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(54) Title: MATRIX BYPASS EVENT PRODUCTION FORECAST DERATION TOOL

(57) Abstract: Example embodiments of the present disclosure provide a new process (tool) to predict the production effects from MBEs. This tool can be based on an extensive study which risked the likelihood of MBE occurrence for patterns grouped by sand and completion type. In one aspect, a method includes determining a risk of Matrix Bypass Event (MBE) occurrence for a given sand type; assigning an MBE status to the given sand type based on the risk of MBE occurrence; and predicting an effect of the MBE status for the given sand type on production in a target production well.

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MATRIX BYPASS EVENT PRODUCTION FORECAST DERATION TOOL

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority to U.S. Provisional Patent Application No. 63/471,387 filed on June 6, 2023, which is incorporated by reference in its entirety herein.

FIELD OF TECHNOLOGY

[0002] Aspects of the present disclosure generally relate to analyzing and hence predicting effects from Matrix Bypass Events (MBEs) in oil production processes.

BACKGROUND

[0003] Poorly consolidated reservoirs (e.g., shallow viscous oil reservoirs) are prone to sand production. For instance, West Sak is a shallow viscous oil reservoir partially located in the Kuparuk River Unit (KRU) on the North Slope of Alaska. The oil gravity ranges from 16° to 22° API, and the targeted in-situ oil viscosity is between 20 and 100 cp. The reservoir represents a shallow marine depositional sequence resulting in three main producing sand intervals. These sands are poorly consolidated, with permeabilities of 20 to 3000 md. Poorly consolidated reservoirs can lead to a significant risk for the development of Matrix Bypass Events (MBEs). MBEs result in pattern breakage and lost production capacity.

SUMMARY

[0004] Example embodiments of the present disclosure provide a new process (tool) to predict the production effects from MBEs. This tool can be based on an extensive study which risked the likelihood of MBE occurrence for patterns grouped by sand and completion type. The tool is capable of building many possible MBE forecast outcomes based on this risk assessment, evaluating the effects on production by simulating the loss of production allocated to broken or remediated patterns. The tool can then output a deration curve for each well to represent the expected outcome.

[0005] In one aspect, a method includes determining a risk of Matrix Bypass Event (MBE) occurrence for a given sand type; assigning an MBE status to the given sand type based on the risk of MBE occurrence; and predicting an effect of the MBE status for the given sand type on production in a target production well.

[0006] In another aspect, determining the risk of MBE occurrence includes generating a random number; comparing the risk of the MBE occurrence to the random number; and assigning the MBE status based on a result of comparing the risk of the MBE occurrence to the random number.

[0007] In another aspect, the method further includes setting the MBE status to no MBE occurred if the random number is greater than the risk of the MBE occurrence; and setting the MBE status to MBE occurred if the random number is less than the risk of the MBE occurrence.

[0008] In another aspect, the method further includes repeating the determining and the assigning for all sand types and all years of interest to yield an MBE risk schedule; and predicting the effect of the MBE status for the given sand type using the MBE risk schedule.

[0009] In another aspect, predicting the effect of the MBE status includes adjusting producer capacity for the target well production based on the MBE status to yield an adjusted producer capacity; and generating a deration curve for the target production well based on the adjusted producer capacity.

[0010] In another aspect, adjusting the producer capacity includes one of reducing the producer capacity by a fixed threshold or based on a multiplier corresponding to a remediation efficiency of the given sand type.

[0011] In another aspect, the method further includes outputting the deration curve on a terminal.

[0012] In one aspect, a system includes one or more memories having computer-readable instructions stored therein and one or more processors. The one or more processors configured to execute the computer-readable instructions to determine a risk of Matrix Bypass Event (MBE) occurrence for a given sand type; assign an MBE status to the given sand type based on the risk of MBE occurrence; and predict an effect of the MBE status for the given sand type on production in a target production well.

[0013] In another aspect, the one or more processors are configured to execute the computer-readable instructions to determine the risk of MBE occurrence by generating a random number; comparing the risk of the MBE occurrence to the random number; and assigning the MBE status based on a result of comparing the risk of the MBE occurrence to the random number.

[0014] In another aspect, the one or more processors are further configured to execute the computer-readable instructions to set the MBE status to no MBE occurred if the random number is greater than the risk of the MBE occurrence; and set the MBE status to MBE occurred if the random number is less than the risk of the MBE occurrence.

[0015] In another aspect, the one or more processors are further configured to execute the computer-readable instructions to repeat determining and assigning processes for all sand types and all years of interest to yield an MBE risk schedule; and predict the effect of the MBE status for the given sand type using the MBE risk schedule.

[0016] In another aspect, the one or more processors are configured to execute the computer-readable instructions to predict the effect of the MBE status by adjusting producer capacity for the target well production based on the MBE status to yield an adjusted producer capacity; and generating a deration curve for the target production well based on the adjusted producer capacity.

[0017] In another aspect, the one or more processors are configured to execute the computer-readable instructions to adjust the producer capacity by one of reducing the producer capacity by a fixed threshold or based on a multiplier corresponding to a remediation efficiency of the given sand type.

[0018] In another aspect, the one or more processors are further configured to execute the computer-readable instructions to output the deration curve on a terminal.

[0019] In one aspect, one or more non-transitory computer-readable media comprising computer-readable instructions, which when executed by one or more processors, cause the one or more processors to determine a risk of Matrix Bypass Event (MBE) occurrence for a given sand type assign an MBE status to the given sand type based on the risk of MBE occurrence; and predict an effect of the MBE status for the given sand type on production in a target production well.

[0020] In another aspect, the execution of the computer-readable instructions, cause the one or more processors to determine the risk of MBE occurrence by generating a random number; comparing the risk of the MBE occurrence to the random number; and assigning the MBE status based on a result of comparing the risk of the MBE occurrence to the random number.

[0021] In another aspect, the execution of the computer-readable instructions, cause the one or more processors to set the MBE status to no MBE occurred if the random number is greater than the risk of the MBE occurrence; and set the MBE status to MBE occurred if the random number is less than the risk of the MBE occurrence.

[0022] In another aspect, the execution of the computer-readable instructions, cause the one or more processors to repeat determining and assigning processes for all sand types and all years of interest to yield an MBE risk schedule; and predict the effect of the MBE status for the given sand type using the MBE risk schedule.

[0023] In another aspect, the execution of the computer-readable instructions, cause the one or more processors to predict the effect of the MBE status by adjusting producer capacity for the target well production based on the MBE status to yield an adjusted producer capacity; and generating a deration curve for the target production well based on the adjusted producer capacity.

In another aspect, the execution of the computer-readable instructions, cause the one or more processors to adjust the producer capacity by one of reducing the producer capacity by a fixed threshold or based on a multiplier corresponding to a remediation efficiency of the given sand type.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] In order to describe the manner in which the above-recited and other advantages and features of the disclosure can be obtained, a more particular description of the principles briefly described above will be rendered by reference to specific example embodiments thereof which are illustrated in the appended drawings. Understanding that these drawings depict only exemplary embodiments of the disclosure and are not therefore to be considered to be limiting of its scope, the principles herein are described and explained with additional specificity and detail through the use of the accompanying drawings in which:

[0025] FIG. 1 illustrates an example on-site setting for performing a fracturing process, according to an aspect of the present disclosure;

[0026] FIG. 2 is a visual presentation of different sand types (patterns), according to some aspects of the present disclosure;

[0027] FIG. 3 illustrates an example multilateral completion design with individual horizontal laterals, according to some aspects of the present disclosure;

[0028] FIG. 4 schematically illustrates an example of a MBE, according to some aspects of the present disclosure;

[0029] FIG. 5 illustrates an example of cumulative risk of MBE for two different types of sands, according to some aspects of the present disclosure;

[0030] FIG. 6 illustrates change in MBE risk versus sand pattern change, according to some aspects of the present disclosure;

[0031] FIG. 7 illustrates the concept of unconfined compressive strength (UCS) of different sands, according to some aspects of the present disclosure;

[0032] FIG. 8 is a plot of UCS versus depth from the top of the producing zone for B and D type sands, according to some aspects of the present disclosure;

[0033] FIG. 9 illustrates a cumulative risk for B sand patterns targeted with horizontal producing laterals with no sand control supported by horizontal slotted liner injectors, according to some aspects of the present disclosure;

[0034] FIG. 10 illustrates frequency plot for B sand pattern completion types according to some aspects of the present disclosure;

[0035] FIG. 11 illustrates a cumulative risk for D sand patterns targeted with horizontal producing laterals with no sand control supported by horizontal slotted liner injectors, according to some aspects of the present disclosure;

[0036] FIG. 12 illustrates frequency plot for D sand pattern completion types according to some aspects of the present disclosure;

[0037] FIG. 13 shows the cumulative MBE risk for B sand patterns targeted with horizontal producing laterals with no sand control supported by horizontal slotted liner injectors, according to some aspects of the present disclosure;

[0038] FIG. 14 shows the frequency plot for B sand pattern completion types, according to some aspects of the present disclosure;

[0039] FIG. 15 shows example final risk curves, extrapolated forward an adequate period for forecasting, according to some aspects of the present disclosure;

[0040] FIG. 16 is a flowchart of an example process performed to determine MBE deration, according to some aspects of the present disclosure;

[0041] FIG. 17 illustrates an example duration curve for a high risk well, according to some aspects of the present disclosure;

[0042] FIG. 18 illustrates an example duration curve for a lower risk well, according to some aspects of the present disclosure;

[0043] FIG. 19 illustrates reduced capacity for wells currently carrying remediated patterns, according to some aspects of the present disclosure;

[0044] FIG. 20 shows an example of computing system, according to some aspects of the present disclosure.

DETAILED DESCRIPTION

[0045] Various example embodiments of the disclosure are discussed in detail below. While specific implementations are discussed, it should be understood that this is done for illustration purposes only. A person skilled in the relevant art will recognize that other components and configurations may be used without parting from the spirit and scope of the disclosure. Thus, the following description and drawings are illustrative and are not to be construed as limiting.

Numerous specific details are described to provide a thorough understanding of the disclosure. However, in certain instances, well-known or conventional details are not described in order to avoid obscuring the description. References to one or an example embodiment in the present disclosure can be references to the same example embodiment or any example embodiment; and, such references mean at least one of the example embodiments.

[0046] Reference to “one embodiment” or “an embodiment” means that a particular feature, structure, or characteristic described in connection with the example embodiment is included in at least one example embodiment of the disclosure. The appearances of the phrase “in one embodiment” in various places in the specification are not necessarily all referring to the same example embodiment, nor are separate or alternative example embodiments mutually exclusive of other example embodiments. Moreover, various features are described which may be exhibited by some example embodiments and not by others.

[0047] The terms used in this specification generally have their ordinary meanings in the art, within the context of the disclosure, and in the specific context where each term is used. Alternative language and synonyms may be used for any one or more of the terms discussed herein, and no special significance should be placed upon whether or not a term is elaborated or discussed herein. In some cases, synonyms for certain terms are provided. A recital of one or more synonyms does not exclude the use of other synonyms. The use of examples anywhere in this specification including examples of any terms discussed herein is illustrative only, and is not intended to further limit the scope and meaning of the disclosure or of any example term. Likewise, the disclosure is not limited to various example embodiments given in this specification.

[0048] Without intent to limit the scope of the disclosure, examples of instruments, apparatus, methods and their related results according to the example embodiments of the present disclosure are given below. Note that titles or subtitles may be used in the examples for convenience of a reader, which in no way should limit the scope of the disclosure. Unless otherwise defined, technical and scientific terms used herein have the meaning as commonly understood by one of ordinary skill in the art to which this disclosure pertains. In the case of conflict, the present document, including definitions will control.

[0049] Additional features and advantages of the disclosure will be set forth in the description which follows, and in part will be obvious from the description, or can be learned by practice of the herein disclosed principles. The features and advantages of the disclosure can be realized and obtained by means of the instruments and combinations particularly pointed out in the

appended claims. These and other features of the disclosure will become more fully apparent from the following description and appended claims, or can be learned by the practice of the principles set forth herein.

DESCRIPTION OF EXAMPLE EMBODIMENTS

[0050] The disclosure begins with a description of an example environment, in which the methods and systems of the present disclosure can be applied.

[0051] FIG. 1 illustrates an example on-site setting for performing a fracturing process, according to an aspect of the present disclosure.

[0052] The system diagram is representative of a hydraulic fracture system 100 operably coupled with a well head 102, and set up to hydraulically fracture stages 104 of a horizontal section 106 of a wellbore 108. The hydraulic fracturing equipment may include pump trucks, sources of water (e.g., water trucks), and sources of proppant, diverter, and other substances that may be combined with water and injected into the well as part of the hydraulic fracturing process. In some configurations, a pump truck is connected to the well head 102 to pump, under controlled pressure and rate, the hydraulic fracturing fluid into the well which flows through a well casing (not shown) to the stage 104 being hydraulic fractured. The casing of the stage has been perforated such that fluid pumped into the stage can flow through the perforations to open fractures 112 in the formation 110 surrounding the well. For illustration, only one stage is shown at the toe of the well; however, a horizontal section typically has numerous stages as a horizontal section of a well may be thousands of feet, and stages are discrete sections around one hundred feet. In some systems discussed herein, data and interactions with an offset well 116 may further be assessed. The offset well 116 may be fitted with various possible sensors for measuring pressure, e.g., tubing pressure in one example, within the well or within some portion or portions of the well. The well and the equipment involved in the hydraulic fracturing process may include sensors, gauges, and other devices to monitor and record data associated with the hydraulic fracturing processes. The data may then be reported and stored at a processing system 114. The processing system 114 may involve one or more computing devices, at the well site. The processing system 114 may be in wired or wireless communication with various aspects of the well and/or the fracturing equipment.

