial HPT reflects an estimate of initial hydrocarbon resources in place. Their product, therefore, represents an estimate of the remaining hydrocarbon potential at any given location. Thus, high RRM regions correspond to regions with high initial HPT and high current pressure ratio (i.e., relatively little produced hydrocarbons). A pair of such regions are indicated by reference number 22.

[0028] Figures 7A and 7B represent high and low estimates for RRM resulting from the range of pressure gradients as shown in Figures 3A and 3B. In either case, multiple RRMs may be produced, and the range of maps may be used for subsequent analysis and decision-making. High RRM regions 22 are highlighted, as in Figure 6.

[0029] A field manager may use this information as the basis for a decision to conduct drilling operations within the high remaining resource regions 22 in order to increase field output. On the other hand, measuring the existence of these additional available resources may not be a sufficient basis for such decision-making. In particular, in the case where the

already drilled wells would eventually recover the resources located in regions 22, additional drilling operations may not be merited. In that case, the additional well would represent accelerated production rather than additional (incremental) production. In other words, accelerated production would represent producing hydrocarbons more quickly while additional production would represent a larger amount of hydrocarbons to be produced. While accelerated production may be desirable, for example where a lease is scheduled to end before all of the resources would be produced, it is not necessarily the most efficient use of drilling funds absent a compelling reason to accelerate production.

[0030] In this regard, it may be useful to augment the method by estimating, for a given proposed location, a ratio of acceleration to incremental production. In accordance with an embodiment, a method of determining this ratio begins by examining performance of other infill wells in the reservoir, with regard to their impact on existing wells, and estimating what proportion of the production of the infill wells represents acceleration versus incremental production.

[0031] Figure 8 illustrates historical production data for a well over time, with associated impact on the production from a nearby infill well. While the selected time period may vary, it should be a period where a decline trend sufficient to make projections is observed, generally a period of 3-5 years. The two trend lines, developed from hyperbolic rate-time decline curve analysis techniques, represent low and high production predictions assuming that the infill well was not drilled and are based on the trend up to the time at which the infill well was drilled. The low versus high trends are developed by varying the initial decline rate and “b” (curvature) factors used in the decline curve analysis. The dashed line indicates the actual observed production trend after drilling the infill well, and the difference between observed and predicted represents the amount (a percentage) of acceleration impact due to the infill well. That is, this difference represents some portion of hydrocarbon expected to be produced at this well, that appears to have instead been produced by the infill well, or at least transported towards the infill well and outside the capture radius of the subject well.

[0032] The upper trend line 30 in Figure 8, indicating acceleration impact of 43% post the date of the infill well, assumes a high initially available hydrocarbon resource for the pre-existing well, while the lower line, indicating acceleration impact of 33% represents an assumption of a somewhat lower initially available hydrocarbon resource.

[0033] Similar estimates may be made for each infill well in the field. Once this is completed a series of acceleration impact radii may be determined for each of the wells, based on actual distance between infills and a given group of surrounding pre-existing wells. The radii distances are based on the actual distance measured between infill wells and the offset existing producers that were reviewed for acceleration impact (example of which was illustrated in Figure 8). The acceleration impact radii are digitized around existing producers and each radii are assigned acceleration impact values based on the average values computed from infill wells drilled within those radii from the technique illustrated in Figure 8. Interpolating these assigned values across the mapped area allows acceleration contours to be defined over the entire field. Since a map of incremental potential is desired to calculate incremental recovery, the acceleration values assigned to each radii are converted to incremental values where $[\text{incremental recovery}] = [1 - \text{acceleration impact}]$. Figure 9 illustrates this concept, showing 70% incremental and 85% incremental contours (i.e., regions in which acceleration was observed is 30% and 15% respectively). As with each of the other steps, it is possible to develop high and low case incremental recovery maps from the upper and lower acceleration impact lines illustrated in Figure 8.

[0034] For additional proposed infill locations, the field-wide correlation between EUR and RRM value developed from prior analyzed years may be further used to estimate total EUR for that location. The correlation may be determined by plotting EUR v. RRM values for various infill wells and then fitting a line to the data. For example, Figure 10 shows, for a number of infill wells B40z, B42, B43, B44, B45 and B46, the correlation between EUR and RRM. A best fit trend line indicating a correlation of 0.92 is illustrated, along with dashed lines indicating plus or minus one standard deviation. For a proposed well, a remaining resource value may be determined from the current remaining resource map. A horizontal line at that value will intersect with the best fit line and the standard deviation lines at points defining low, average and high estimates of EUR for that well. By way of example, an infill well at a site having RRM of 7.8, the estimate of EUR will be: low – 36 BCF, average – 50 BCF, and high – 63 BCF, as illustrated in Figure 11.

[0035] Once the estimates are produced, estimate information may be combined with acceleration/incremental production information at each proposed infill site from the map in Figure 9 to make decisions regarding appropriate placement of infill wells from among a group of possible locations.

[0036] The above described methods can be implemented in the general context of instructions executed by a computer. Such computer-executable instructions may include programs, routines, objects, components, data structures, and computer software technologies that can be used to perform particular tasks and process abstract data types. Software implementations of the above described methods may be coded in different languages for application in a variety of computing platforms and environments. It will be appreciated that the scope and underlying principles of the above described methods are not limited to any particular computer software technology.

