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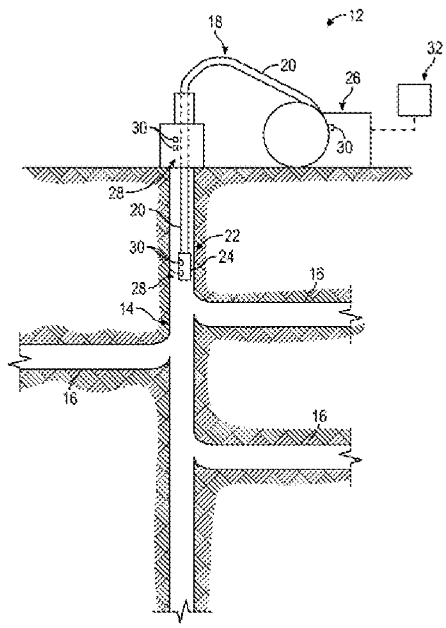
(71)	Applicant	Schlumberger Technology B.V., Parkstraat 83-89, 2514JG HAAG, Nederland
(72)	Inventor	Luis Silva, c/o Schlumberger Oilfield Services, 555 Industrial Blvd, TX77478 SUGARLAND, USA Michael Hayes Kenison, c/o Schlumberger KTC, 23500 Colonial Parkway, TX77493 KATY, USA Sascha Trummer, 11123 Lowthorpe Ln, TX77407 RICHMOND, USA
(74)	Agent or Attorney	BRYN AARFLOT AS, Stortingsgata 8, 0161 OSLO, Norge

(54) Title **AUTOMATED MULTILATERAL ACCESS FOR COILED TUBING SYSTEM USING EDGE COMPUTING**

(57) Abstract

A technique facilitates automated location of and access into specific laterals in a multilateral well utilizing a coiled tubing system. The locating and access technique employs an automated sequence using edge computing capabilities while providing a solution fully compatible with pumping stimulation fluids. According to an embodiment, the technique leverages computation of edge data and historical data, e.g. cloud stored data, to reliably locate and access specific laterals of a multilateral well. For example, the methodology and system may utilize surface measurement data and other edge data in combination with historical/treatment data stored in the cloud to substantially improve the accuracy and consistency of tubing force prediction at a multilateral window. As a result, specific laterals may be reliably located and entered for the desired servicing/intervention operation.



AUTOMATED MULTILATERAL ACCESS FOR COILED TUBING SYSTEM USING EDGE COMPUTING

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present document is based on and claims priority to US Provisional Application Serial No.: 62/914146 , filed October 11, 2019, which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] In many well applications, coiled tubing equipment is used in well servicing and intervention operations. Depending on the operation, a bottom hole assembly (BHA) and/or other tools may be attached to an end of the coiled tubing and deployed to an area or areas of interest in the well. Coiled tubing equipment may comprise a continuous metal or composite tube deployable in a wellbore via a reel, an injector, and associated equipment located at the surface. Coiled tubing may be used for performing well treatment and/or well intervention operations in existing wellbores and such operations may include hydraulic fracturing, matrix acidizing, milling, perforating, coiled tubing drilling, or other services.

[0003] Additionally, modern wells often have secondary wellbores, referred to as laterals, drilled off a main wellbore to improve efficiency of reservoir contact and to reduce overall well construction cost. Creating the laterals during the drilling phase is relatively straightforward, but accessing the laterals later in the well completion phase or servicing phase can be problematic. In coiled tubing intervention operations, an angled arm referred to as a bent sub may be placed at the bottom of the coiled tubing and manipulated in an attempt to steer the coiled tubing string into the desired lateral. However, this process can be difficult. Various current techniques utilize substantial amounts of pumping and multiple iterations to find the correct laterals in a multilateral well.

SUMMARY

[0004] In general, a methodology and system enable automated location and access to specific laterals in a multilateral well utilizing a coiled tubing system. The locating and access technique employs an automated sequence using edge computing capabilities while providing a solution fully compatible with pumping stimulation fluids. According to an embodiment, the technique leverages computation of edge data and historical data, e.g. cloud stored data, to reliably locate and access specific laterals of a multilateral well. For example, the methodology and system may utilize surface measurement data, downhole data, and/or other edge data in combination with historical/treatment data stored, for example, in the cloud to substantially improve the accuracy and consistency of tubing force prediction at a multilateral window. As a result, specific laterals may be reliably located and entered for the desired servicing/intervention operation.

