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SYSTEMS, METHODS, AND APPARATUSES FOR OPTIMIZED PERFORATION CONFIGURATION MODELLING

Abstract

Systems, methods and devices are disclosed for optimizing a completion stage perforation configuration. Some examples includes a wellbore in a subterranean feature having one or more perforations. One or more imaging devices are operable to collect erosion image data of the one or more perforations. Moreover, one or more non-transitory storage devices store instructions which, when executed by one or more processors, cause the system to perform various operations. These operations can include determining a proppant distribution prediction based on the erosion image data. The system can use a correction equation of an erosion model to calculate a corrected uniformity index value for the proppant distribution prediction. An amount of proppant per cluster is determined in some scenarios, based on the corrected uniformity index value, to optimize a completion perforation configuration for the wellbore.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] The present application claims priority to U.S. Provisional Patent Application No. 63/551,170 filed on Feb. 8, 2024, which is incorporated by reference in its entirety herein.

FIELD

[0002] Aspects of the present disclosure relate generally to systems and methods for analyzing a subterranean structure and more particularly to optimizing a perforation configuration for a completion stage of a well.

BACKGROUND

[0003] During hydraulic fracturing, proppants are pumped through perforations in the subterranean surface. The perforations are arranged according to an initial completion design and to the extent that reservoir formation permits. Finding the right perforation design to optimize the proppant allocation is a major factor in unconventional completion engineering.

[0004] It is with these observations in mind, among others, that the presently disclosed technology was conceived.

SUMMARY

[0005] Implementations described and claimed herein can address the foregoing problems by providing a system for optimizing a completion stage perforation configuration. The system can include one or more sensor devices operable to collect erosion data of one or more perforations of a wellbore in a subterranean feature. The system can also include an erosion model having a correction equation for calculating a corrected uniformity index value based on the collected erosion data. A proppant distribution prediction can be determined based on the corrected uniformity index value, and an amount of proppant per cluster can be determined based on the proppant distribution prediction. The system can also include a completion perforation configuration for the wellbore being optimized based on the amount of proppant per cluster.

[0006] In some examples, the proppant distribution prediction can be a first proppant distribution prediction; and/or a discrepancy between the first proppant distribution prediction and a second proppant distribution prediction. Also, the completion perforation configuration can be optimized at least partly based on organizing the discrepancy by cluster. Additionally, based on the discrepancy, the first proppant distribution prediction and the second proppant distribution prediction can indicate that the first proppant distribution prediction has a more uniform proppant distribution than the second proppant distribution prediction. The system can further include a stage level uniformity metric indicating that both the first proppant distribution prediction and the second proppant distribution prediction show a difference between two modeled perforation designs independently and in a same direction, and/or the completion perforation configuration can be optimized at least partly based on the difference being in the same direction.

[0007] In some instances, a proppant variance associated with un-eroded perforations can be calculated using the collected erosion data; and/or the proppant variance can be removed from an initial proppant allocation of the second proppant distribution prediction. Furthermore, removing the proppant variance can increase an alignment of the first proppant distribution prediction with the second proppant distribution prediction. The first proppant distribution prediction and the second proppant distribution prediction can estimate a distribution of proppant out of multiple perforation clusters in the subterranean feature. Also, the collected erosion data can include eroded dimensions of perforations after stimulation. Additionally, a quality of erosion calculations can be determined using the first proppant distribution prediction; and/or the collected erosion data can be corrected based on the quality of the erosion calculations to form corrected erosion data. Also, the amount of proppant per cluster can be determined at least partly based on the corrected erosion data.

[0008] In some examples, a device for perforation distribution modeling can include a sensor unit of a drill string operable to receive image data or acoustic data of one or more perforations of a wellbore in a subterranean feature; and/or a computing device communicatively coupled to the sensor unit for executing an erosion model, the erosion model including a correction equation for calculating a corrected uniformity index value based on the image data or the acoustic data, an erosion-based prediction of proppant allocation for the one or more perforations being based on the corrected uniformity index value, and a completion perforation configuration model for the wellbore being optimized based on the corrected uniformity index value.

[0009] In some examples, the sensor unit can include an ultrasonic sound generator. Additionally, optimizing the completion perforation configuration model can include determining, using the erosion model, an amount of proppant per cluster for the wellbore. Determining the amount of proppant per cluster for the wellbore can also include changing the amount of perforation per cluster from three to two. Moreover, optimizing the completion perforation configuration model can includes calculating a proppant variance associated with un-eroded perforations; and/or removing the proppant variance from an initial proppant allocation of the erosion-based prediction. Determining the erosion-based prediction of proppant allocation can include determining a baseline erosion assumption of a constant starting diameter based on projecting uneroded starting perforations as being a same size.