[0037] Moreover, those skilled in the art will appreciate that the above described methods may be practiced using any one or a combination of computer processing system configurations, including, but not limited to, single and multi-processor systems, hand-held devices, programmable consumer electronics, mini-computers, or mainframe computers. The above described methods may also be practiced in distributed computing environments where tasks are performed by servers or other processing devices that are linked through a one or more data communications networks. In a distributed computing environment, program modules may be located in both local and remote computer storage media including memory storage devices.

[0038] Also, an article of manufacture for use with a computer processor, such as a CD, pre-recorded disk or other equivalent devices, could include a computer program storage medium and program means recorded thereon for directing the computer processor to facilitate the implementation and practice of the above described methods. Such devices and articles of manufacture also fall within the spirit and scope of the present invention.

[0039] As used in this specification and the following claims, the terms “comprise” (as well as forms, derivatives, or variations thereof, such as “comprising” and “comprises”) and “include” (as well as forms, derivatives, or variations thereof, such as “including” and “includes”) are inclusive (i.e., open-ended) and do not exclude additional elements or steps. Accordingly, these terms are intended to not only cover the recited element(s) or step(s), but may also include other elements or steps not expressly recited. Furthermore, as used herein, the use of the terms “a” or “an” when used in conjunction with an element may mean “one,” but it is also consistent with the meaning of “one or more,” “at least one,” and “one or more than one.” Therefore, an element preceded by “a” or “an” does not, without more constraints, preclude the existence of additional identical elements.

While in the foregoing specification this invention has been described in relation to certain preferred embodiments thereof, and many details have been set forth for the purpose of illustration, it will be apparent to those skilled in the art that the invention is susceptible to alteration and that certain other details described herein can vary considerably without departing from the basic principles of the invention. For example, the invention can be implemented in numerous ways, including for example as a method (including a computer-implemented method), a system (including a computer processing system), an apparatus, a computer readable medium, a computer program product, a graphical user interface, a web portal, or a data structure tangibly fixed in a computer readable memory.

WHAT IS CLAIMED IS:

1. A method for mapping remaining hydrocarbon resources in a subsurface reservoir, comprising:
 - generating a pressure depletion map of the subsurface reservoir based on a pressure depletion dataset representing a pressure change in at least one well over a time interval;
 - obtaining a hydrocarbon pore thickness map of the subsurface reservoir based on a hydrocarbon pore thickness dataset representing a hydrocarbon pore thickness substantially at a beginning of the time interval;
 - using the pressure depletion map and the hydrocarbon pore thickness map, generating a remaining resource map of the subsurface reservoir;
 - for each of a plurality of infill wells located in the subsurface reservoir and operated during a portion of the time interval, determining an estimated ultimate recovery value;
 - using each estimated ultimate recovery value with data from the remaining resource map for the locations of the infill wells to determine a correlation; and
 - using the correlations and the remaining resource map, evaluating a location for a proposed infill well.
2. A method as in claim 1, further comprising, estimating, for the proposed infill well location, a proportion of infill well production that represents accelerated production and a proportion of infill well production that represents incremental impact of the infill well, wherein the estimating is based on the remaining resource map and the correlations.
3. A method as in claim 2, wherein the estimating is further used to generate contours of incremental reserves for the subsurface reservoir.
4. A method as in claim 2, wherein an ensemble of estimates of incremental impact is generated.
5. A method as in claim 1, wherein the estimated ultimate recovery value for each well is estimated based, at least in part, on measured pressure decline rate and cumulative production for each well.
6. A method as in claim 1, wherein the estimated ultimate recovery value for each well comprises a range of estimated ultimate recoveries.
7. A method as in claim 1, wherein the generating a pressure depletion map comprises generating high and low case pressure depletion maps.
8. A system for mapping remaining hydrocarbon resources in a subsurface reservoir, comprising:
 - a depletion map module configured and arranged to generate a pressure depletion map

of the subsurface reservoir based on a pressure depletion dataset representing a pressure change in at least one well over a time interval;

a pore thickness map module configured and arranged to obtain a hydrocarbon pore thickness map of the subsurface reservoir based on a hydrocarbon pore thickness dataset representing hydrocarbon pore thickness substantially at a beginning of the time interval;

a remaining resource map module configured and arranged to use the pressure depletion map and the hydrocarbon pore thickness map, to generate a remaining resource map of the subsurface reservoir;

an estimated ultimate recovery module configured and arranged to, for each of a plurality of infill wells located in the subsurface reservoir and operated during a portion of the time interval, determine an estimated ultimate recovery value;

a correlation module configured and arranged to use each estimated ultimate recovery value with data from the remaining resource map for the locations of the infill wells to determine a correlation; and

an evaluation module configured and arranged to, using the correlations and the remaining resource map, evaluate a location for a proposed infill well.