[0053] Processing system 114 may be communicatively coupled to an off-site (remote) processing center 118. As will be described below, remote processing center 118 may receive

streams of data from processing system 114 to perform real-time processing of the received data to determine start and end times of various stages of the fracturing process.

[0054] While not shown in Figure 1, a zipper fracturing process may involve multiple wells such as well 108, each with multiple fracture stages such as stages 104. Various sensors installed in each such well may monitor statistics and data, as described above for each stage of fracturing of each well. Such data is then transmitted, using any known or to be developed method, from on-site processing systems such as processing system 114 to remote processing center 118 for analysis, as will be described below. Remote processing center 118 may also be referred to as remote processor 118 and/or controller 118.

[0055] While example setting of claim 1 is more specific to a fracturing process, the MBE forecasting tool disclosed herein is not limited to being applicable to a fracturing process but can be used in other settings including, but not limited to, other oil and natural resources extraction processes and settings.

[0056] As noted above, poorly consolidated reservoirs are prone to sand production. For instance, West Sak is a shallow viscous oil reservoir partially located in the Kuparuk River Unit (KRU) on the North Slope of Alaska. The oil gravity ranges from 16° to 22° API, and the targeted in-situ oil viscosity is between 20 and 100 cp. The reservoir represents a shallow marine depositional sequence resulting in three main producing sand intervals A(A1-A4), B, and C. FIG. 2 is a visual presentation of different sand types (patterns), according to some aspects of the present disclosure. These sands are poorly consolidated, with permeabilities of 20 to 3000 md. Poorly consolidated reservoirs can lead to a significant risk for the development of Matrix Bypass Events (MBEs). MBEs result in pattern breakage and lost production capacity.

[0057] To address this risk, the present disclosure provides a new tool to predict these production effects from MBEs. This example tool is based on an extensive study which risked the likelihood of MBE occurrence for patterns grouped by sand and completion type. Based on this risk assessment, the tool builds many possible MBE forecast outcomes, evaluating the effects on production by simulating the loss of production allocated to broken or remediated patterns. It then outputs a deration curve for each well to represent the expected outcome. While built on several simplifications and assumptions, back-casting exercises indicate that the new tool is useful and more predictive than previous approaches.

[0058] In the example of West Sak, production began in 1997 with vertical producers and injectors. These projects were uneconomic, but advancements in multilateral drilling allowed

implementation of economic multilateral wells since 1999. A multilateral development can target the producing sands with individual horizontal laterals. FIG. 3 illustrates an example multilateral completion design 300 with individual horizontal laterals 302, 304, and 306, according to some aspects of the present disclosure. The number of individual horizontal laterals is not limited to three but may be more or less.

[0059] Because the sands are poorly consolidated in regions such as West Sak, issues with sand production have been prevalent. While sand production is an operational challenge on its own, sand production can also lead to the formation of void space conduits, commonly referred to as Matrix Bypass Events (MBEs). To date, 39 MBEs have been confirmed in West Sak. These MBEs essentially represent pattern breakage, and as such can have a significant impact on production that should be accounted for in production forecasting.

[0060] The poorly consolidated sands are prone to sand production. If sand production is concentrated in a specific interval, a wormhole connected to the producing lateral can begin to form. Continued sand production will result in extension of the wormhole, and the wormhole could connect back to the injecting lateral, forming an infinite conductivity conduit between the injector and the producer. This is referred to as a MBE. FIG. 4 schematically illustrates an example of a MBE, according to some aspects of the present disclosure. As shown in FIG. 4, multilateral producer 400, as described with reference to FIG. 3, may have horizontal laterals 400-1, 400-2, and 400-3 while multilateral injector 402 may have horizontal laterals 402-1, 402-2, and 402-3. MBEs may cause multilateral producer 400 to be ‘connected’ to multilateral injector 402 via conduit 404 at horizontal laterals 400-1 and 402-1 (shows as heel MBE event), and via conduit 406 at horizontal laterals 400-2 and 402-2 (caused by a toe MBE event).

[0061] MBEs result in pattern breakage since all fluid injected into the broken lateral (e.g., lateral 400-1 and/or lateral 402-1) can go through the corresponding one of conduits 404 and 406 instead of sweeping oil from the pattern. Furthermore, any other patterns supported by this broken injecting lateral will also lose injection support and will be effectively broken. These patterns may be ‘indirectly’ affected by any of these MBEs.

[0062] Timing of MBEs may be understood through a risk-assessment informed by applicable risk factors, both within and beyond an operator’s control. Geomechanical studies have helped to identify a number of these risk factors. These risk factors can include, but are not limited to, rock strength, flow rate, pressure, etc.

[0063] Cohesiveness or strength of the reservoir rock itself can be indicative of an MBE risk (e.g., the stronger the rock, the more resistant it will be to sand production, and thus a lower

risk of an MBE). The three main productive sands in the non-limiting example of West Sak show contrasting MBE risk that can be convincingly tied to differences in rock strength.

[0064] Flow rate is another risk factor, where higher liquid throughput rates result in more rapid sand production and a higher risk of an MBE. The flow rate may be influenced by injection conformance. If a single interval sees higher flow rates, then that zone would also see higher rates of sand production and a higher risk of MBE development. Once an MBE forms, regardless of where it is located, the entire pattern is broken. Furthermore, a higher permeability zones also tend to have lower rock strength. As such, injection conformance should be maintained to avoid overflowing a single zone and forming an MBE.

[0065] Pressure is another risk factor. The strength of the rock can be influenced by the pressure exerted upon it. Hence, reservoir pressure by targeting a voidage replacement ratio of about one. Drawdown pressure and interwell pressure gradient can be limited to keep sand grains in place. Accordingly,, pre-production on the injectors should be limited during development start-up.

[0066] In addition to the above factors, lower completions installed on both producers and injectors such as multilateral producer 400 and multilateral injector 402 can influence the risk of an MBE.

[0067] When an MBE occurs, all fluid sent to the involved injecting lateral will enter the conduit, bypassing the matrix and flooding out the involved producing lateral, as shown in FIG. 4 and described above. Any other patterns supported by the injecting lateral may no longer have injection support. As such, there is no value in keeping this injecting lateral online while the MBE is active. The immediate response to an MBE is to identify and shut in multilateral injector 402. While some shut-in time is expected for multilateral producer 400 as an immediate mitigation response and for diagnostic work, multilateral producer 400 can continue to produce oil from its remaining unaffected patterns. Therefore, multilateral producer 400 may be kept online as much as possible. Diagnostic work, particularly injection profiles, is performed, and about a month or two after the MBE has occurred, the nature and location of the MBE should be identified and remediation options evaluated.

[0068] If the MBE is not immediately treatable due to reservoir or mechanical constraints, and if the injecting well completion includes the necessary lateral entry modules, then injecting lateral carrying the MBE (e.g., lateral 402-1 and/or 402-2) may be isolated with an iso-sleeve and the remaining injecting laterals are brought back online. If the MBE is deemed treatable, then the appropriate treatment option is selected.

[0069] For MBEs corresponding to toe MBE of FIG. 4, cement remains the preferred treatment option, being cheap and simple with the reasonable downside of losing injection in the toe of the well. For more proximal MBEs, the downside of cement treatments becomes less palatable, and other treatment options have been developed. Commonly, polymer-based chemicals that expand when hydrated are injected into the MBE, with the idea that they will expand within the conduit and effectively plug it off. Marcit and RPPG are non-limiting examples of these chemicals, with RPPG having been developed more recently and demonstrated a higher success rate.

[0070] Currently and with practice, the cycle time to treat an easily remediated MBE has been reduced to about 6 to 8 months from the time since the event is first detected. Current treatment options demonstrate a success rate of about 70%. So far, these options show resistance to failure later in time, though previous treatment options did demonstrate later-time failures and recurrence of an MBE. To prevent recurrence of a treated MBE, the throughput rate must remain somewhat limited, suggesting a residual loss in the producing well's capacity.

[0071] Example embodiments of tool disclosed herein for MBE deration and the underlying model addresses both the timing and the effects of an MBE. The question of timing – when an MBE will occur – is based on a detailed risk assessment, whereas the question of effect – what happens to production after an MBE occurs – is based on simulation of injecting lateral shut-ins and pattern breakage.

[0072] The disclosure first addresses the question of timing and associated risk management.

[0073] To inform the structure and inputs into an MBE deration model, the risk of an MBE occurring based on influencing parameters is assessed first.

[0074] First, the influence of sand on the MBE risk is examined, followed by the influence of lower completion types. Cumulative risk is assessed through pie charts, examples of which are shown in FIG. 5, with wedges representing the overall percent of patterns of a given type having experienced an MBE, indirect MBE effects, or no effects. FIG. 5 illustrates an example of cumulative risk of MBE for two different types of sands, according to some aspects of the present disclosure.

[0075] In FIG. 5, pie chart 502 shows MBE risk associated with type B sand while pie chart 504 shows MBE risk associated with type D sand. Cumulatively, as shown in FIG. 5, 30% of all B sand patterns considered have been influenced by MBEs, with 18% having directly sustained an MBE. By comparison, about 13% of all D sand patterns have been influenced by

an MBE, with only 9% having sustained an MBE directly. The A sand has yet to have a confirmed MBE.

[0076] Instantaneous risk, which indicates how the risk changes as sand patterns age, is assessed through the MBE frequency plot. FIG. 6 illustrates change in MBE risk versus sand pattern change, according to some aspects of the present disclosure. In graph 600 of FIG. 6, each bar may represent the percentage of patterns (binned by pattern type) having reached or exceeded a given age that experienced an MBE in that year of their life.

[0077] Risk curves may be developed based on the data grouped by these classifications shown in FIGs. 5 and 6. As will be described, these curves may be extrapolated and used to describe the MBE risk in final deration model (described below).

[0078] FIG. 7 illustrates the concept of unconfined compressive strength (UCS) of different sands, according to some aspects of the present disclosure. UCS considers the inherent strength of the rock without the strengthening influence of applied pressure. In concept, a reservoir rock with a higher UCS would have lower sanding tendencies and a lower risk for MBE formation. This concept seems to hold well as shown by graph 700 of FIG. 7, with the A sands displaying the highest UCS and the lowest MBE risk while the B sand shows the lowest UCS and the highest MBE risk.

[0079] Because the A sands have the highest UCS, have additional overburden, and have yet to experience a confirmed MBE, the model can assume the MBE risk for the A sands to be negligible. This is supported practically as the A sands are not the strongest producing zone in West Sak on account of their poor lateral extent and lesser reservoir quality.

[0080] Referring back to FIG. 6, the difference between the B and D sand risk not only in scale but in behavior is apparent, with the B sand showing an early-time risk that is not observed in the D sand.

[0081] FIG. 8 is a plot of UCS versus depth from the top of the producing zone for B and D type sands, according to some aspects of the present disclosure. Plot 800 shows UCS v. depth from top by B sand while plot 802 shows UCS v. depth from top for D sands. By sand features a weak interval within its uppermost five feet, which is expected to fail earlier and more frequently. This differential MBE risk is compounded by two additional factors. One such factor being is that the C shale, a competent rock, unconformably overlies this preferentially weak zone and is believed to form a structural “ceiling” that effectively prevents MBEs from collapsing. The second factor is that this uppermost five feet is also the highest permeability zone that results in differentially high throughput rates and thus carries an even greater risk of

MBEs. Accordingly, this zone may be directly responsible for the early-time MBE events observed in the B sand while the same are not observed in the D sand.

[0082] Visually filtering out early-time MBEs in the B sand as being an artifact of the weak zone, one can see from plots 800 and 802 that the B and the D sand have similar late time MBE frequency behavior, with a gradual increase in risk that asymptotically flattens with time. This can be explained by the similar UCS values between the remaining portions of the B sand and the weaker failure-prone portions of the D sand.

[0083] Having described the differential MBE risk by sand, the next step is to drill down MBE risk by completion type. In this regard, risk influences from both the producer and injector lower completions must be considered. A number of these completions seem to provide negligible risk. First, the producer completions will be discussed.

[0084] While development strategies in areas with similar formation such as West Sak involves targeting multiple isolated sand bodies with multilateral producing wells (examples of which are described above with reference to FIGs. 3 and 4, several legacy vertical producing wells remain on production. With about 25 years of production on these vertical producers in West Sak, only one MBE has occurred. This low risk is likely due to the limited throughput rates of the vertical producer within the viscous reservoir. The lower flow rates result in lesser amounts of sand production and thus a reduced MBE risk. Based on this reasoning and given the sparsity of vertical producer MBEs, it is assumed that the risk for future vertical producer MBEs is negligible. This assumption is practical because the low oil rates of vertical producers mean that they do not have a major impact on base forecast results, and vertical wells are not considered for future developments due to their unfavorable economics.