[0010] In some instances, a method of perforation distribution modeling includes receiving, from an imaging device, image data of one or more perforations of a wellbore in a subterranean feature; causing the image data to be used to determine an erosion-based prediction of proppant allocation for the one or more perforations; and/or causing a computing device communicatively coupled to the imaging device to execute an erosion model. The erosion model can include a correction equation for calculating a corrected uniformity index value based on the image data, an erosion-based prediction of proppant allocation for the one or more perforations can be based on the corrected uniformity index value, and/or a completion perforation configuration model for the wellbore can be optimized based on the corrected uniformity index value.

[0011] In some examples, optimizing the completion perforation configuration model for the wellbore can include changing, based on the erosion model, an amount of proppant per cluster in the wellbore. Optimizing the completion perforation configuration model can include calculating a proppant variance associated with un-eroded perforations; and removing the proppant variance from an initial proppant allocation of the erosion-based prediction. Optimizing the completion perforation configuration model can also include determining a quality of erosion calculations of erosion-based prediction; correcting the image data to create corrected image data based on the quality of the erosion calculations; and/or determining an amount of proppant per cluster using the corrected image data. Optimizing the completion perforation configuration model can also include forming either two perforations per cluster or three perforations per cluster in the wellbore based on optimizing the completion perforation configuration model.

[0012] Other implementations are also described and recited herein. Further, while multiple implementations are disclosed, still other implementations of the presently disclosed technology will become apparent to those skilled in the art from the following detailed description, which shows and describes illustrative implementations of the presently disclosed technology. As will be realized, the presently disclosed technology is capable of modifications in various aspects, all without departing from the spirit and scope of the presently disclosed technology. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not limiting.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. **1** illustrates an example system for optimizing a perforation configuration for a well at the completion stage.

[0014] FIG. **2** illustrates an example system for optimizing a perforation configuration for a well completion stage environment using predicted proppant masses for different perforation cluster configurations.

[0015] FIG. **3** illustrates an example system for optimizing a perforation configuration for a well completion stage environment using a cross-plot.

[0016] FIG. **4** illustrates an example system for optimizing a perforation configuration for a well completion stage environment using a comparison of Uniformity Index (UI) values.

[0017] FIGS. **5**A and **5**B illustrate an example system for optimizing a perforation configuration for a well completion stage environment using erosion dimension predictions.

[0018] FIG. **6** illustrates an example system for optimizing a perforation configuration for a well completion stage environment using a comparison of Uniformity Index (UI) values with corrected erosion data.

[0019] FIG. **7** illustrates a flow diagram illustrating example operations of a method for optimizing a perforation configuration for a well completion stage environment, which can be performed by the systems disclosed in FIGS. **1-6** and **8**.

[0020] FIG. **8** depicts an example computing system that may implement various systems and methods discussed regarding FIGS. **1-7**.

DETAILED DESCRIPTION

[0021] Aspects of the present disclosure involve systems and methods for optimizing a completion stage perforation configuration. For instance, a wellbore in a subterranean feature can have one or more perforations. One or more imaging devices can be operable to collect erosion image data of the one or more perforations. Furthermore, the system can include a distributed acoustic sensing (DAS) unit operable to collect acoustic sensing data.

[0022] The system can determine a first proppant distribution prediction based on the erosion image data. Moreover, a second proppant distribution prediction can be determined based on the sensor data such as ultrasonic data, video data, and/or combinations thereof; and/or the system can determine an amount of proppant per cluster based on the first proppant distribution prediction and the second proppant distribution prediction, to optimize a completion perforation configuration for the wellbore.

[0023] Systems and methods disclosed herein can optimize completion stage perforation configurations using an improved proppant distribution model which includes a correction equation. Finding the right perforation design to optimize the uniformity of proppant distribution can be a major factor in unconventional-terrain engineering. In the systems, methods, and devices disclosed herein, eroded dimensions of perforations after stimulation can be used by the perforation configuration model to estimate the distribution of proppant out of multiple perforation clusters in a well formation stage and can lead to improved perforation practices and well performance. Additional advantages will become apparent from the detailed description below.

[0024] In the description, phraseology and terminology are employed for the purpose of description and should not be regarded as limiting. For example, the use of a singular term, such as “a”, is not intended as limiting of the number of items. Also, the use of relational terms in the description for clarity in specific reference to the figures are not intended to limit the scope of the present inventive concept or the appended claims. Further, any one of the features of the present inventive concept may be used separately or in combination with any other feature. For example, references to the term “implementation” means that the feature or features being referred to are included in at least one aspect of the presently disclosed technology. Separate references to the term "implementation" in this description do not necessarily refer to the same implementation and are also not mutually exclusive unless so stated and/or except as will be readily apparent to those skilled in the art from the description. For example, a feature, structure, process, step, action, or the like described in one implementation may also be included in other implementations but is not necessarily included. Thus, the presently disclosed technology may include a variety of combinations and/or integrations of the implementations described herein. Additionally, all aspects of the presently disclosed technology as described herein are not essential for its practice.