9. A non-transitory processor readable medium containing computer readable software instructions for performing the method comprising:

generating a pressure depletion map of the subsurface reservoir based on a pressure depletion dataset representing a pressure change in at least one well over a time interval;

obtaining a hydrocarbon pore thickness map of the subsurface reservoir based on a hydrocarbon pore thickness dataset representing hydrocarbon pore thickness substantially at a beginning of the time interval;

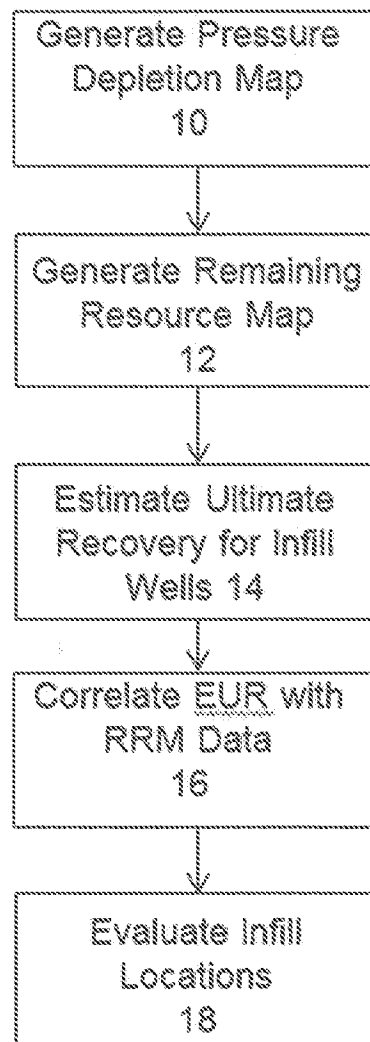
using the pressure depletion map and the hydrocarbon pore thickness map, generating a remaining resource map of the subsurface reservoir;

for each of a plurality of infill wells located in the subsurface reservoir and operated during a portion of the time interval, determining an estimated ultimate recovery value;

using each estimated ultimate recovery value with data from the remaining resource map for the locations of the infill wells to determine a correlation; and

using the correlations and the remaining resource map, evaluating a location for a proposed infill well.