[0085] Of the horizontal producing laterals, a few of the more recent developments are completed with ultra-fine (107-micron mesh) open-hole stand-alone screens (OHSAS). These ultra-fine screens can prevent most of the sand from being produced, only allowing the finest grains through. In theory, if sand is not being produced and remains in place within the formation, a void conduit cannot form, thus mitigating any MBE risk. This theory seems to be holding well in practice; with about 7 years of production on OHSAS, no MBEs have been observed. Based on this, it is assumed that the MBE risk for this “sand exclusion” category is negligible. However, this assumption may prove invalid in the future depending on the longevity of OHSAS. For example, if we have issues with screens plugging from either formation solids or scale and have to perforate the screens, or if the screens erode or corrode,

then the sand exclusion advantage of the screens would be lost, and forward-looking risking would need to consider this “shelf-life.”

[0086] This leaves horizontal producing laterals that do not have sand-exclusion installed, including slotted liners, perforated liners, or legacy coarser-mesh screens. This group collectively bears most of the MBE risk from the producer completions perspective. No differential risk behavior is apparent between these producer completion types, and they are lumped into the “No Control” category to reflect that they do not provide sand exclusion.

[0087] Based on the assumptions made here, only the horizontal producing laterals with no sand control have meaningful risk for an MBE. On the other side of the pattern, West Sak producers have been supported by single and multilateral horizontal injectors as well as vertical injectors, with several completion types attempted for these geometries. As will be shown, there is a differential MBE risk for these injector completion types.

[0088] Most of the horizontal injecting laterals have been completed with slotted liners, with a few being perforated instead. Lumping these together in the slotted liner (SL) category, it is observed that most of the MBE risk is accrued for these completion types.

[0089] FIG. 9 illustrates a cumulative risk for B sand patterns targeted with horizontal producing laterals with no sand control supported by horizontal slotted liner injectors, according to some aspects of the present disclosure. As can be seen from pie chart 900, one-third of these patterns have had an MBE, with well over half having been impacted by MBEs in some way. FIG. 10 illustrates frequency plot for B sand pattern completion types according to some aspects of the present disclosure. Graph 1000 shows both the early-time risk characteristic of the B sand along with the later time risk as the patterns mature.

[0090] FIG. 11 illustrates a cumulative risk for D sand patterns targeted with horizontal producing laterals with no sand control supported by horizontal slotted liner injectors, according to some aspects of the present disclosure. As can be seen from pie chart 1100, About a quarter of these patterns have experienced MBE impacts. FIG. 12 illustrates frequency plot for D sand pattern completion types according to some aspects of the present disclosure. Graph 1200 shows, as is typical of the D sand, the risk increases with pattern age, asymptotically flattening in later time.

[0091] A few of the horizontal injecting laterals have been completed with injection control devices (ICDs). These devices are designed to prevent overflowing a single interval, encouraging injection conformance. ICDs can reduce the risk of an MBE by preventing zones

from experiencing differentially high throughput rates. This concept seems to have held well, with no MBEs occurring on patterns with functioning ICDs.

[0092] Vertical injectors are also used to support horizontal producing laterals. FIG. 13 shows the cumulative MBE risk for B sand patterns targeted with horizontal producing laterals with no sand control supported by horizontal slotted liner injectors, according to some aspects of the present disclosure. As can be seen from pie chart 1400, less than a quarter of these patterns have been influenced by MBEs, which is in contrast to the much greater risk for B sand slotted liner injectors shown in FIG. 9. The reasoning for this lower risk is two-fold. First, vertical injectors have lower throughput rates than horizontal injectors, and a lower flow rate would suggest a lower risk for MBEs. Second, a single horizontal producing lateral can be supported by many vertical injectors along its length, allowing the operator to more precisely maintain an even injection front compared to horizontal injectors. This conveys the advantage of avoiding overflowing a single zone, thus reducing the MBE risk. FIG. 14 shows the frequency plot for B sand pattern completion types, according to some aspects of the present disclosure. Only the early-time risk is observed for vertical injectors in the B sand compared to FIG. 10.

[0093] The comparison between vertical and horizontal injectors is the same in the D sand as that shown in FIGs. 11 and 12, to the point where there appears to be a negligible risk for D sand MBEs on vertical injectors. Only one D sand vertical injector event has occurred in a 1E well, influenced by heavy pre-production that has not since been pursued.

[0094] As noted above, risk curves are fit to MBE frequency plot and then extrapolated for forecasting MBE risk. Risk curves may then be provided as input into the MBE deration model. These curves are based on the fatigue life distribution family of curves, which describe material failure risk with age. The probability density function (PDF) without horizontal shift is given by:

$$f(x) = \left(\frac{\sqrt{\frac{x}{\beta}} + \sqrt{\frac{\beta}{x}}}{2\gamma x} \right) * \phi * \left(\frac{\sqrt{\frac{x}{\beta}} - \sqrt{\frac{\beta}{x}}}{\gamma} \right) \quad (1)$$

Where β is a scale parameter (value greater than 0) which “flattens” the curve, γ is a shape parameter (value greater than 0), x represents the year, and ϕ is the PDF of the standard normal distribution, given by:

$$\phi = \frac{e^{-\frac{x^2}{2}}}{\sqrt{2\pi}} \quad (2)$$

The cumulative distribution function (CDF) of the fatigue life distribution is given by:

$$F(x) = \Phi * \left(\frac{\left(\sqrt{x} - \sqrt{\frac{1}{x}} \right)}{\gamma} \right) \quad (3)$$

Where Φ is the CDF of the standard normal distribution, evaluated numerically as the integral of the standard normal PDF. Finally, the hazard function for the fatigue life distribution is given by:

$$h(x) = \frac{f(x)}{1 - F(x)} \quad (4)$$

Either the PDF or the hazard function can fit the MBE frequency data by appropriately tuning the scale and shape parameters.

[0095] Curve fits based on the fatigue life distribution are shown in FIGs. 10, 12, and 14. For example, FIG. 12 shows curve fit 1202 to D sand patterns with uncontrolled horizontal producers and slotted liner injectors. This data displays the asymptotic increasing risk with pattern age and was fit accordingly. FIG. 14 stands in contrast. Curve fit 1402 is fit with appropriate shape factor to the B sand patterns with vertical injectors display the early-time differential risk. The B sand horizontal slotted liner injector patterns shown in FIG. 10 display both an early time and a later time risk. Therefore, no single fatigue life distribution curve could capture both behaviors. Instead, a separate curve is used to model the early time risk tied to the differentially weak B sand zone, which is then spliced with a second curve capturing the later time risk. These curves together form curve 1002 in FIG. 10. For B sand patterns outside of the Core Area, the weak zone and corresponding early time risk does not seem to be present. These B sand patterns were modelled with just the second curve.

[0096] FIG. 15 shows example final risk curves, extrapolated forward an adequate period for forecasting, according to some aspects of the present disclosure. Extrapolated risk curves by pattern sand and completion. In graph 1500, curve 1502 represents the patterns with a negligible risk. Curve 1504 represents B sand patterns with slotted liner injectors and no sand control on the producers, with the weak B sand zone present. Curve 1506 represents the B sand patterns with vertical injectors and no sand control on the producers. Curve 1508 represents D sand patterns with slotted liner injectors and no sand control on the producers.

Curve 1510 represents B sand patterns with slotted liner injectors and no sand control on the producers, without the weak B sand zone present.

[0097] Example embodiments of tool disclosed herein for MBE deration and the underlying model addresses both the timing and the effects of an MBE. The question of timing (when an MBE will occur), is based on a detailed risk assessment, whereas the question of effect – what happens to production after an MBE occurs (effect), is based on simulation of injecting lateral shut-ins and pattern breakage.

[0098] FIG. 16 is a flowchart of an example process performed to determine MBE deration, according to some aspects of the present disclosure. Process of FIG. 16 may be performed by any processing component (e.g., processing system 114, at remote processing center 118 of FIG. 1, etc.). It should be understood that such processing component can have one or more memories storing computer-readable instructions, which when executed by one or more processors, cause the processing component(s) to implement steps of FIG. 16. For sake of description, processes of FIG. 16 will be described from the perspective of processing system 114 of FIG. 1.

[0099] With respect to timing, because the risk assessment of MBE timing is statistical in nature, a range of risk-informed possible outcomes may be produced, collectively from which the expected outcome can be assessed. As such, the model can be structured in the spirit of a Monte Carlo analysis and can be highly iterative.

[0100] At step 1602, processing system 114 may determine a risk of MBE occurrence for a particular sand pattern from age and risk curve assigned to the particular sand pattern, ' p ' in a given year ' y ', as described above with reference to FIGs. 9-15. The risk may be represented as a number, ' R ' for a particular pattern ' p '. In other words at step 1602 R_p is determined.

[0101] In a single iteration for a given year, processing system 114 starts by resolving the MBE status of each pattern from the previous year. If the particular pattern had an MBE or was carrying a remediation in the previous year, processing system 114 determines a remediation in the given year. If the particular pattern was indirectly affected by an MBE in the previous year or had no MBE effects, then processing center 114 assigns a no MBE effects to the particular pattern in the given year. The tool determines which patterns experience MBEs in a given year. For each pattern that is listed as remediated or unaffected, the risk of an MBE occurring is determined based on the assigned risk curve and the pattern age in the given year, as described above with reference to FIGs. 9-15.

[0102] At step 1604, processing system 114 generates a random number and compares R_p to the random number ' n '.

[0103] At step 1606, processing system 114 determines if n is greater than R_p or not. If at step 1606, processing system 114 determines that n is greater than R_p , then at step 1608, processing center 114 determines no MBE for the particular sand type ' p ' in that given year (assigns no MBE to sand type ' p ' in year ' y '). If n is less than R_p , at step 1610, processing system 114 assigns MBE status to the particular sand pattern (assigns MBE to sand type ' p ' in year ' y '). In this case, any other patterns that are supported by the involved injecting lateral (same injector in the same sand) are assigned the "indirect" status.

[0104] At step 1612, processing system 114 determines if there are more active sand patterns for which an MBE status is to be determined (e.g., p being less than ' P ', with ' P ' being an upper threshold on the number of different sand patterns). If there are more active sand patterns (No at step 1612), ' p ' is incremented by 1 and the process reverts back to step 1602 and processing system 114 repeats steps 1602 to 1610 for all remaining sand patterns.

[0105] If processing system 114 determines that no more active sand patterns remain to be analyzed for MBE status determination ($p = P$ and Yes at step 1612), at step 1614, processing system 114 determines if all desired years (during which each active sand pattern may or may not have experienced an MBE) have been covered (i.e., whether ' y ' is equal to ' Y ', with ' Y ' being an upper limit on the number of years for which the analysis is being carried out).

[0106] If processing system 114 determines that more years are to be covered (No at step 1614), ' y ' is incremented by one and the process reverts back to step 1602 and processing system 114 repeats steps 1602-1612 for all desired years. If not ($y=Y$ and YES at step 1614), the process proceeds to step 1616.

[0107] At step 1616 and based on the iterative processes performed at steps 1602-1614 for all sand types and all desired years, processing system 114 generates a single risk-informed MBE schedule.

[0108] Steps 1602-1616 address the timing aspect of the MBE deration model creation mentioned above. With respect to the effect aspect, the model evaluates the effects of the constructed MBE schedule on production. If an MBE occurs, the tool simulates the shut-in of the involved injecting lateral. This is achieved by removing the production allocation assigned to patterns supported by said injecting lateral (these patterns were identified in the previous steps of 1602-1616 with the MBE and indirect status assignments).

[0109] Hereinafter, an assumption is made that producers (operators of wells) start with a 100% capacity that may subsequently be derated based on assigned pattern MBE status described above.

[0110] At step 1618, processing system 114 determines the MBE status for a given sand pattern p from the schedule of step 1616. If the MBE status indicates an MBE assigned (direct and/or indirect) to the sand pattern p , then at step 1620, processing system 114 reduces capacity of the given sand pattern by a threshold (e.g., fixed threshold (e.g., percentage) such as 15% - from 100% to 85%). In one example, sand patterns subject to the determination at step 1618 may be those that are relevant to a particular producer for a particular reservoir location.

[0111] If the MBE status indicates no MBE assigned to the sand pattern p , then at step 1621, processing system 114 maintains full producer capacity for the given sand pattern. If the MBE status indicates remediated MBE status to the sand pattern p , at step 1622, processing system 114 multiplies the percent allocated to the sand pattern p by the remediation efficiency, and this reduced percent allocation is returned to the producer.

[0112] At step 1624, processing system 114 determines if the processes of steps 1602-1622 are repeated (m times) for a statistically significant number of iterations (k iterations), where the number of iterations may be determined based on experiments and/or empirical studies. In other words, processing system 114, at step 1624 determines if $m=k$ or not. If not (NO at step 1626), m is incremented by one and the process reverts back to 1602 and the entire process of FIG. 16 is repeated. Each iteration of the process of FIG. 16 produces a unique risk-informed MBE occurrence schedule and then evaluates the effects on production for this particular outcome.

[0113] If $m=k$ (YES at step 1626), at step 1626, processing system 114 generates a deration curve for each well based on the remaining capacity for each producer for each year, averaged across all iterations.

[0114] At step 1628, processing system 114 may output the deration curves on a user interface available to an operator via terminal (e.g., computer device) communicatively coupled to processing system 114.