[0025] Lastly, the terms "or" and "and/or" as used herein are to be interpreted as inclusive or meaning any one or any combination. Therefore, "A, B or C" or "A, B and/or C" mean any of the following: "A"; "B"; "C"; "A and B"; "A and C"; "B and C"; or "A, B and C." An exception to this definition will occur only when a combination of elements, functions, steps or acts are in some way inherently mutually exclusive.

[0026] The technology disclosed herein can improve a set of correction equations aimed at improving the interpretation accuracy of image analysis. These systems can be an extension of an erosion-based interpretation practice with a correction for the expected deviation of proppant associated with starting perforation dimensions and erosional conditions of the well in statistics. For instance, the techniques disclosed herein can be used for image data including ultrasonic based measurement data, which may require interpretation and calculations to turn image dimensions into expected proppant quantities.

[0027] In some examples, a misalignment in proppant allocation can occur between an erosion model based on a perforation imaging analysis and other analysis techniques, such as video or ultrasonic analysis. The perforation distribution model(s) disclosed herein can expand the comparison to the entire well and offer a possible continuing explanation and/or correction for the discrepancy between these two model components.

[0028] In some examples, the model can organize the discrepancy between interpreted proppant masses by cluster. The model can determine that the corrected analysis outputs yield a more uniform proppant distribution than erosion-based outputs based on analyzing perforation images. Furthermore, the model can determine the discrepancy with cluster is random and/or with no trend suggesting that either one of the diagnostics model components is inaccurate to a large degree, or that the results need to be averaged at a larger scale for common behaviors to be identified.

[0029] In some scenarios, the perforation distribution model can determine stage level uniformity metrics indicating that both diagnostic model components showed a difference between two modeled perforation designs independently and/or in the same direction. Based on this output, the model can determine that analysis of the erosion imaging data, if averaged at the stage level, would produce the same identified completion behavior for optimization decisions. In some examples, the model can output a recommended amount of perforations per cluster as a proppant allocation optimization output, for instance, based on the determination regarding averaging the erosion imaging data. For instance, the model can indicate a predicted improvement by changing an amount of perforations per cluster (e.g., from three to two). Furthermore, quantitative uniformity metrics between the diagnostics methods can be different, and a correction to the erosion-based image analysis component can be applied.

[0030] In some examples, the difference in predicted proppant allocation between the erosion-imaging analysis and the corrected values can be partially explained by calculating the proppant allocation variance associated with un-eroded perforations and removing it from the original proppant allocation. The process can result in an increase in expected uniformity based on uncorrected erosion analysis, and this data removal can better align with uniformity metrics.

[0031] In some instances, a wider investigation into the erosion correction process can determine that erosional conditions should be analyzed on a case-by-case (e.g., well-by-well) basis to determine the quality of the erosion calculations and/or the degree that the uniformity needs correction. In some scenarios, conditions can occur where the correction is helpful to get more aligned with expected values but can still show the correct behavior in the erosion analysis without any correction. Correcting the erosion-imaging allocation component of the perforation distribution model can reduce false trends across multiple completions designs and perforation settings.

[0032] To begin a detailed discussion of an example perforation optimization modeling system, reference is made to FIG. **1**.

[0033] FIG. **1** illustrates an example system **100** for optimizing a perforation configuration for a well completion stage environment **102**. The well completion stage environment **102** can be a well site **104** with a bore hole **106** into a subterranean feature **108** (e.g., an underground reservoir) for extracting oil or gas from the subterranean feature **108**.

[0034] In some instances, the system **100** includes a wellhead assembly **110** connected to a string assembly **112** which is inserted into the bore hole **106**. The string assembly **112** can include one or more sensor units such as an imaging device **114**, an ultrasonic unit **116**, as well as various other sensors, hardware, and other computing device components. The imaging device **114** can include one or more of a camera or a light sensor operable to collect image data **115** in the bore hole **106**, such as erosion image data of one or more perforations **118**. The ultrasonic unit **116** with one or more acoustic sensors and/or actuators (e.g., speakers, microphones, etc.) can collect ultrasonic data **117** of the one or more perforations **118**. The string assembly **112** can also include a wired or a wireless communication unit **120**, such as a wireless transmitter, a wireless receiver, an antenna, a controller, and so of forth. The wired or wireless communication unit **120** can communicate, via a network connection, with one or more control devices **122**, which can be housed at one or more center(s) **123** at surface level and/or outside the bore hole **106**. The control center(s) **123** can house the control devices **122** as well as various other equipment for controlling the operations of the wellhead assembly **110** and/or the string assembly **112** to perform the perforation configuration techniques discussed herein.

[0035] For instance, the one or more control devices **122** can include one or more computer devices (e.g., such as the computing system **802** of FIG. **8**) configured to provide a proppant optimization model **124**. The proppant optimization model **124** can receive and/or store the data collected at the string assembly **112**, such as the image data **115** and/or the ultrasonic data **117**. As discussed in greater detail below, the proppant optimization model **124** can determine a first proppant distribution prediction **126** based on the image data **115** and/or a second proppant distribution prediction **128** based on the acoustic sensing data. Furthermore, the proppant optimization model **124** can generate or determine a target variable **130** (e.g., a target output), which can include an amount of proppant per cluster, based on the first proppant distribution prediction **126** and the second proppant distribution prediction **128**.