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**FIG. 1**

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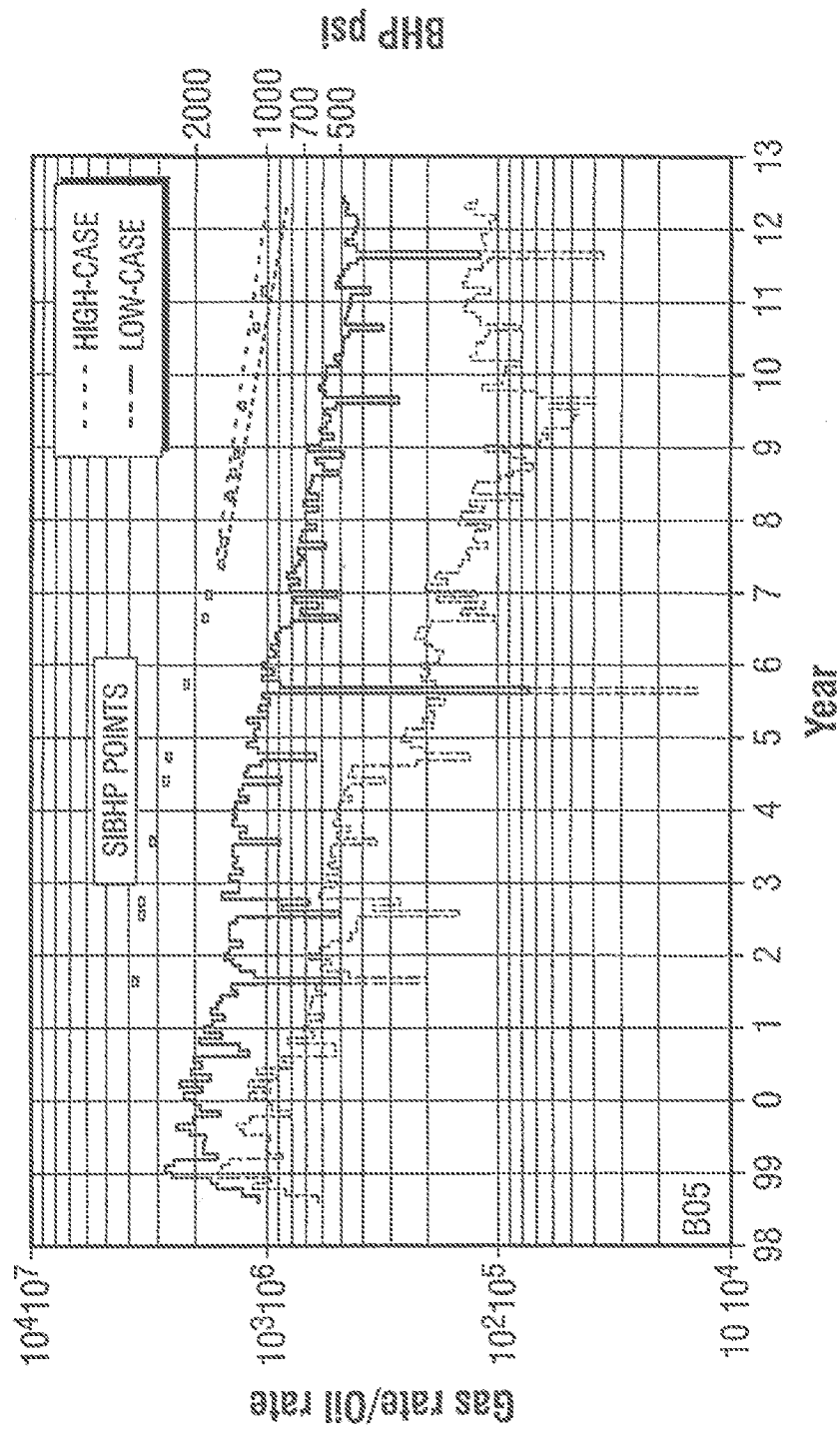
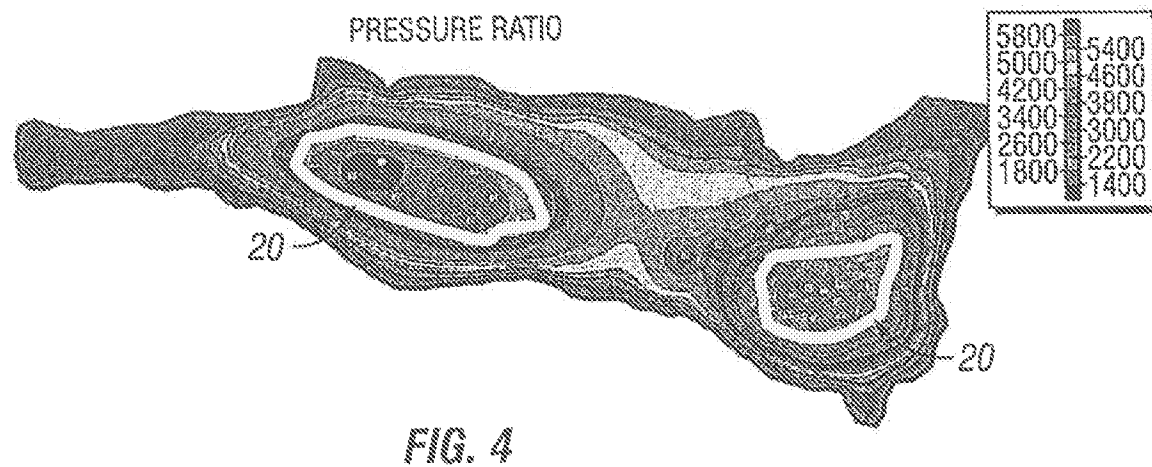