[0115] An example advantage of the deration process (tool) implemented via the process of FIG. 16, is that it produces unique deration curves for each well, allowing that well's risk to be appropriately classified. For example, a well with a higher risk for MBEs will have a steeper deration curve. FIG. 17 illustrates an example duration curve for a high risk well (see graph 1700), according to some aspects of the present disclosure. FIG. 18 illustrates an example

duration curve for a lower risk well (see graph 1800), according to some aspects of the present disclosure.

[0116] The tool also acknowledges existing MBE history through a user input, incorporating reduced capacity for wells currently carrying remediated patterns as shown in FIG. 19.

[0117] Example embodiments of the present disclosure provide a new tool to predict the production effects from MBEs. This tool can be based on an extensive study which risked the likelihood of MBE occurrence for patterns grouped by sand and completion type. Similar to a Monte Carlo analysis, the tool is capable of building many possible MBE forecast outcomes based on this risk assessment, evaluating the effects on production by simulating the loss of production allocated to broken or remediated patterns. The tool can then output a duration curve for each well to represent the expected outcome.

[0118] FIG. 20 shows an example of computing system, according to some aspects of the present disclosure. Computing system 2000 can be for example any computing device can include processing system 114, remote processing center 118. Components of computing system 2000 may be in communication with each other using connection 2005. Connection 2005 can be a physical connection via a bus, or a direct connection into processor 2010, such as in a chipset architecture. Connection 2005 can also be a virtual connection, networked connection, or logical connection.

[0119] In some embodiments, computing system 2000 is a distributed system in which the functions described in this disclosure can be distributed within a datacenter, multiple data centers, a peer network, etc. In some embodiments, one or more of the described system components represents many such components each performing some or all of the function for which the component is described. In some embodiments, the components can be physical or virtual devices.

[0120] Example system 2000 includes at least one processing unit (CPU or processor) 2010 and connection 2005 that couples various system components including system memory 2015, such as read-only memory (ROM) 2020 and random access memory (RAM) 2025 to processor 2010. Computing system 2000 can include a cache of high-speed memory 2012 connected directly with, in close proximity to, or integrated as part of processor 2010.

[0121] Processor 2010 can include any general purpose processor and a hardware service or software service, such as services 2032, 2034, and 2036 stored in storage device 2030, configured to control processor 2010 as well as a special-purpose processor where software instructions are incorporated into the actual processor design. Processor 2010 may essentially

be a completely self-contained computing system, containing multiple cores or processors, a bus, memory controller, cache, etc. A multi-core processor may be symmetric or asymmetric. [0122] To enable user interaction, computing system 2000 includes an input device 2045, which can represent any number of input mechanisms, such as a microphone for speech, a touch-sensitive screen for gesture or graphical input, keyboard, mouse, motion input, speech, etc. Computing system 2000 can also include output device 2035, which can be one or more of a number of output mechanisms known to those of skill in the art. In some instances, multimodal systems can enable a user to provide multiple types of input/output to communicate with computing system 2000. Computing system 2000 can include communications interface 2040, which can generally govern and manage the user input and system output. There is no restriction on operating on any particular hardware arrangement, and therefore the basic features here may easily be substituted for improved hardware or firmware arrangements as they are developed.

[0123] Storage device 2030 can be a non-volatile memory device and can be a hard disk or other types of computer readable media which can store data that are accessible by a computer, such as magnetic cassettes, flash memory cards, solid state memory devices, digital versatile disks, cartridges, random access memories (RAMs), read-only memory (ROM), and/or some combination of these devices.

[0124] The storage device 2030 can include software services, servers, services, etc., that when the code that defines such software is executed by the processor 2010, it causes the system to perform a function. In some embodiments, a hardware service that performs a particular function can include the software component stored in a computer-readable medium in connection with the necessary hardware components, such as processor 2010, connection 2005, output device 2035, etc., to carry out the function.

[0125] For clarity of explanation, in some instances, the various examples can be presented as individual functional blocks comprising devices, device components, steps or routines in a method embodied in software, or combinations of hardware and software.

[0126] In some examples, the computer-readable storage devices, media, and memories can include a cable or wireless signal containing a bit stream and the like. However, when mentioned, non-transitory computer-readable storage media expressly exclude media such as energy, carrier signals, electromagnetic waves, and signals per se.

[0127] Methods according to the above-described examples can be implemented using computer-executable instructions that are stored or otherwise available from computer readable

media. Such instructions can comprise, for example, instructions and data which cause or otherwise configure a general-purpose computer, special purpose computer, or special purpose processing device to perform a certain function or group of functions. Portions of computer resources used can be accessible over a network. The computer executable instructions can be, for example, binaries, intermediate format instructions such as assembly language, firmware, or source code. Examples of computer-readable media that can be used to store instructions, information used, and/or information created during methods according to described examples include magnetic or optical disks, flash memory, USB devices provided with non-volatile memory, networked storage devices, and so on.

[0128] Devices implementing methods according to these disclosures can comprise hardware, firmware, and/or software, and can take various form factors. Some examples of such form factors include general-purpose computing devices such as servers, rack mount devices, desktop computers, laptop computers, and so on, or general-purpose mobile computing devices, such as tablet computers, smartphones, personal digital assistants, wearable devices, and so on. The functionality described herein also can be embodied in peripherals or add-in cards. Such functionality can also be implemented on a circuit board among different chips or different processes executing in a single device, by way of further example.

[0129] The instructions, media for conveying such instructions, computing resources for executing them, and other structures for supporting such computing resources are means for providing the functions described in these disclosures.

[0130] Although a variety of examples and other information was used to explain aspects within the scope of the appended claims, no limitation of the claims should be implied based on particular features or arrangements in such examples, as one of ordinary skill would be able to use these examples to derive a wide variety of implementations. Further and although some subject matter can have been described in language specific to examples of structural features and/or method steps, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to these described features or acts. For example, such functionality can be distributed differently or performed in components other than those identified herein. Rather, the described features and steps are disclosed as examples of components of systems and methods within the scope of the appended claims.

[0131] Claim language reciting "at least one of" refers to at least one of a set and indicates that one member of the set or multiple members of the set satisfy the claim. For example, claim language reciting "at least one of A and B" means A, B, or A and B.

CLAIMS

What is claimed is:

1. A method comprising:
determining a risk of Matrix Bypass Event (MBE) occurrence for a given sand type;
assigning an MBE status to the given sand type based on the risk of MBE occurrence;
and
predicting an effect of the MBE status for the given sand type on production in a target production well.
2. The method of claim 1, wherein determining the risk of MBE occurrence comprises:
generating a random number;
comparing the risk of the MBE occurrence to the random number; and
assigning the MBE status based on a result of comparing the risk of the MBE occurrence to the random number.
3. The method of claim 2, further comprising:
setting the MBE status to no MBE occurred if the random number is greater than the risk of the MBE occurrence; and
setting the MBE status to MBE occurred if the random number is less than the risk of the MBE occurrence.
4. The method of claim 1, further comprising:
repeating the determining and the assigning for all sand types and all years of interest to yield an MBE risk schedule; and
predicting the effect of the MBE status for the given sand type using the MBE risk schedule.
5. The method of claim 1, wherein predicting the effect of the MBE status comprises:
adjusting producer capacity for the target well production based on the MBE status to yield an adjusted producer capacity; and

generating a deration curve for the target production well based on the adjusted producer capacity.

6. The method of claim 5, wherein adjusting the producer capacity includes one of reducing the producer capacity by a fixed threshold or based on a multiplier corresponding to a remediation efficiency of the given sand type.

7. The method of claim 6, further comprising:
outputting the deration curve on a terminal.

8. A system comprising:
one or more memories having computer-readable instructions stored therein; and
one or more processors configured to execute the computer-readable instructions to:
determine a risk of Matrix Bypass Event (MBE) occurrence for a given sand type;
assign an MBE status to the given sand type based on the risk of MBE occurrence; and
predict an effect of the MBE status for the given sand type on production in a target production well.

9. The system of claim 8, wherein the one or more processors are configured to execute the computer-readable instructions to determine the risk of MBE occurrence by:
generating a random number;
comparing the risk of the MBE occurrence to the random number; and
assigning the MBE status based on a result of comparing the risk of the MBE occurrence to the random number.

10. The system of claim 9, wherein the one or more processors are further configured to execute the computer-readable instructions to:
set the MBE status to no MBE occurred if the random number is greater than the risk of the MBE occurrence; and
set the MBE status to MBE occurred if the random number is less than the risk of the MBE occurrence.

11. The system of claim 8, wherein the one or more processors are further configured to execute the computer-readable instructions to:
 - repeat determining and assigning processes for all sand types and all years of interest to yield an MBE risk schedule; and
 - predict the effect of the MBE status for the given sand type using the MBE risk schedule.
12. The system of claim 8, wherein the one or more processors are configured to execute the computer-readable instructions to predict the effect of the MBE status by:
 - adjusting producer capacity for the target well production based on the MBE status to yield an adjusted producer capacity; and
 - generating a deration curve for the target production well based on the adjusted producer capacity.
13. The system of claim 12, wherein the one or more processors are configured to execute the computer-readable instructions to adjust the producer capacity by one of reducing the producer capacity by a fixed threshold or based on a multiplier corresponding to a remediation efficiency of the given sand type.
14. The system of claim 13, wherein the one or more processors are further configured to execute the computer-readable instructions to output the deration curve on a terminal.
15. One or more non-transitory computer-readable media comprising computer-readable instructions, which when executed by one or more processors, cause the one or more processors to:
 - determine a risk of Matrix Bypass Event (MBE) occurrence for a given sand type;
 - assign an MBE status to the given sand type based on the risk of MBE occurrence; and
 - predict an effect of the MBE status for the given sand type on production in a target production well.

16. The one or more non-transitory computer-readable media of claim 15, wherein the execution of the computer-readable instructions, cause the one or more processors to determine the risk of MBE occurrence by:

generating a random number;

comparing the risk of the MBE occurrence to the random number; and

assigning the MBE status based on a result of comparing the risk of the MBE occurrence to the random number.

17. The one or more non-transitory computer-readable media of claim 16, wherein the execution of the computer-readable instructions, cause the one or more processors to:

set the MBE status to no MBE occurred if the random number is greater than the risk of the MBE occurrence; and

set the MBE status to MBE occurred if the random number is less than the risk of the MBE occurrence.

18. The one or more non-transitory computer-readable media of claim 15, wherein the execution of the computer-readable instructions, cause the one or more processors to:

repeat determining and assigning processes for all sand types and all years of interest to yield an MBE risk schedule; and

predict the effect of the MBE status for the given sand type using the MBE risk schedule.

19. The one or more non-transitory computer-readable media of claim 15, wherein the execution of the computer-readable instructions, cause the one or more processors to predict the effect of the MBE status by:

adjusting producer capacity for the target well production based on the MBE status to yield an adjusted producer capacity; and

generating a deration curve for the target production well based on the adjusted producer capacity.

20. The one or more non-transitory computer-readable media of claim 19, wherein the execution of the computer-readable instructions, cause the one or more processors to adjust the

producer capacity by one of reducing the producer capacity by a fixed threshold or based on a multiplier corresponding to a remediation efficiency of the given sand type.