[0036] FIG. **2** depicts an example system **100** for optimizing a perforation configuration for the well completion stage environment **102**, which can form at least a portion of the system **100** depicted in FIG. **1**.

[0037] FIG. **2** shows an example data output of both the first proppant distribution prediction **126** and the second proppant distribution prediction **128**. For instance, the data output can include predicted proppant masses for different perforation clusters using the erosion-based image proppant mass calculations for each cluster in the well, which can be compared to distributed acoustic sensing (DAS)-based proppant mass calculations for verification. The red and blue indicate the stages with 3 and 2 perforations per cluster, respectively. The horizontal black line is the average or baseline of 121,000. As such, FIG. **2** depicts an example system of interpreted proppant masses by cluster in the well site **104** from erosion modeling of perforation images. For any given stage, there can be a low chance interpreted proppant masses agree between the two diagnostics techniques.

[0038] FIG. **3** depicts the proppant masses from FIG. **2** as a cross-plot **302**. The cross-plot **302** can show no correlation between the diagnostics techniques. This cross-plot **302** could have resulted in a trend but not a straight line of y=x. A non-straight-line trend would indicate one of the diagnostics is over/underestimating certain technical assumptions in the process. In that case, assumptions would need to be adjusted to get better agreement. Alternatively, as shown in FIG. **3**, the discrepancy can be considered random with no trend suggesting that either one of the diagnostics is inaccurate to a large degree or that the results need to be averaged at a larger scale for common behaviors to be identified. In other words, FIG. **3** depicts a cross-plot **302** analysis of examples of proppant masses by cluster in the well site **104** which compares the erosion model of perforation images to calculations from the DAS model.

[0039] FIG. **4** depicts an example system **100** including a comparison of a Uniformity Index **400** for the well site **104** based on the image data **115** and/or the ultrasonic data **117**. As shown in FIG. **4**, proppant quantities at the cluster level can be combined into a stage level metric of the Uniformity Index **400**.

[0040] In some instances, a comparison between an erosion-based image analysis **402** and a DAS-based analysis **404** can be split into two perforations-per-cluster designs **406** and three perforations-per-cluster designs **408**, as shown in FIG. **4**. The values of UI **400** can be consistently higher for the DAS-based analysis **404** than the erosion-based image analysis **402**, but a trend comparing the two perforations-per-cluster designs **406** and the three perforations-per-cluster designs **408** can be seen in both diagnostic techniques, both the erosion-based image analysis **402** and the DAS-based analysis **404**. The system **100** can determine that, even though cluster level quantities are not in agreement at all, either diagnostic would lead to the same trend in perforation design. In other words, in general, the trend of fluid distribution from fiber measurement can match the trends of erosion data from camera measurements. In some scenarios, other key behavior can be found to be consistent while behaviors at the lower cluster level can be lacking.

[0041] FIGS. **5**A and **5**B illustrate an example system **100** including a visualization **502** of un-eroded perforation dimensions **504** and eroded perforation dimensions **506** with a constant and even distribution of un-eroded perforation sizes. The system **100** depicted FIGS. **5**A and **5**B can form at least a portion of the system **100** depicted in FIG. **1**.

[0042] In some examples, resolution between the two diagnostic techniques is likely to be explained in engineering statistics rather than scrutiny over technical assumptions. The trends can be identified in groups of common designs because they can be aggregated together to overcome randomness. General disagreement between amounts of uniformity of the interpretations can also be possibly resolved with an engineering statistical approach by suggesting that variance not necessarily associated with proppant allocation is included in the calculations of one or both diagnostics.

[0043] In some instances, the proppant optimization model **124** can focus on the erosion-based image analysis because the un-eroded perforations can provide a source of additional variance. Visually this can be seen in FIGS. **5**A and **5**B. FIG. **5**A depicts a first chart **508** depicting the baseline erosion assumption of a constant starting diameter by projecting every un-eroded starting base perforation as the same size. FIG. **5**B depicts a second chart **510** depicting a possible range of outcomes of the un-eroded perforation sizes that needs to be considered. This can be understood as a normal distribution with a standard deviation and an average. Visually with FIGS. **5**A and **5**B, it is shown how the proppant optimization model **124** can determine how the distribution of un-eroded holes can impact the final eroded dimensions. Some of the variance of the eroded sizes (green-measured) can be associated with the starting perforation variance, not the proppant allocation. If the proppant optimization model **124** removes the variance from the erosion analysis, the proppant optimization model **124** can get a corrected distribution projection for every stage. The correction can increase the uniformity of each stage, making it closer to the metric calculated from the image data **115** and/or the ultrasonic data **117**.