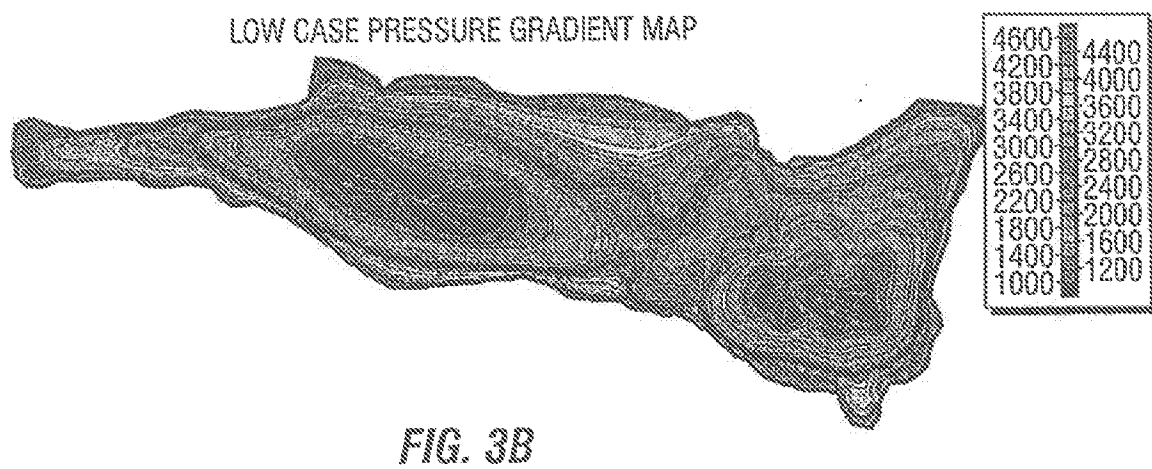
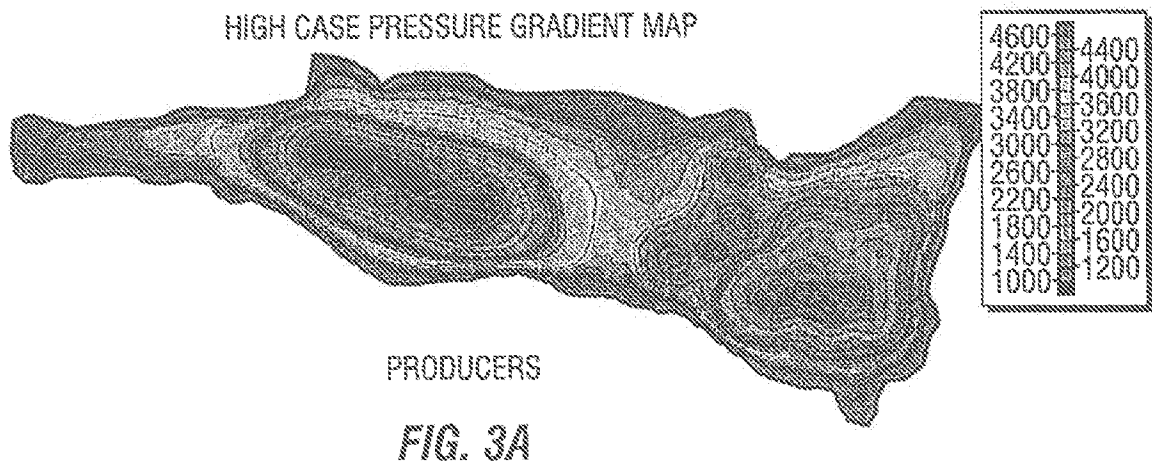
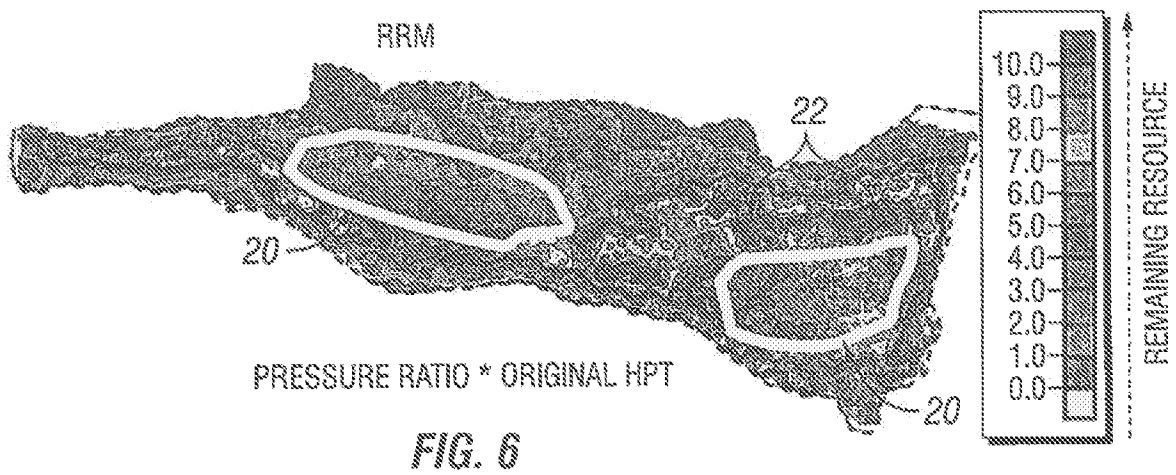
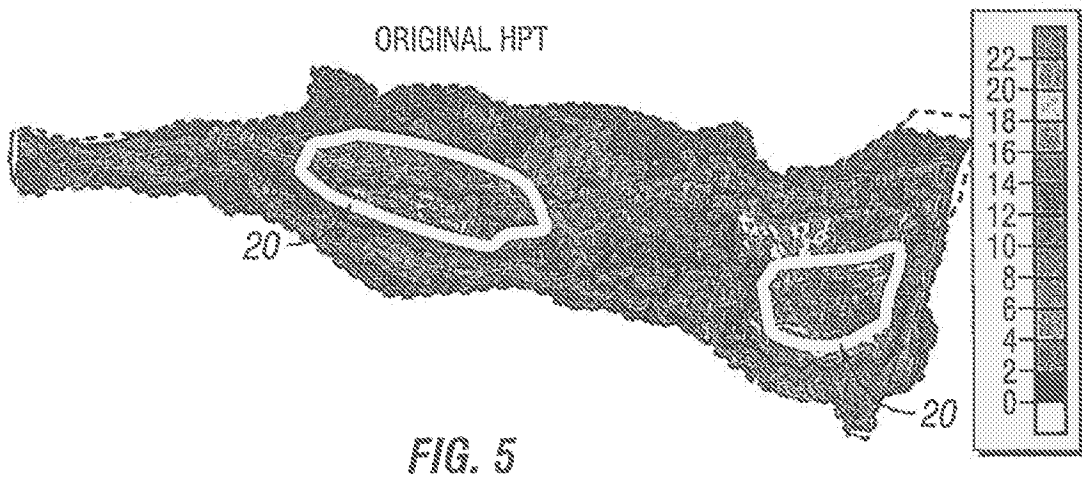