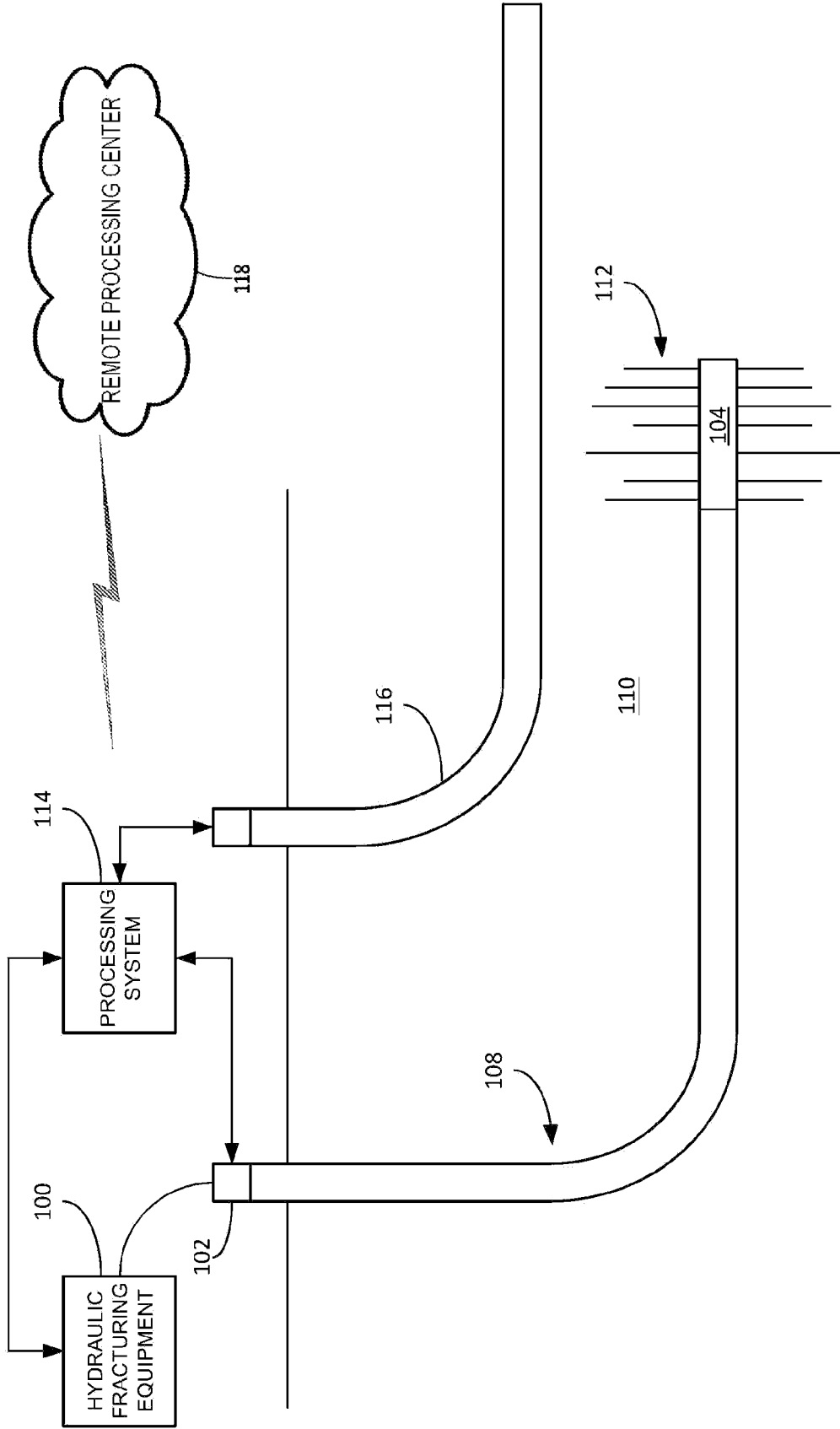


FIG. 1

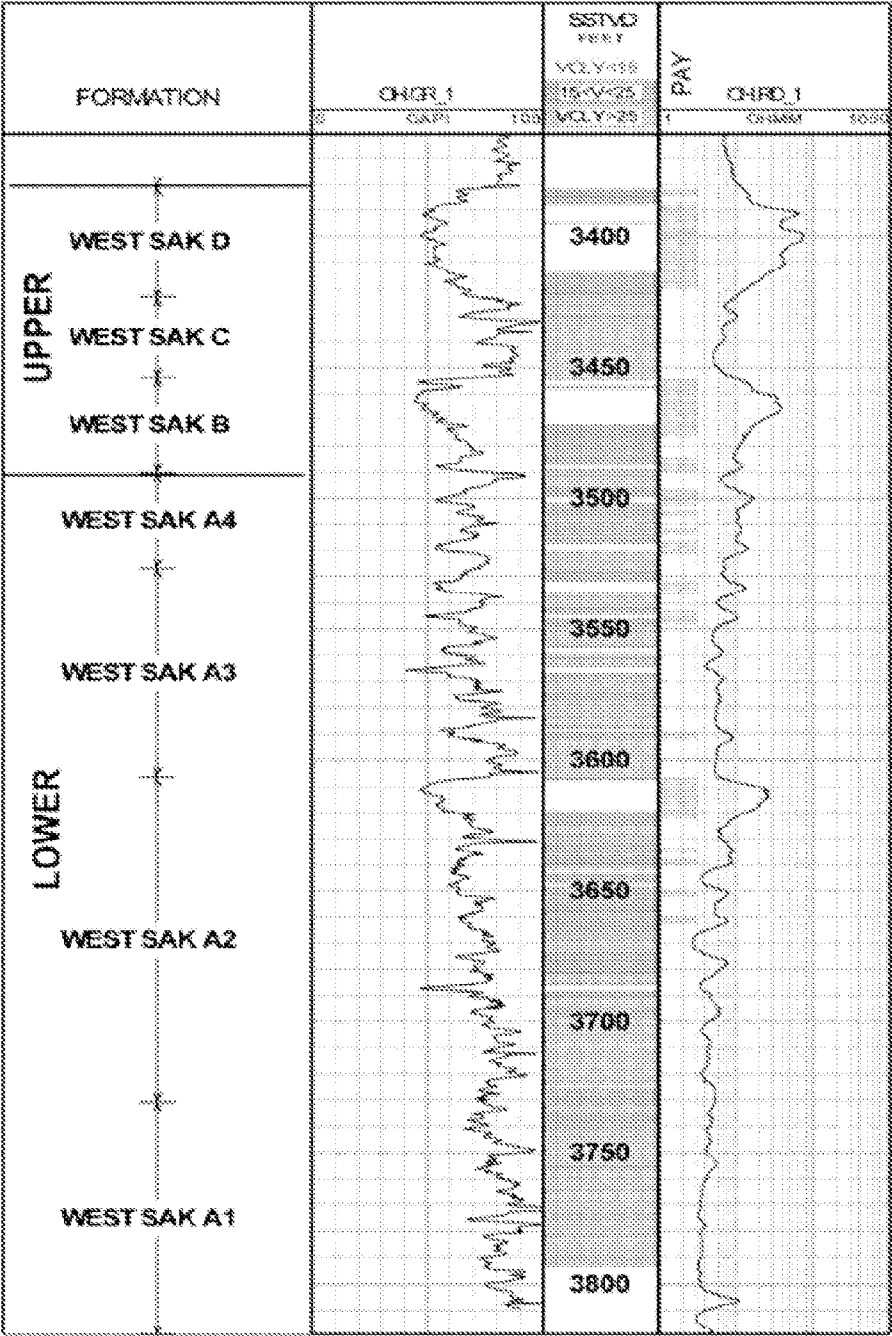


FIG. 2

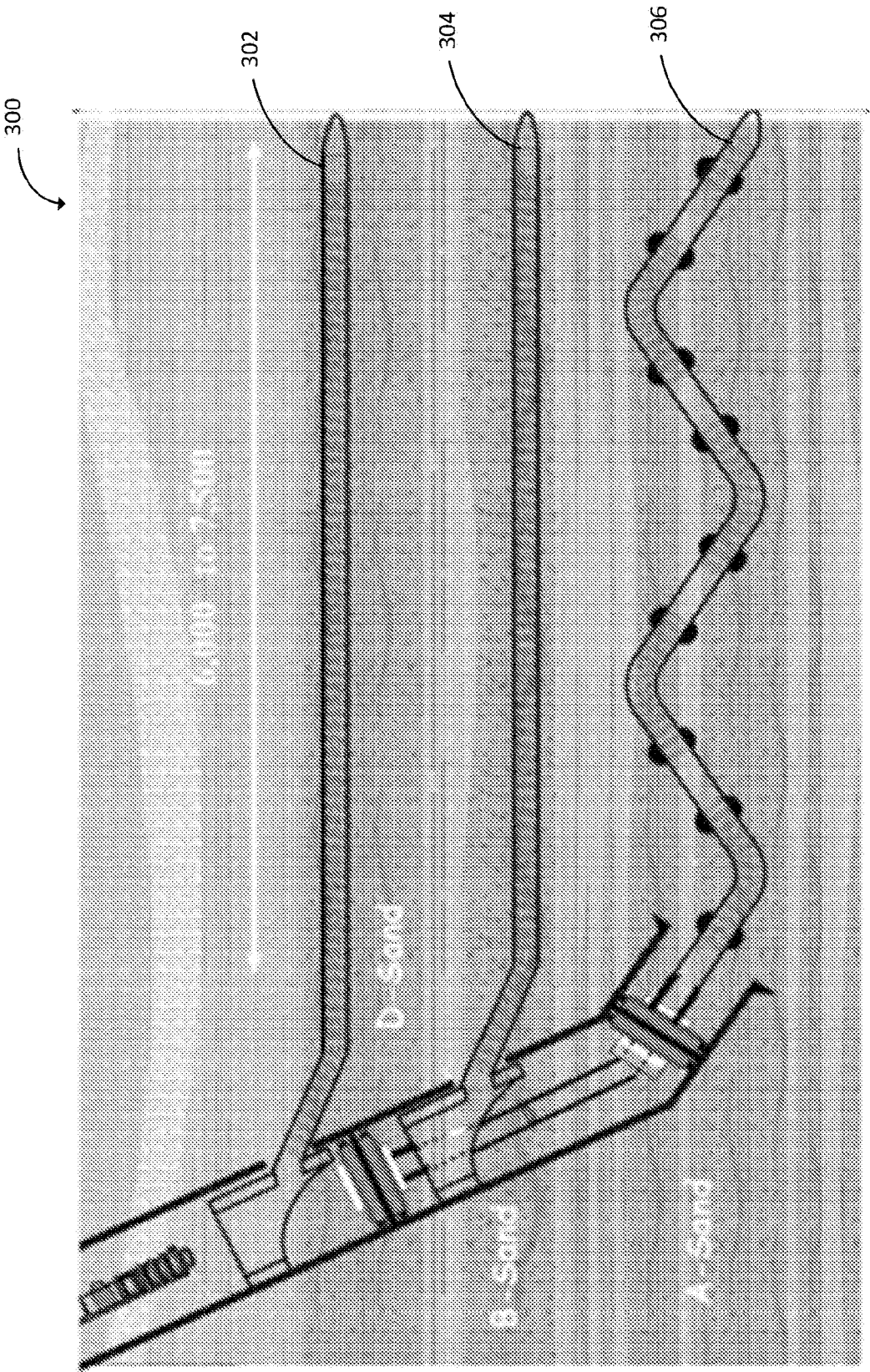
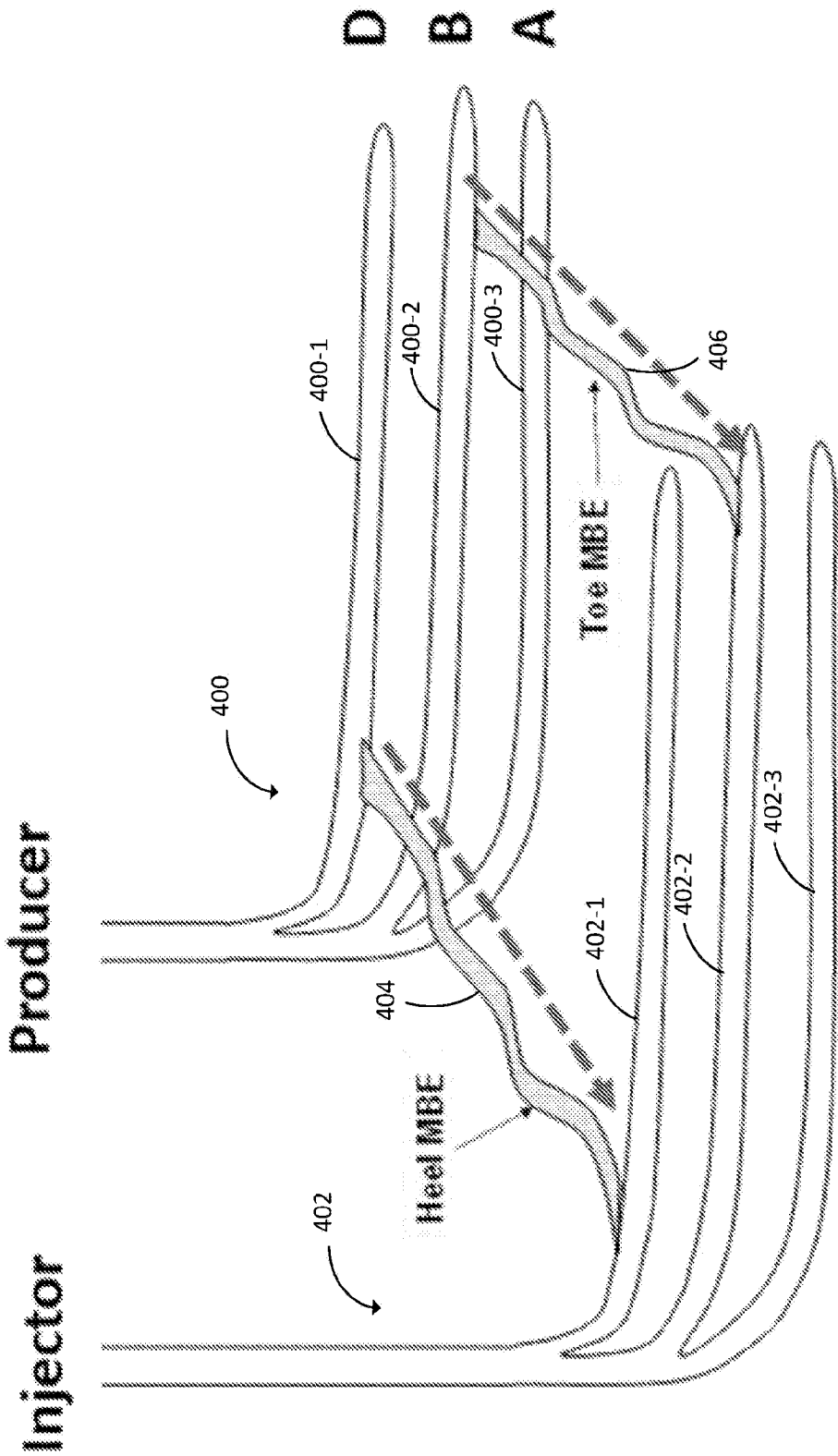