[0044] In some examples, this concept can be illustrated in equation form as:

[00001]

$$\text{Variance}[\text{proppantdistribution}] = \text{Variance}[\text{measuredinerodedperfs}] - \text{Variance}[\text{un - erodedperforations}]$$

[0045] These variance concepts can be expanded into the following correction equation which is in terms of an original UI calculation with constant un-eroded perforation and the perforation parameters:

[00002] $$UI_{corrected} = 1 - \frac{\sqrt{\left[\frac{\#}{cl}(1 - UI)\right]^2 - spf^2\left[\frac{(\sqrt{2}+1)}{\sqrt{2}}\frac{1000 * bh}{ER}\right]^2}}{\frac{\#}{cl}}$$

[0046] spf=number of perforations in cluster. [0047] UI=Uniformity Index (UI) calculated from erosion model. [0048] #/cl=Ib proppant per cluster (Ibm). [0049] ER=Erosion Rate (in/1000 lbm). [0050] bh=standard deviation of base un-eroded perforations.

[0051] This equation can provide a correction to be applied to an erosion outcome matter by correcting for the factors affecting the variance. Furthermore, this equation can assume an original UI is calculated from proppant masses of the average perforation eroded dimensions of the cluster, and not on each individual perforation. Spf can be replaced with spf if an original UI was calculated using an erosion model on each perforation instead.

[0052] In some instances, each perforation shot is not an independent and random sample of the distribution of base holes. The proppant optimization model **124** can determine that perforations in the same cluster can show less variance than a completely random sample. The second equation Spf,eq can be introduced to take this into account. Spf,eq can vary between 1 and spf and can be determined from a base hole analysis by proppant optimization model **124** of clusters by calculating the standard deviation of base holes at the cluster level vs all the perforations independently.

[00003] $$Spf, eq = \left[\frac{bh}{bh, cl}\right]^2$$

[0053] When spf,eq is used, spf can be replaced with spf*spf,eq or in the case of erosion model on each perforation cases, spf can be directly replaced with spf,eq.

[0054] FIG. **6** depicts an example system **100** including a Uniformity Index (UI) comparison **600** for the well site **104** from the erosion model of perforation images. As shown in FIG. **6**, a UI correction **602** can be added by the proppant optimization model **124**. The system **100** depicted in FIG. **6** can form at least a part of the system **100** depicted in FIG. **1**.

[0055] In some examples, the proppant optimization model **124** can determine a standard deviation of un-eroded perforation diameters (bh) to be 0.032 inches, and/or an erosion rate (ER) to be 0.0025 inches/1000 lbs, which can be used to correct the previously calculated UI metrics. The corrected UI values **602** are shown in FIG. **6**, which can be integrated into the calculations shown in FIG. **4**.

[0056] In some examples, a completion design may use a particular amount of proppant per cluster, but the quantities of UI can be much closer together when comparing the erosion corrected values **602** to the DAS values. The gap between 2 shots per foot (spf) **604** and 3 spf **606** can widen once the UI is corrected. This can be due to the 3 spf configuration **606** being a worse erosion condition than the 2 spf configuration **604** and/or by injecting less proppant per perforation. The un-eroded perforation variance can have a disproportionate effect on correction values when that is the case. The proppant optimization model **124** can further determine that original erosion UI metrics can still be higher for the 3 spf configuration **606** than the 2 spf configuration **604**, but an erosion setting can minimize the difference in terms of the metric.

[0057] In some scenarios, the erosion correction can increase the UI **400**, but median outcomes can still be lower for the erosion-based second proppant distribution prediction **128** than the DAS-based first proppant distribution prediction **126**. In general, DAS interpretations can still be more uniform than erosion-based interpretations, even after correction. The DAS interpretations could include a similar statistical refinement which lowers the UI **400**. The proppant optimization model **124** could also determine that DAS methods do have a systematic bias creating more uniformity.

[0058] In some examples, any metric calculated by the proppant optimization model **124** can show the behavior of the 3 spf configuration **606** showing more uniformity than the 2 spf configuration

604. Picking any analytical method may come to similar conclusion, even if one method calculates more uniform allocations than the other.

[0059] In some instances, the proppant optimization model **124** can use un-eroded perforation variance in a candidate selection procedure. For example, with candidate selection, a parameter (V) can be defined as a dimensionless parameter quantifying the quality of erosion conditions vs the base hole variance:

[00004] $$V = \frac{1000 * {}_{bh} * \mathrm{spf}}{\mathrm{ER} * \frac{\#}{\mathrm{cl}}}$$

TABLE-US-00001 0 < V < 0.15 Good candidate. Correction does very little change. 0.15 < V < 0.25 Good candidate. Should do correction. 0.25 < V < 0.4 Marginal candidate. Correction may be needed. V > 0.4 Bad candidate. Consider not doing erosion analysis.