FIG. 2

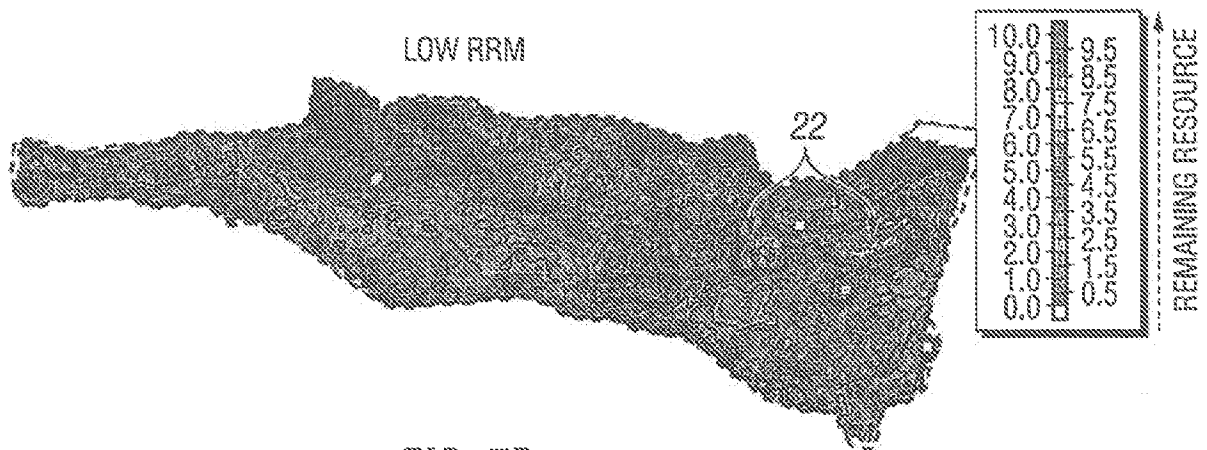
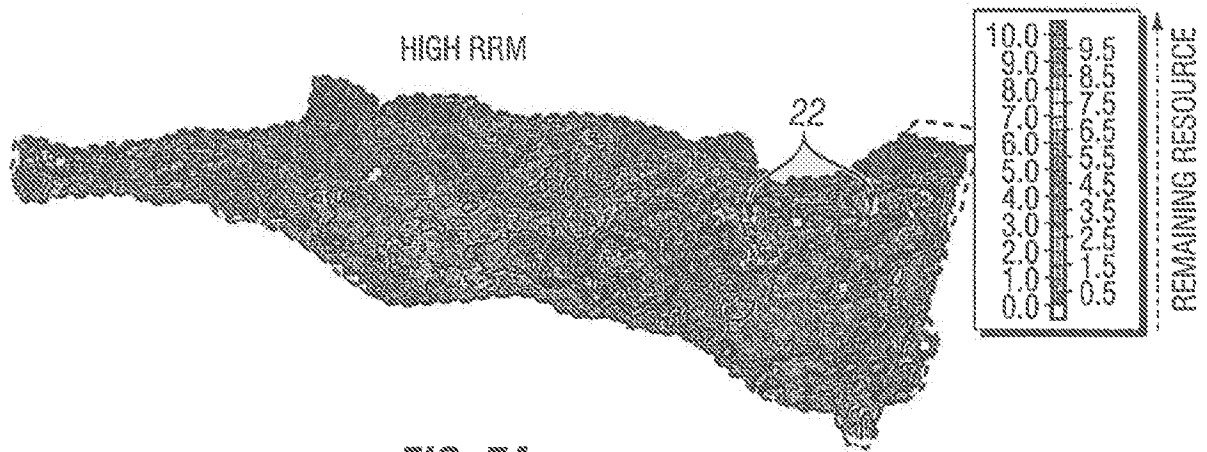
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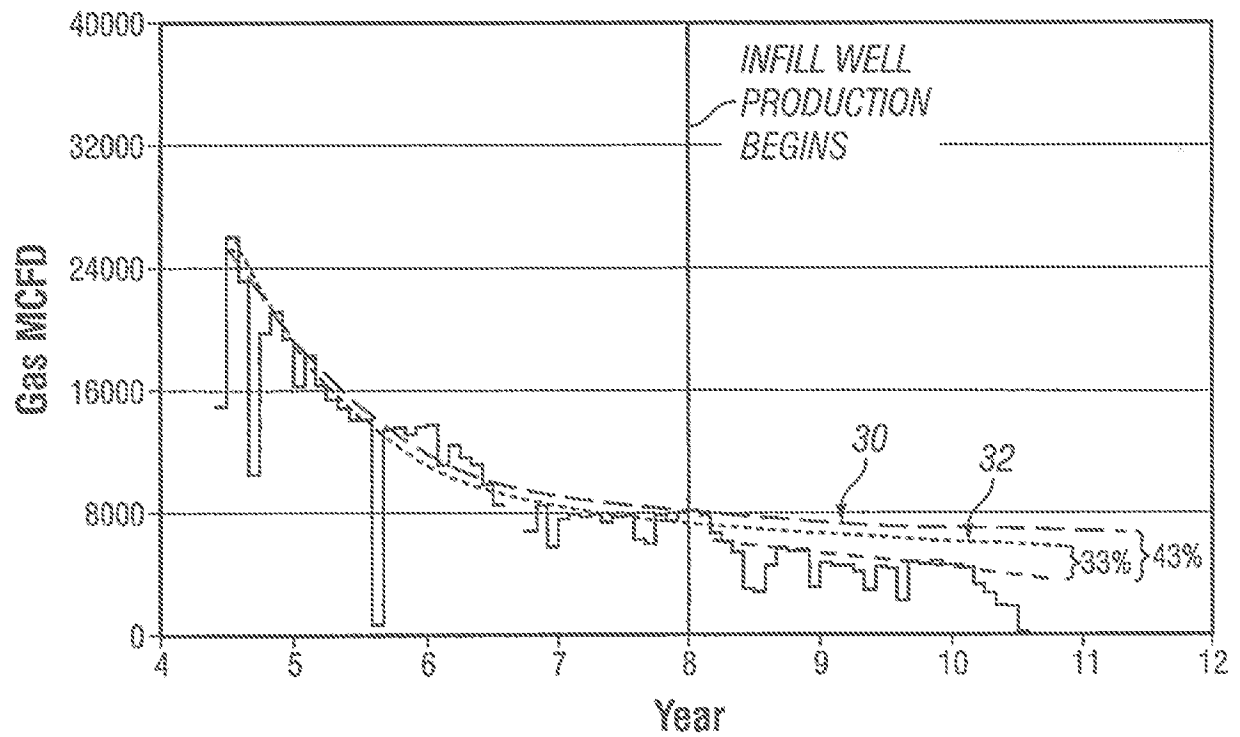