FIG. 3



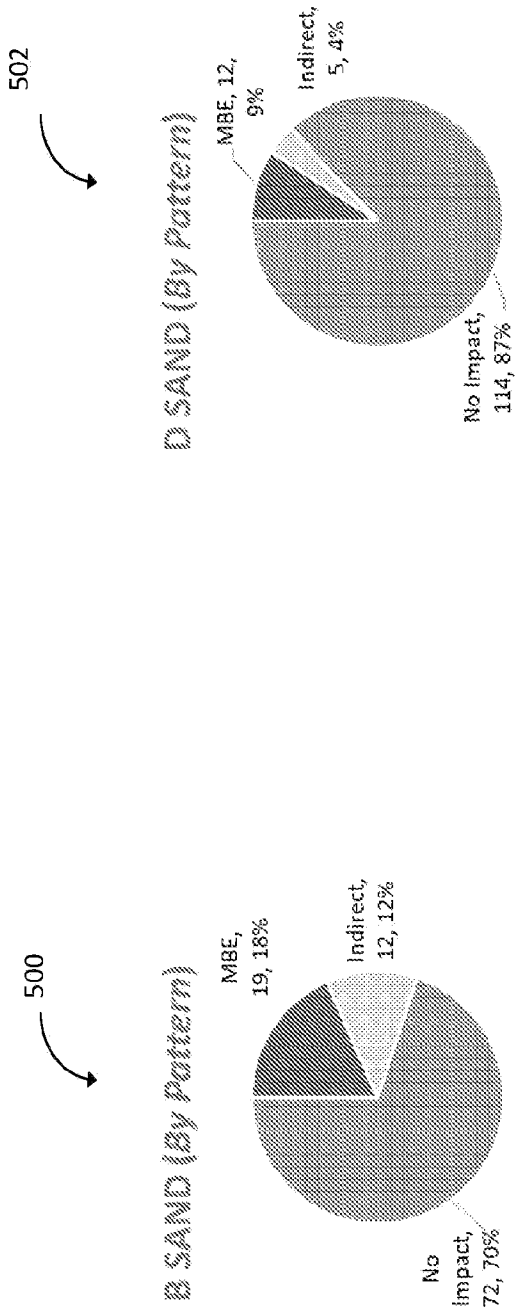


FIG. 5

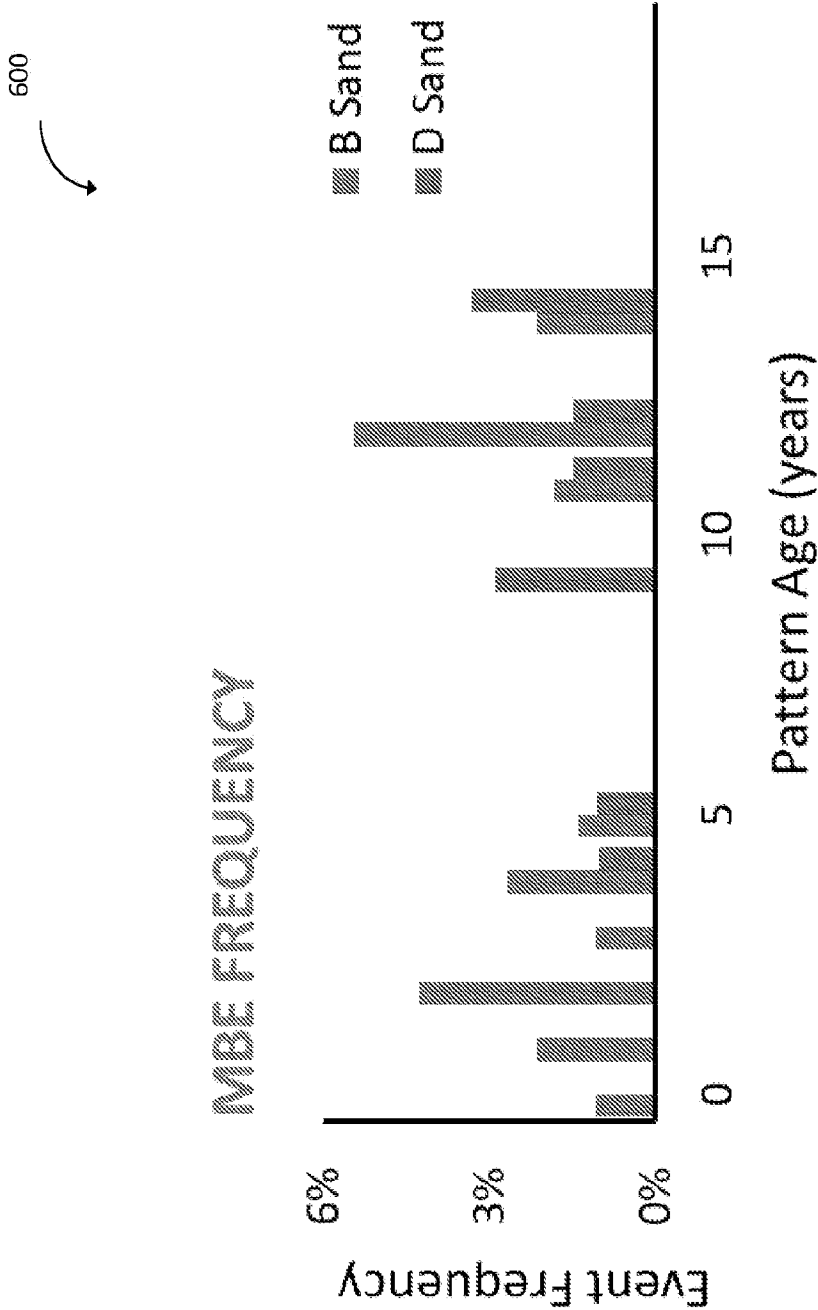


FIG. 6

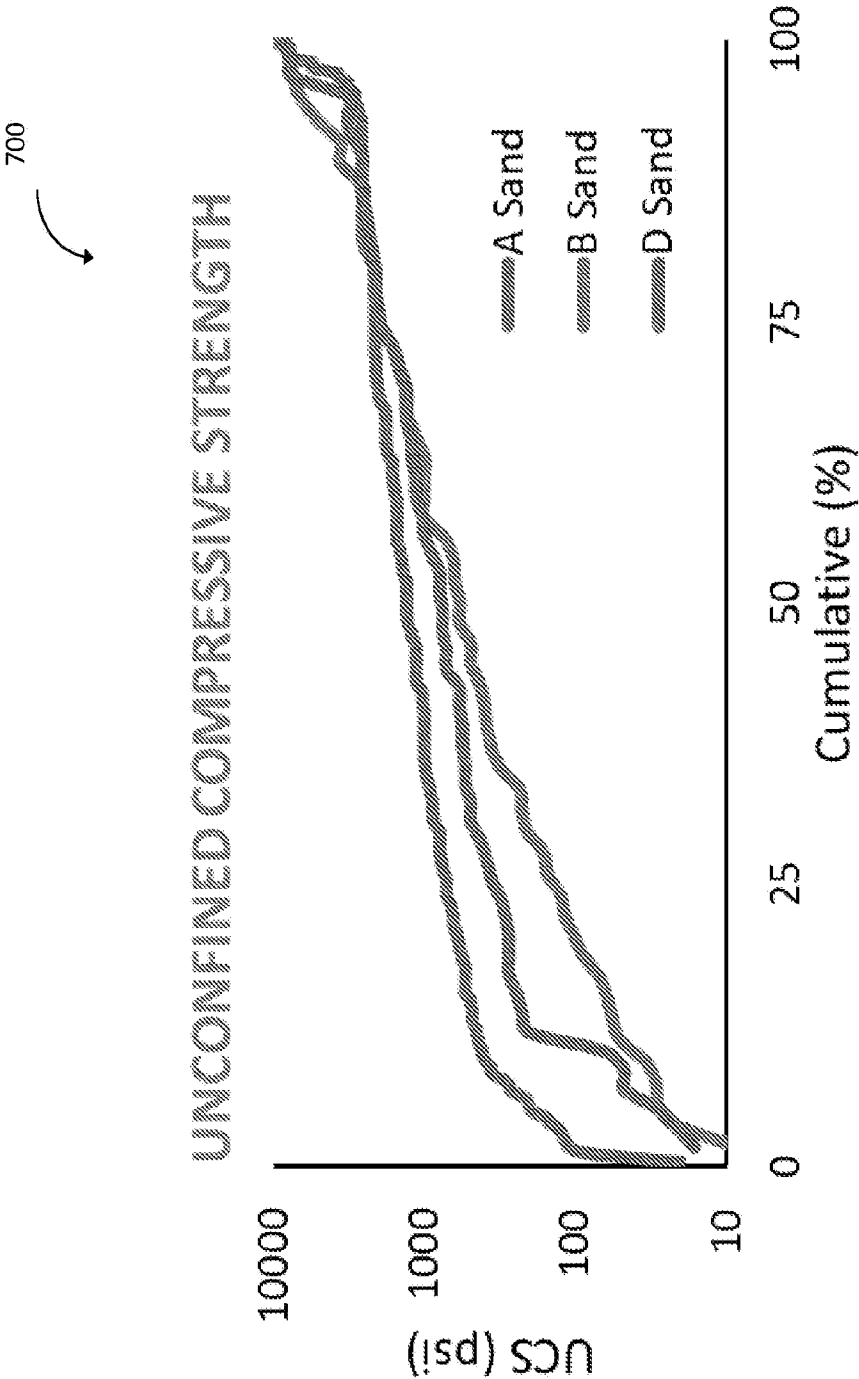


FIG. 7

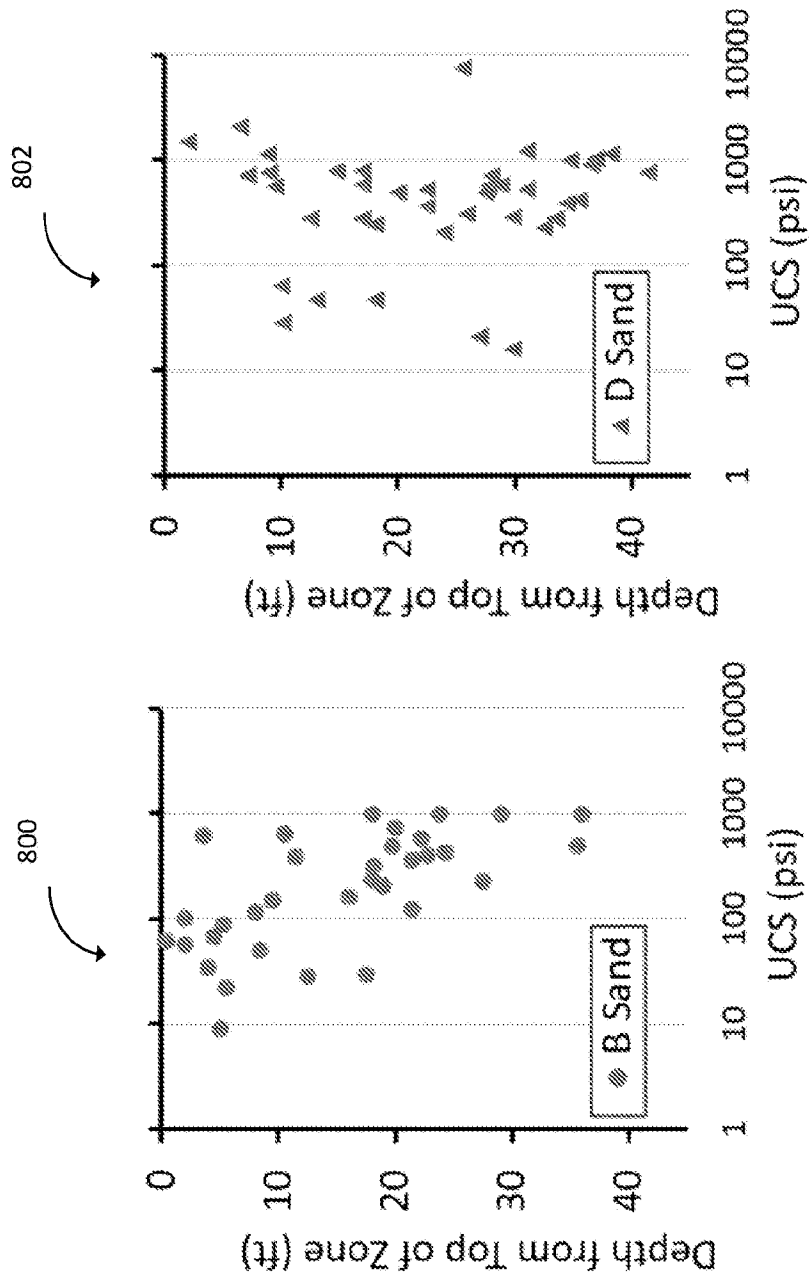


FIG. 8

900

B SAND – NO CONTROL/SL

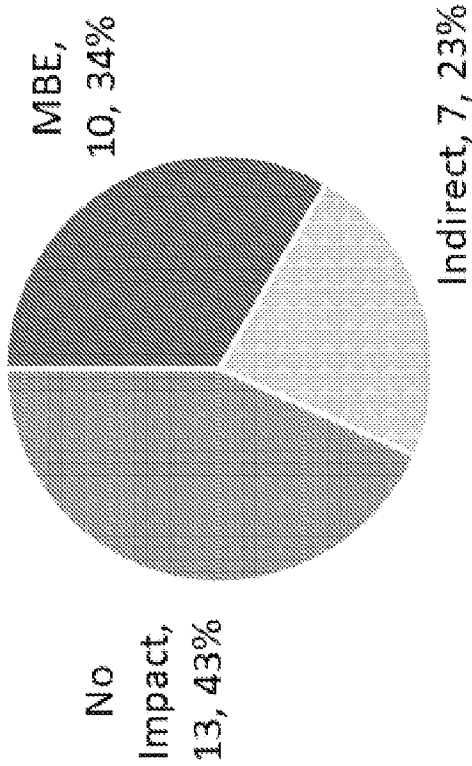


FIG. 9

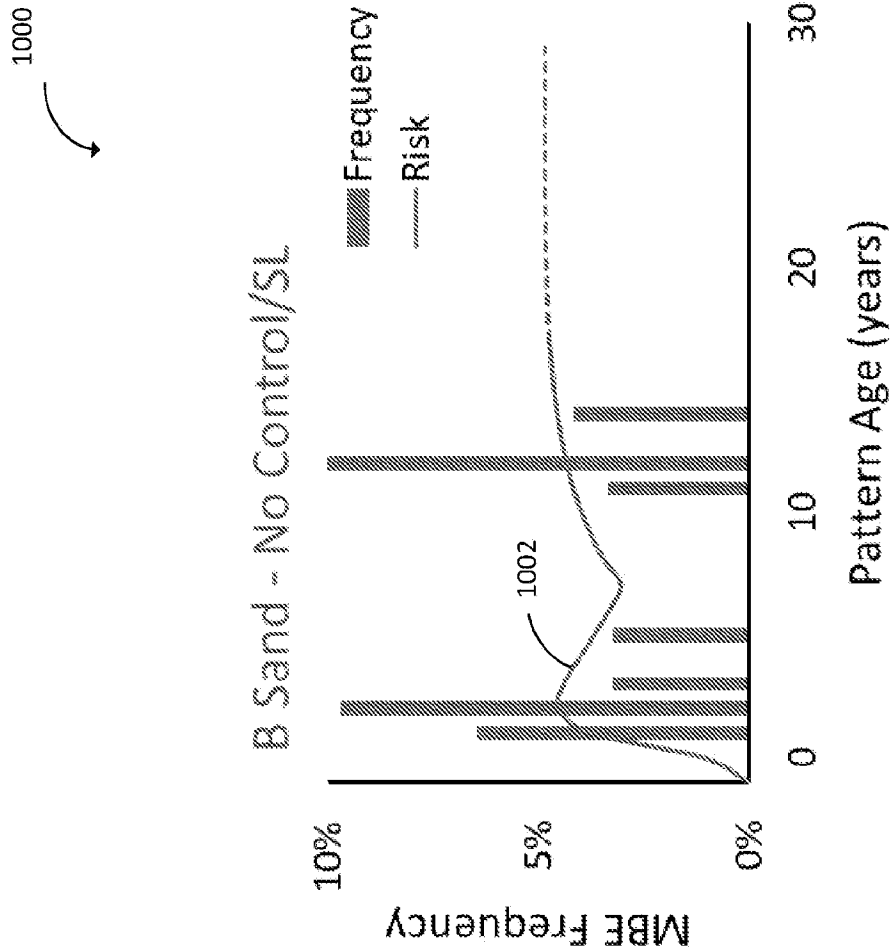


FIG. 10

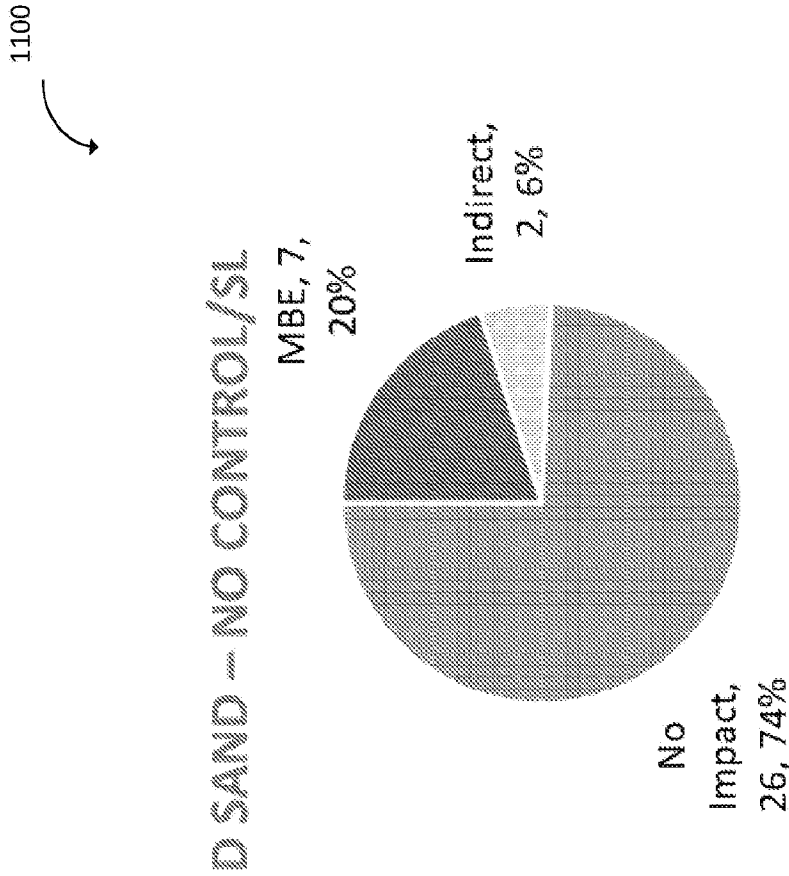


FIG. 11

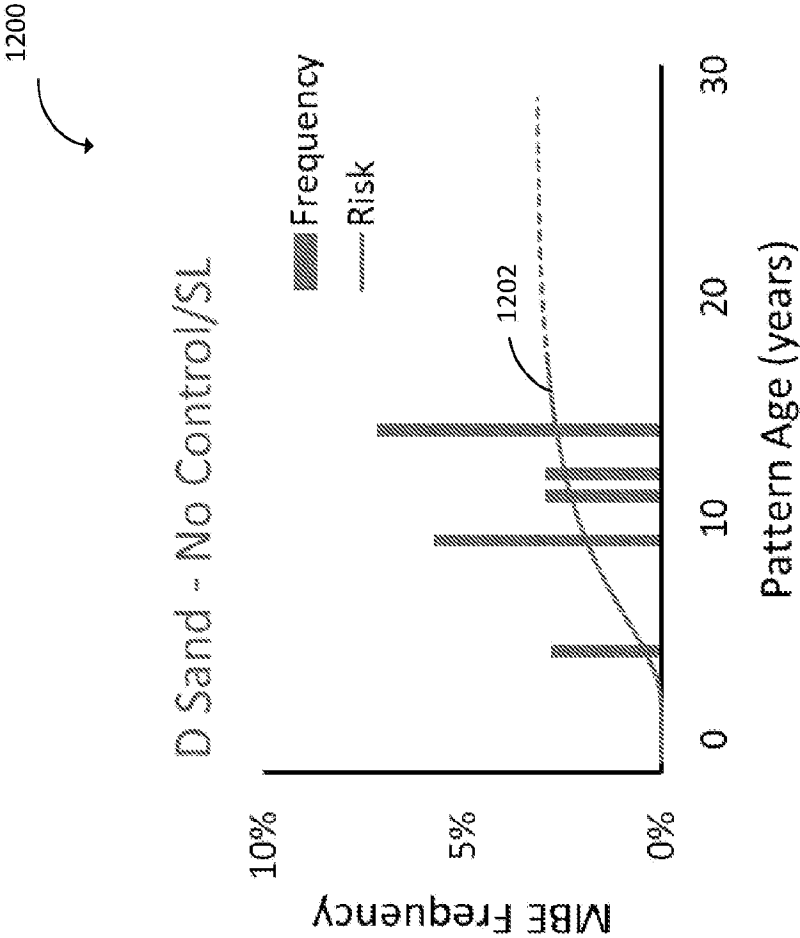


FIG. 12

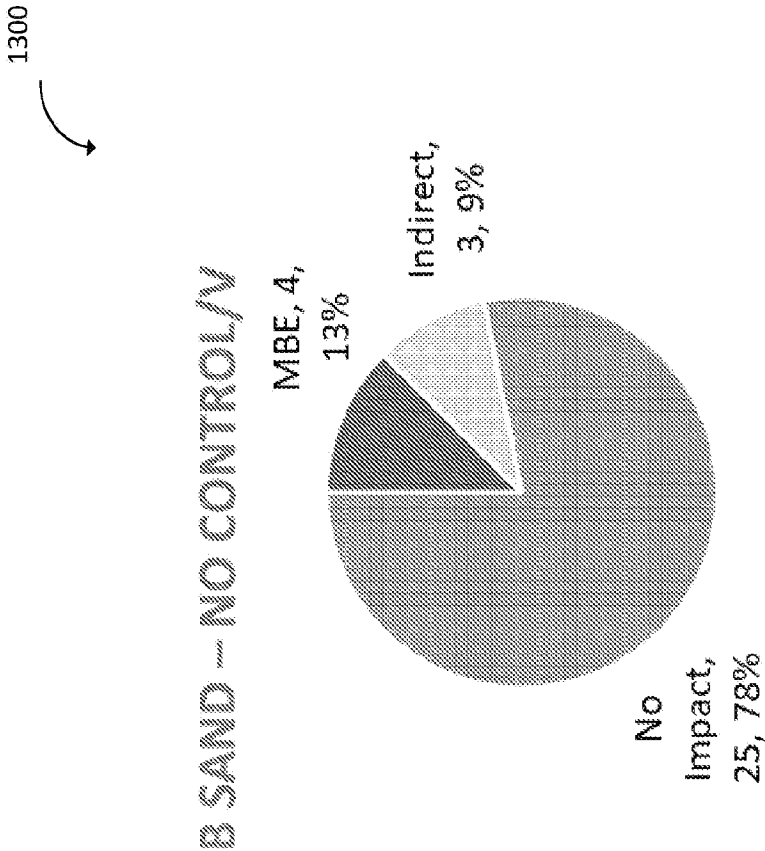


FIG. 13

1400

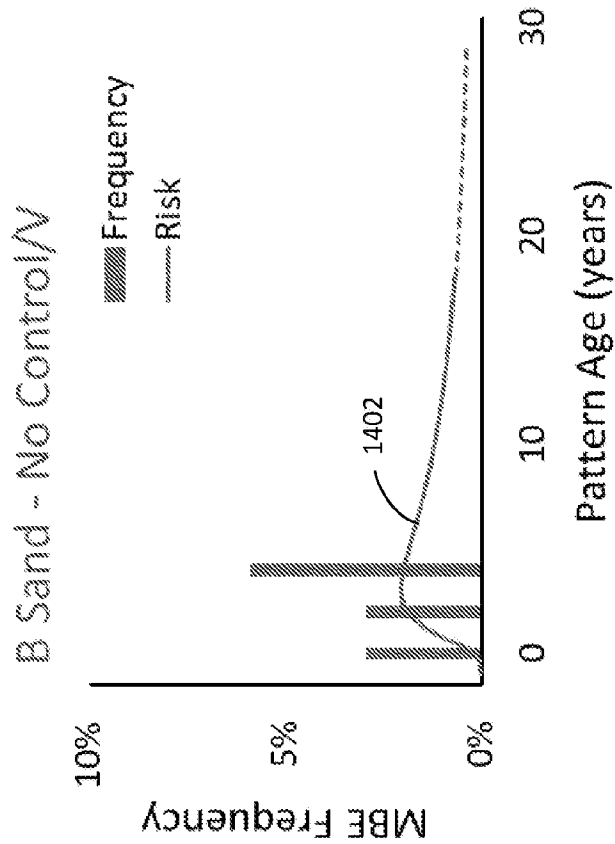


FIG. 14

1200

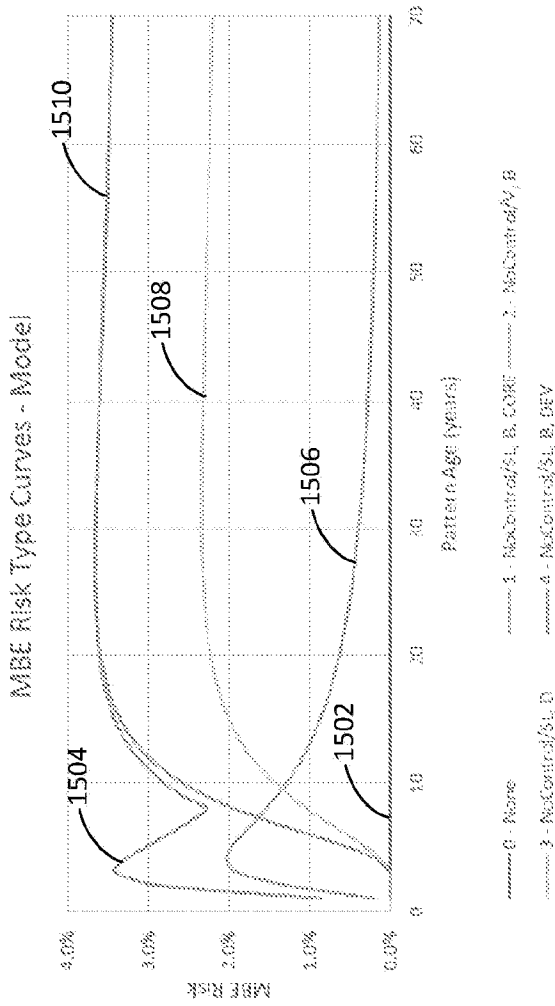


FIG. 15

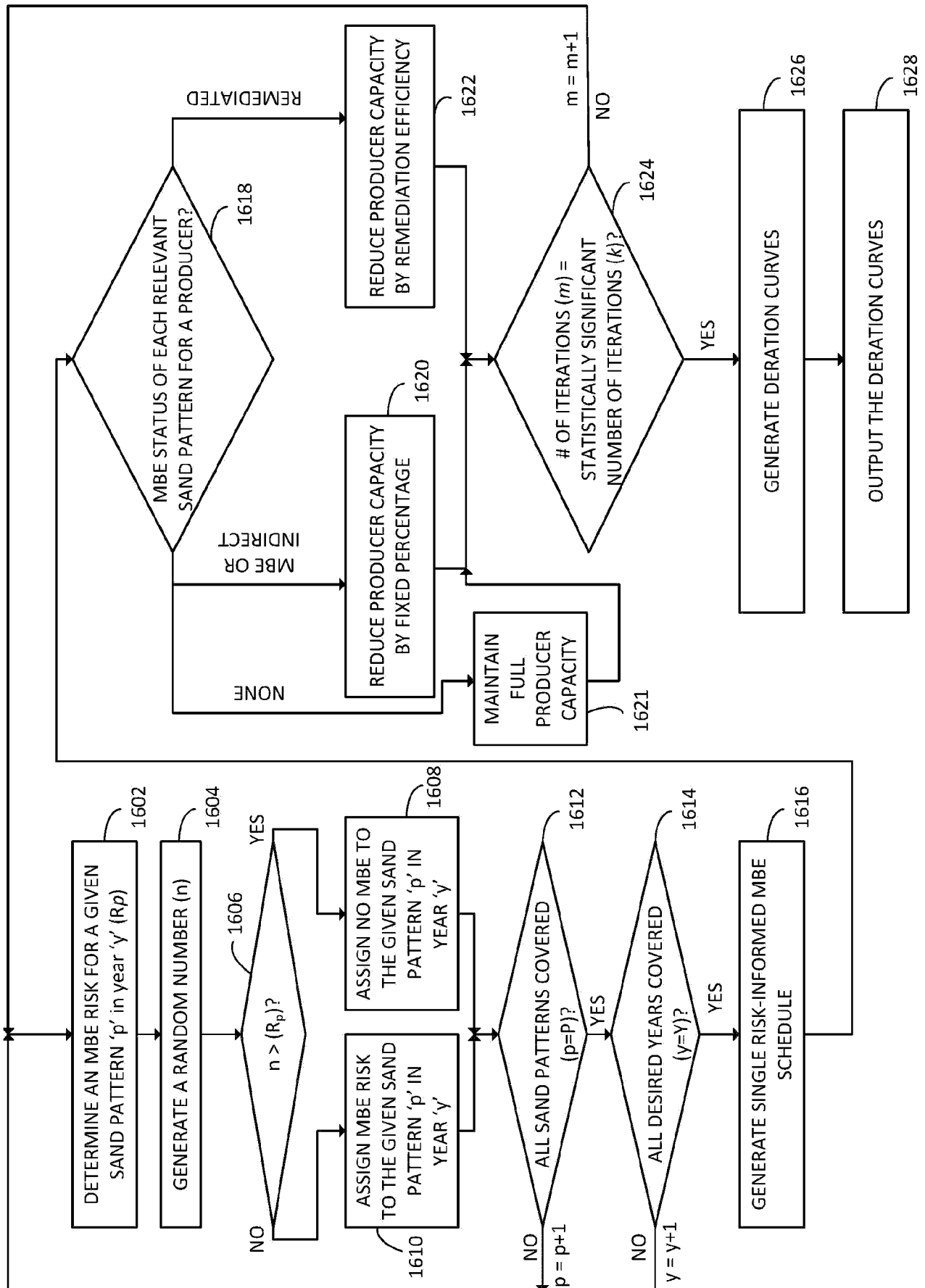


FIG. 16

1700

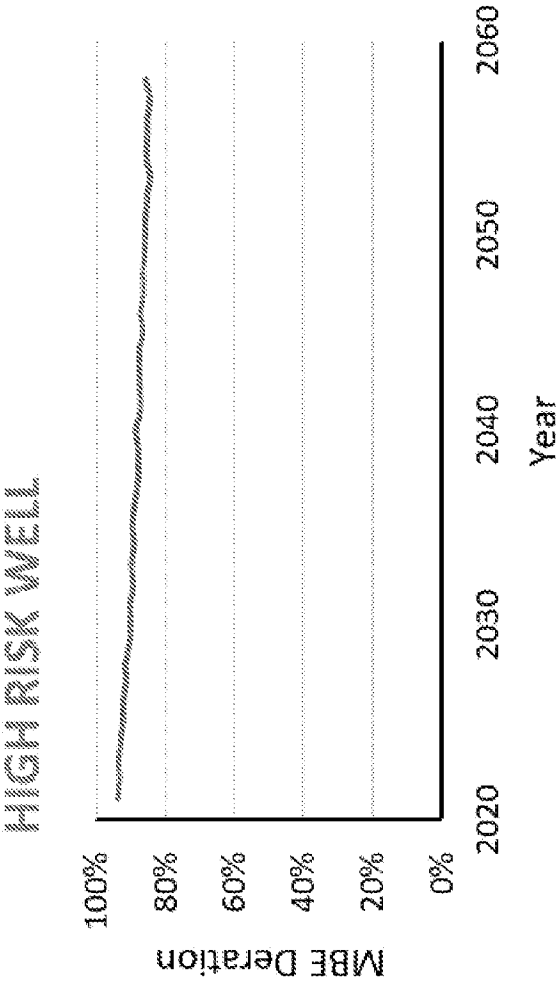


FIG. 17

1800

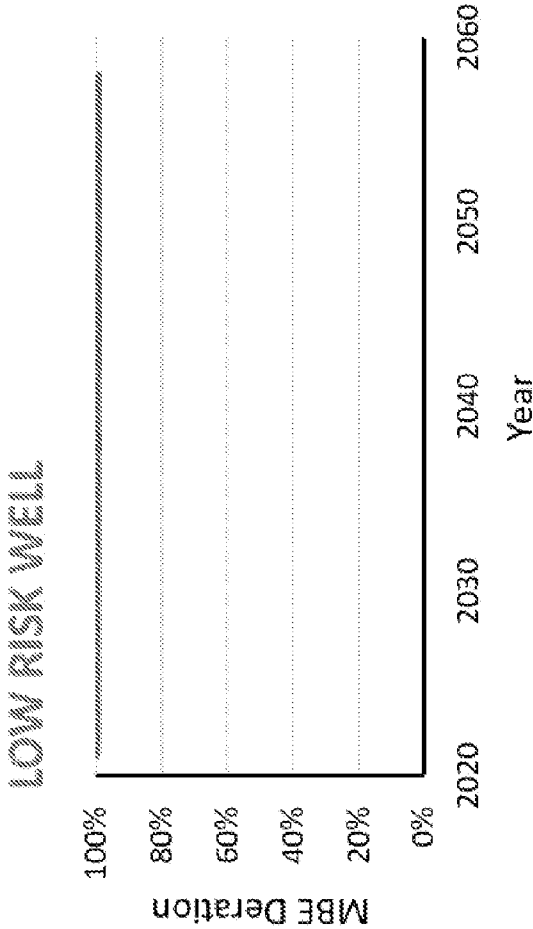


FIG. 18

1900