[0060] In some scenarios, the 2 spf V=0.21 (Good candidate) and 3 spf V=0.31 (marginal candidate). This can be demonstrated in FIG. **6** because both the 2 spf configuration **604** and the 3 spf configuration **606** can show a significant increase in UI **400** from correction, but the 3 spf configuration **606** can have more correction. In cases where comparison are made between 2 to 6 spf and 50,000 #/cluster, then uncorrected analysis could lead to false trends and very wide range of outcomes for the marginal or bad erosion conditions.

[0061] FIG. **7** depicts an example method **700** of perforation distribution modeling, which can be performed by any of the systems **100** depicted in FIGS. **1-6**.

[0062] In some examples, at operation **702**, the method **700** receives, from an imaging device, image data of one or more perforations of a wellbore in a subterranean feature. At operation **704**, the method **700** can cause the image data to be used to determine an erosion-based prediction of proppant allocation for the one or more perforations. At operation **706**, the method **700** can cause a computing device communicatively coupled to the imaging device to execute an erosion model, the erosion model including a correction equation for calculating a corrected uniformity index value based on the image data, an erosion-based prediction of proppant allocation for the one or more perforations being based on the corrected uniformity index value, and a completion perforation configuration model for the wellbore being optimized based on the corrected uniformity index value.

[0063] FIG. **8** illustrates an example computing system **802** having one or more computing units that may implement the various systems **100** and methods **700** discussed herein.

[0064] In some examples, the computing system **802** may can in included in at least one of the one or more control devices **122**, the string assembly **112**, the imaging device **114**, the ultrasonic unit **116**, the wireless communication unit **120**, and/or combinations thereof. The computing system **802** may be a computing system capable of executing a computer program product to execute a computer process. Data and program files may be input to the computing system **802**, which reads the files and executes the programs therein. Some of the elements of the computing system **802** are shown in FIG. **8**, including one or more hardware processors **804**, one or more data storage devices **806**, one or more memory devices **808**, and/or one or more ports **810-812**. Various elements of the computing system **802** may communicate with one another by way of one or more communication buses, point-to-point communication paths, or other communication means, as discussed in greater detail below.

[0065] The processor **804** may include, for example, a central processing unit (CPU), a microprocessor, a microcontroller, a digital signal processor (DSP), a graphics processing unit (GPU) and/or one or more internal levels of cache. There may be one or more processors **804**, such that the processor **804** comprises a single central-processing unit, or a plurality of processing units capable of executing instructions and performing operations in parallel with each other, referred to as a parallel processing environment.

[0066] The computing system **802** may be a computer, a distributed computer, or any other type of computer, such as one or more external computers made available via a cloud computing architecture. The presently described technology including the proppant optimization model **124** can optionally be implemented in software stored on the data stored device(s) **806**, stored on the memory device(s) **808**, and/or communicated via one or more of the ports **810-812**, thereby transforming the computing system **802** in FIG. **8** to a special purpose machine for implementing the operations described herein. Examples of the computing system **802** can include personal computers, terminals, workstations, mobile phones, tablets, laptops, personal computers, multimedia consoles, gaming consoles, wearable devices, internet of thing devices, vehicle devices, set top boxes, and the like. As such, the computing system **802** can implement the presently disclosed technology into various practical applications.

[0067] The one or more data storage devices **806** may include any non-volatile data storage device capable of storing data generated or employed within the computing system **802**, such as computer executable instructions for performing a computer process, which may include instructions of both application programs and an operating system (OS) that manages the various components of the computing system **802**. The data storage devices **806** may include, without limitation, magnetic disk drives, optical disk drives, solid state drives (SSDs), flash drives, and the like. The data storage devices **806** may include removable data storage media, non-removable data storage media, and/or external storage devices made available via a wired or wireless network architecture with such computer program products, including one or more database management products, web server products, application server products, and/or other additional software components. Examples of removable data storage media include Compact Disc Read-Only Memory (CD-ROM), Digital Versatile Disc Read-Only Memory (DVD-ROM), magneto-optical disks, flash drives, and the like. Examples of non-removable data storage media include internal magnetic hard disks, SSDs, and the like. The one or more memory devices **808** may include volatile memory (e.g., dynamic random-access memory (DRAM), static random-access memory (SRAM), etc.) and/or non-volatile memory (e.g., read-only memory (ROM), flash memory, etc.).

[0068] Computer program products containing mechanisms to effectuate the systems and methods in accordance with the presently described technology may reside in the data storage devices **806** and/or the memory devices **808**, which may be referred to as machine-readable media. It will be appreciated that machine-readable media may include any tangible non-transitory medium that is capable of storing or encoding instructions to perform any one or more of the operations of the present disclosure for execution by a machine or that is capable of storing or encoding data structures and/or modules utilized by or associated with such instructions. Machine-readable media may include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) that store the one or more executable instructions or data structures.

[0069] In some implementations, the computing system **802** includes one or more ports, such as an input/output (I/O) port **810** and a communication port **812**, for communicating with other computing systems, network, or devices. It will be appreciated that the ports **810-812** may be combined or separate and that more or fewer ports may be included in the computing system **802**.