FIG. 8

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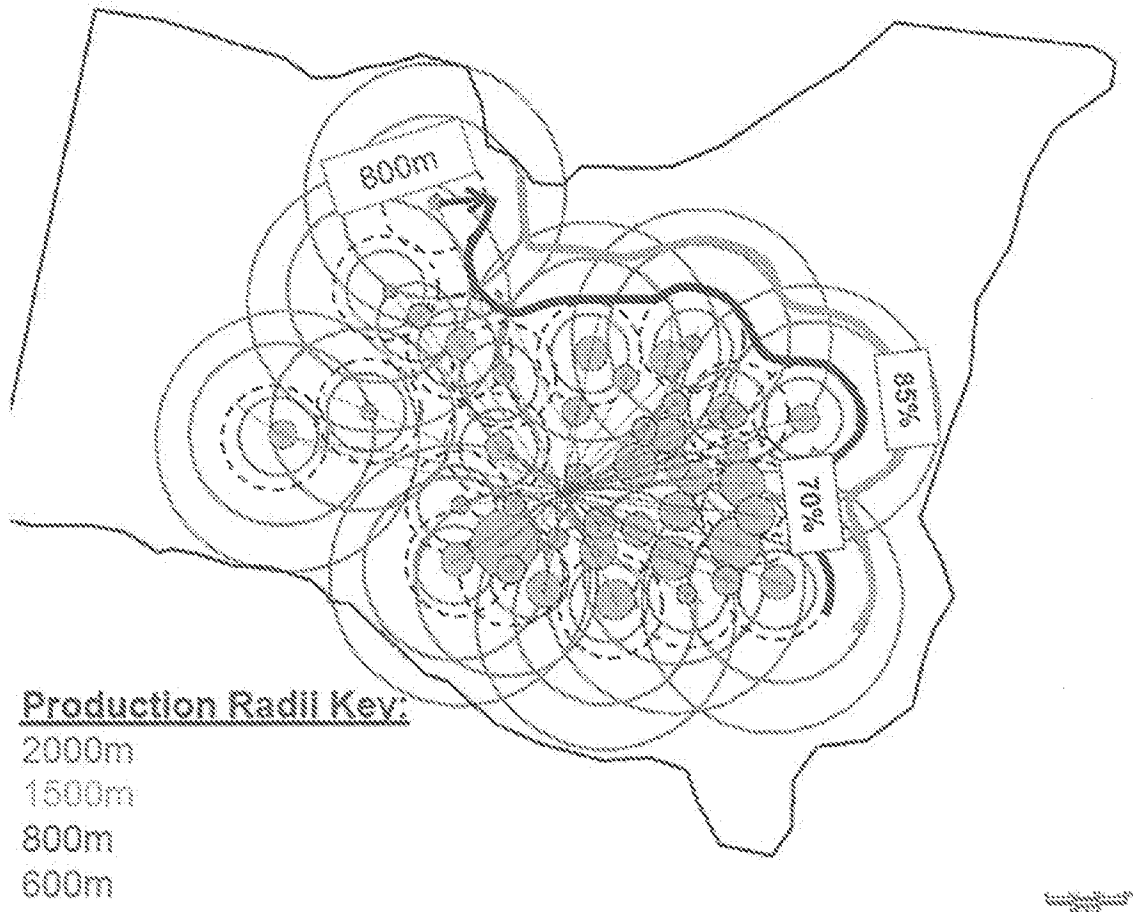


FIG. 9

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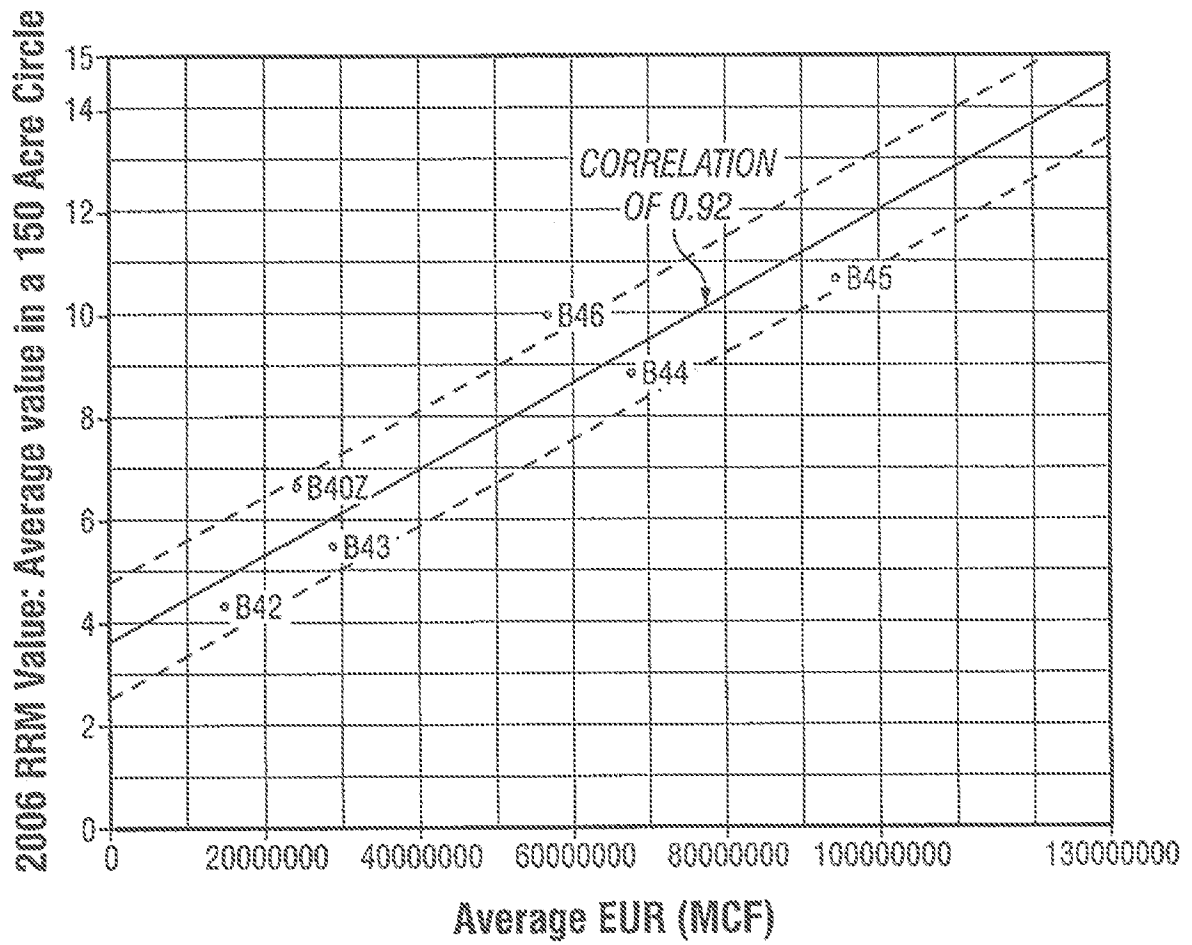