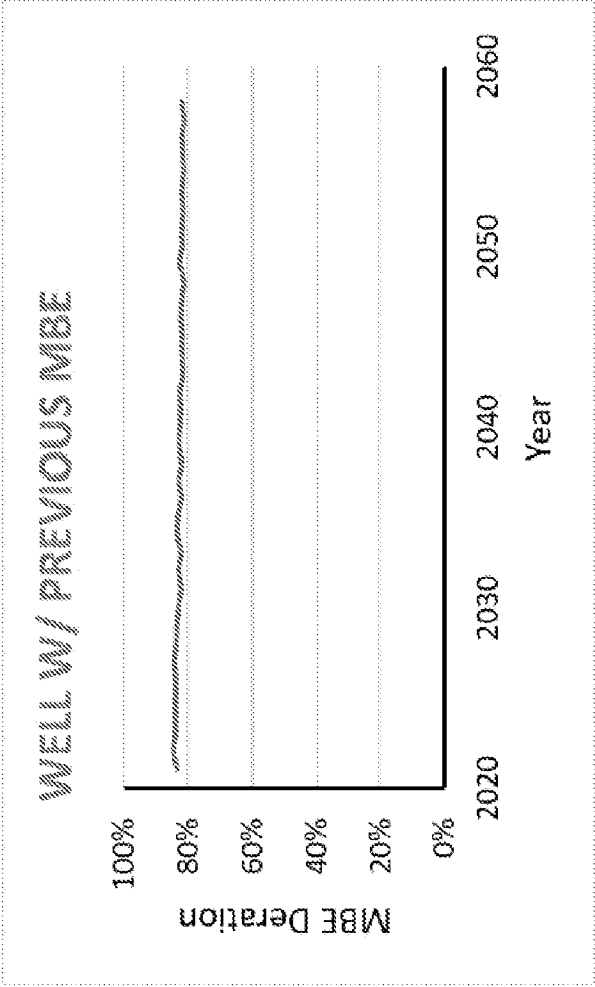


FIG. 19

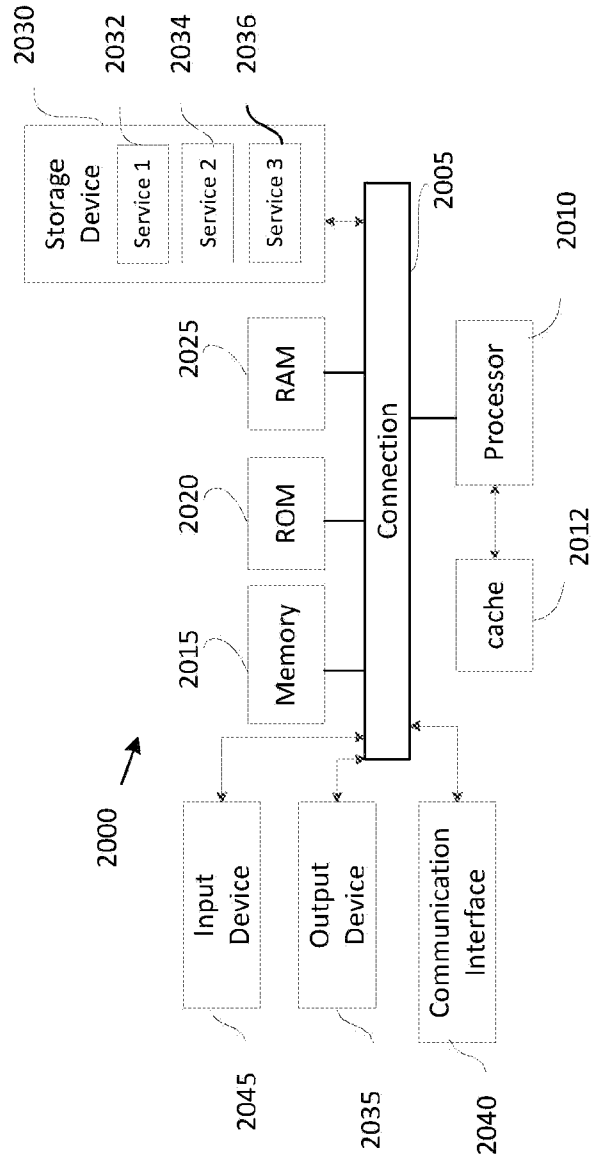


FIG. 20

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2024/032784

A. CLASSIFICATION OF SUBJECT MATTERIPC: *G06F 30/28* (2024.01); *E21B 47/10* (2024.01); *E21B 47/26* (2024.01); *G01V 20/00* (2024.01)CPC: *G06F 30/28*; *E21B 47/10*; *E21B 47/26*; *G01V 20/00*

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)

See Search History Document

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

See Search History Document

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

See Search History Document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2012/0267098 A1 (PEIRCE) 25 October 2012 (25.10.2012) entire document	1-20
A	US 2013/0096890 A1 (VANDERHEYDEN et al.) 18 April 2013 (18.04.2013) entire document	1-20
A	US 2011/0010143 A1 (DAI et al.) 13 January 2011 (13.01.2011) entire document	1-20
X	KEITH et al. Data Driven Risk Analysis and Production Forecast Deration for Matrix Bypass Events in the West Sak Oil Pool, Alaska North Slope. 22 May 2023 (22.05.2023). [retrieved on 22.08.2024]. Retrieved from the Internet: <URL: https://onepetro.org/SPEWRM/proceedings-abstract/23WRM/2-23WRM/D021S002R001/519684 > pgs. 1-19	1-20

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

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“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

23 August 2024 (23.08.2024)

Date of mailing of the international search report

04 September 2024 (04.09.2024)

Name and mailing address of the ISA/US

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