[0070] The I/O port **810** may be connected to an I/O device, or other device, by which information is input to or output from the computing system **802**. Such I/O devices may include, without limitation, one or more input devices, output devices, and/or environment transducer devices.

[0071] In one implementation, the input devices convert a human-generated signal, such as, human voice, physical movement, physical touch or pressure, and/or the like, into electrical signals as input data into the computing system **802** via the I/O port **810**. Similarly, the output devices may convert electrical signals received from computing system **802** via the I/O port **810** into signals that may be sensed as output by a human, such as sound, light, and/or touch. The input device may be an alphanumeric input device, including alphanumeric and other keys for communicating information and/or command selections to the processor **804** via the I/O port **810**. The input device may be another type of user input device including, but not limited to: direction and selection control devices, such as a mouse, a trackball, cursor direction keys, a joystick, and/or a wheel; one or more sensors, such as a camera, a microphone, a positional sensor, an orientation sensor, a gravitational sensor, an inertial sensor, and/or an accelerometer; and/or a touch-sensitive display screen (“touchscreen”). The output devices may include, without limitation, a display, a touchscreen, a speaker, a tactile and/or haptic output device, and/or the like. In some implementations, the input device and the output device may be the same device, for example, in the case of a touchscreen.

[0072] The environment transducer devices can convert one form of energy or signal into another for input into or output from the computing system **802** via the I/O port **810**. For example, an electrical signal generated within the computing system **802** and/or by the components of the string assembly **112** and/or the wellhead assembly **110** may be converted to another type of signal, and/or vice-versa. In one implementation, the environment transducer devices sense characteristics or aspects of an environment local to or remote from the computing system **802**, such as, light, sound, temperature, pressure, magnetic field, electric field, chemical properties, physical movement, orientation, acceleration, gravity, operational machine characteristics, and/or the like. Further, the environment transducer devices may generate signals to impose some effect on the environment either local to or remote from the example computing system **802**, such as, physical movement of some object (e.g., a mechanical actuator), heating or cooling of a substance, adding a chemical substance, and/or the like.

[0073] In one implementation, a communication port **812** is connected to a network by way of which the computing system **802** may receive network data useful in executing the methods and systems set out herein as well as transmitting information and network configuration changes determined thereby. Stated differently, the communication port **812** can connect the computing system **802** to one or more communication interface devices configured to transmit and/or receive information between the computing system **802** and other devices by way of one or more wired or wireless communication networks or connections. Examples of such networks or connections include, without limitation, Universal Serial Bus (USB), Ethernet, Wi-Fi, Bluetooth®, Near Field Communication (NFC), Long-Term Evolution (LTE), and so on. One or more such communication interface devices may be utilized via the communication port **812** to communicate one or more other machines, either directly over a point-to-point communication path, over a wide area network (WAN) (e.g., the Internet), over a local area network (LAN), over a cellular (e.g., third generation (3G), fourth generation (4G), or fifth generation (5G)) network, or over another communication means. Further, the communication port **812** may communicate with an antenna or other link for electromagnetic signal transmission and/or reception.

[0074] In an example implementation, the proppant optimization model **124**, the image data **115**, the ultrasonic data **117**, the first proppant distribution prediction **126**, the second proppant distribution prediction **128**, the target variable **130**, the cross-plot **302**, the UI **400**, the erosion-based image analysis **402**, the DAS-based analysis **404**, the two perforations-per-cluster designs **406**, the three perforations-per-cluster designs **408**, the visualization **502**, the un-eroded perforation dimensions **504**, the perforation dimensions **506**, the first chart **508**, the second chart **510**, the comparison **600**, the UI correction **602**, the 2 spf configuration **604**, the 3 spf configuration **606**, the method **700**, other data files, other software, and/or other modules or services may be embodied by data files and/or instructions stored on the data storage devices **806** and/or the memory devices **808** and retrieved and/or executed by the processor **804**.

[0075] The system set forth in FIG. **8** is but one possible example of a computer system that may employ or be configured in accordance with aspects of the present disclosure. It will be appreciated that other non-transitory tangible computer-readable storage media storing computer-executable instructions for implementing the presently disclosed technology on a computing system may be utilized.

[0076] In the present disclosure, the methods disclosed may be implemented as sets of instructions or software readable by a device. Further, it is understood that the specific order or hierarchy of steps in the methods disclosed are instances of example approaches. Based upon design preferences, it is understood that the specific order or hierarchy of steps in the method can be rearranged while remaining within the disclosed subject matter. The disclosed methods present elements of the various steps in a sample order and are not necessarily meant to be limited to the specific order or hierarchy presented.

[0077] While the present disclosure has been described with reference to various implementations, it will be understood that these implementations are illustrative and that the scope of the present disclosure is not limited to them. Many variations, modifications, additions, and improvements are possible. More generally, embodiments in accordance with the present disclosure have been described in the context of particular implementations. Functionality may be separated or combined in blocks differently in various embodiments of the disclosure or described with different terminology. These and other variations, modifications, additions, and improvements may fall within the scope of the disclosure as defined in the claims that follow.