FIG. 10

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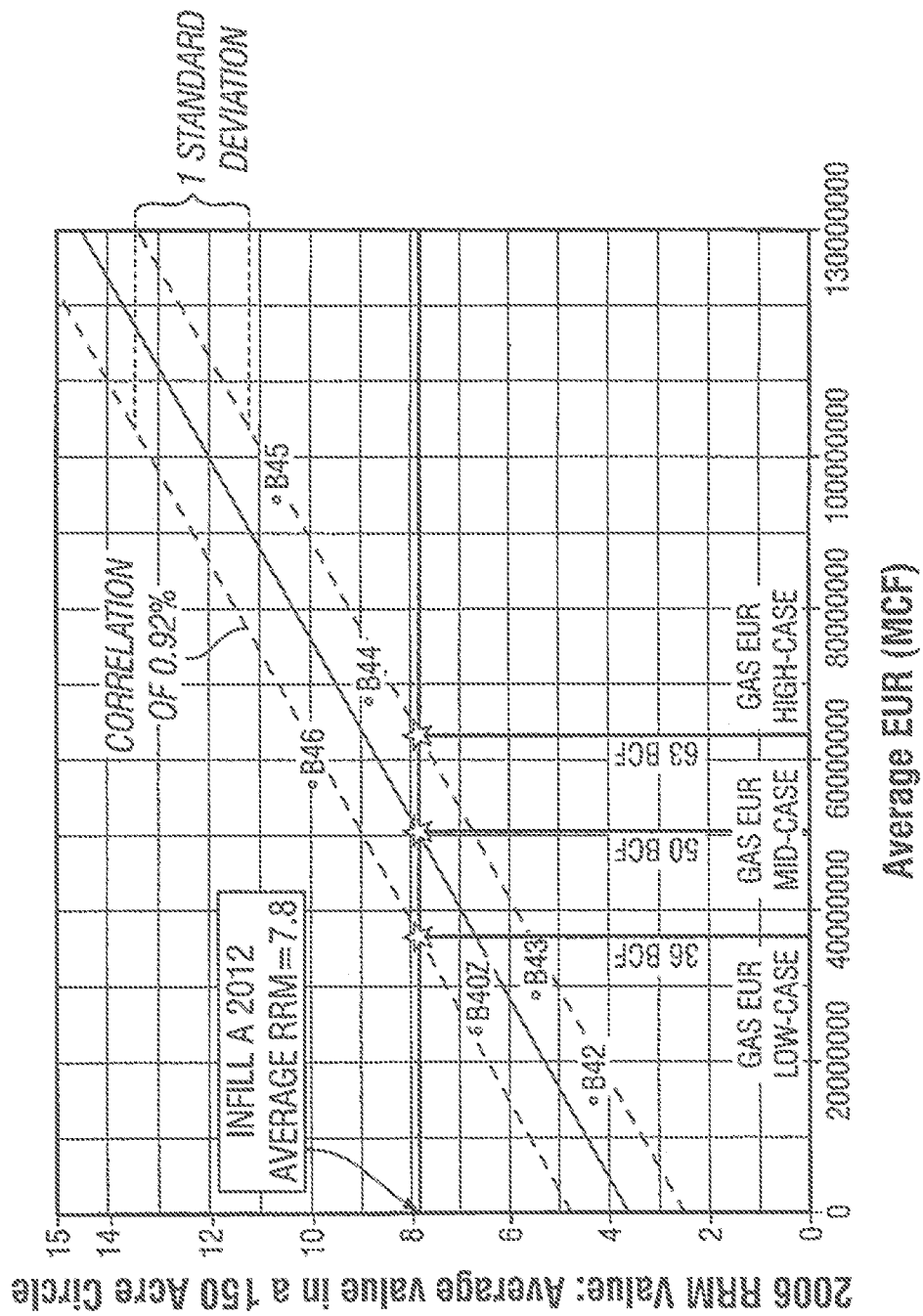


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2014/031882

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01V99/00

ADD.

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)

G01V

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 01/62603 A2 (SCHLUMBERGER TECHNOLOGY CORP [US]) 30 August 2001 (2001-08-30) abstract; claims 7,10,16,35,36; figures 9A,9B,12A,12B -----	1-9



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

18 December 2014

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09/01/2015

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2014/031882

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