Claims

1. A system for optimizing a completion stage perforation configuration, the system including: one or more sensor devices operable to collect erosion data of one or more perforations of a wellbore in a subterranean feature; an erosion model including a correction equation for calculating a corrected uniformity index value based on the collected erosion data, a proppant distribution prediction determined based on the corrected uniformity index value, an amount of proppant per cluster being determined based on the proppant distribution prediction; and a completion perforation configuration for the wellbore being optimized based on the amount of proppant per cluster.

2. The system of claim 1, wherein: the proppant distribution prediction is a first proppant distribution prediction; and a discrepancy between the first proppant distribution prediction and a second proppant distribution prediction is organized by cluster, and the completion perforation configuration is optimized at least partly based on organizing the discrepancy by cluster.

3. The system of claim 2, wherein, based on the discrepancy, the first proppant distribution prediction and the second proppant distribution prediction indicate that the first proppant distribution prediction has a more uniform proppant distribution than the second proppant distribution prediction.

4. The system of claim 2, further comprising: a stage level uniformity metric indicating that both the first proppant distribution prediction and the second proppant distribution prediction show a difference between two modeled perforation designs independently and in a same direction, the completion perforation configuration is optimized at least partly based on the difference being in the same direction.

5. The system of claim 2, wherein: a proppant variance associated with one or more un-eroded perforations is calculated using the collected erosion data; and the proppant variance is removed from an initial proppant allocation of the second proppant distribution prediction.

6. The system of claim 5, wherein removing the proppant variance increases an alignment of the first proppant distribution prediction with the second proppant distribution prediction.

7. The system of claim 2, wherein the first proppant distribution prediction and the second proppant distribution prediction estimate a distribution of proppant out of multiple perforation clusters in the subterranean feature.

8. The system of claim 2, wherein the collected erosion data includes eroded dimensions of perforations after stimulation.

9. The system of claim 8, wherein: a quality of erosion calculations is determined using the first proppant distribution prediction; and the collected erosion data is corrected based on the quality of the erosion calculations to form corrected erosion data, the amount of proppant per cluster is determined at least partly based on the corrected erosion data.

10. A device for perforation distribution modeling, the device comprising: a sensor of a drill string operable to receive image data or acoustic data of one or more perforations of a wellbore in a subterranean feature; and a computing device communicatively coupled to the sensor for executing an erosion model, the erosion model including a correction equation for calculating a corrected uniformity index value based on the image data or the acoustic data, an erosion-based prediction of proppant allocation for the one or more perforations being based on the corrected uniformity index value, and a completion perforation configuration model for the wellbore being optimized based on the corrected uniformity index value.
11. The device of claim 10, wherein the sensor includes an ultrasonic sound generator.
12. The device of claim 10, wherein optimizing the completion perforation configuration model further includes determining, using the erosion model, an amount of proppant per cluster for the wellbore.
13. The device of claim 12, wherein determining the amount of proppant per cluster for the wellbore includes changing an amount of perforations per cluster from three to two.
14. The device of claim 10, wherein optimizing the completion perforation configuration model includes: calculating a proppant variance associated with un-eroded perforations; and removing the proppant variance from an initial proppant allocation of the erosion-based prediction.
15. The device of claim 10, wherein determining the erosion-based prediction of proppant allocation includes determining a baseline erosion assumption of a constant starting diameter based on projecting uneroded starting perforations as being a same size.
16. A method of perforation distribution modeling, the method including: receiving, from an imaging device, image data of one or more perforations of a wellbore in a subterranean feature; causing the image data to be used to determine an erosion-based prediction of proppant allocation for the one or more perforations; and causing a computing device communicatively coupled to the imaging device to execute an erosion model, the erosion model including a correction equation for calculating a corrected uniformity index value based on the image data, an erosion-based prediction of proppant allocation for the one or more perforations being based on the corrected uniformity index value, and a completion perforation configuration model for the wellbore being optimized based on the corrected uniformity index value.
17. The method of claim 16, wherein optimizing the completion perforation configuration model for the wellbore includes changing, based on the erosion model, an amount of proppant per cluster in the wellbore.
18. The method of claim 16, wherein optimizing the completion perforation configuration model includes: calculating a proppant variance associated with un-eroded perforations; and removing the proppant variance from an initial proppant allocation of the erosion-based prediction.
19. The method of claim 16, wherein optimizing the completion perforation configuration model includes: determining a quality of erosion calculations of erosion-based prediction; correcting the image data to create corrected image data based on the quality of the erosion calculations; and determining an amount of proppant per cluster using the corrected image data.
20. The method of claim 19, wherein optimizing the completion perforation configuration model includes: forming either two perforations per cluster or three perforations per cluster in the wellbore based on optimizing the completion perforation configuration model.