[0005] However, many modifications are possible without materially departing from the teachings of this disclosure. Accordingly, such modifications are intended to be included within the scope of this disclosure as defined in the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] Certain embodiments of the disclosure will hereafter be described with reference to the accompanying drawings, wherein like reference numerals denote like elements. It should be understood, however, that the accompanying figures illustrate the various implementations described herein and are not meant to limit the scope of various technologies described herein, and:

[0007] Figure 1 is a schematic illustration of an example of a well system which is able to utilize a variety of data for locating specific laterals of a multilateral well, according to an embodiment of the disclosure;

[0008] Figure 2 is a schematic illustration of an example of a real-time tubing force module which effectively provides a model that can be updated for use in locating specific laterals of a multilateral well, according to an embodiment of the disclosure;

[0009] Figure 3 is a schematic illustration of an example of real-time updating of coefficient of friction values for tubing force modeling, according to an embodiment of the disclosure; and

[0010] Figure 4 is a schematic illustration of an example of compositions and sources of real-time job data which may be used by the automated coiled tubing system to locate and access specific laterals of a multilateral well, according to an embodiment of the disclosure.

DETAILED DESCRIPTION

[0011] In the following description, numerous details are set forth to provide an understanding of some embodiments of the present disclosure. However, it will be understood by those of ordinary skill in the art that the system and/or methodology may be practiced without these details and that numerous variations or modifications from the described embodiments may be possible.

[0012] The disclosure herein generally involves a methodology and system which facilitate automated location and access to specific laterals in a well, e.g. a multilateral well. The system comprises a coiled tubing system deployed downhole into a primary borehole and then out into one or more selected lateral boreholes. By way of example, the primary borehole may be a generally vertical borehole and the lateral boreholes may comprise secondary boreholes extending laterally from the primary borehole to establish the multilateral well. In some cases, a single lateral borehole may extend from the primary borehole.

[0013] The locating and access technique described herein employs an automated sequence using edge computing capabilities while providing a solution fully compatible with pumping stimulation fluids. Additionally, the technique utilizes historical data, e.g. cloud-based data, to further enhance the accuracy of locating and accessing selected laterals in the multilateral well. For example, the technique may involve computation of edge data collected from various sensors and historical data, e.g. cloud stored data, to reliably locate and access specific laterals of a multilateral well. In some embodiments, surface measurement data, downhole data, and/or other edge data may be used in combination with historical/treatment data stored in the cloud to substantially improve the accuracy and consistency of tubing force prediction at a multilateral window. This accurate predictive ability enables reliable location of specific laterals. Once located, the specific laterals may be entered with a coiled tubing system for the desired servicing/intervention operation.

[0014] The methodology may be carried out using various edge data and cloud data by, for example, integrating downhole and surface measurement data with historical well data and well treatment data. The technique may involve calculating tubing force, torque, and friction in real-time through parametric calibration without compromising bottom hole assembly (BHA) and surface equipment integrity. Effectively, the technique may be used to substantially improve the accuracy and consistency of tubing force prediction at a specific lateral window, thus enhancing the accuracy of lateral location and entry. More accurate and consistent tubing force prediction leads to a more accurate and consistent lateral junction profiling, sometimes referred to as the lateral window. The lateral junction profiling may be achieved without having to pump fluid to manipulate a bent sub and without multiple iterations of bent sub actuation in an attempt to identify the lateral.

[0015] Selected edge data and historical/cloud data may be provided to a processing system, e.g. a surface control system, for processing to determine real-time jobs data which can be used to accurately locate and enter specific laterals of the multilateral well. The technique enables, for example, automating a sub-routine for controlling or steering a downhole apparatus into a lateral junction based on electrical signals sent from the surface control system or other processing system for a desired well intervention treatment.

[0016] Additionally, the technique may be used to enable automating a sub-routine to map dimensions of a lateral junction by determining the status and positioning of the downhole apparatus, thus facilitating a well intervention treatment. According to another example, the technique may be used to enable automating a sub-routine for controlling or directing the path of fluid pumped from the surface and through a wellbore lateral junction based on electrical signals sent from the surface control system or other processing system to facilitate the desired well intervention treatment.

[0017] By way of further example, the technique may be used to enable automating a sub-routine for controlling or directing the path of fluid pumped from the surface and through a wellbore lateral junction. The control and direction may be based on distributed sensor measurements, e.g. distributed temperature measurements, to thus facilitate a well intervention treatment. Additionally, the technique may be used to enable automating a sub-routine to control or steer a downhole tractor apparatus into a lateral junction based on downhole load measurements, thus facilitating a well intervention treatment. The automated ability to reliably locate and enter desired laterals may be combined with various other treatment operations, monitoring operations, well evaluation operations, and/or other desired well operations. Use of edge computation based on data collected at the wellsite in combination with historical/cloud data enables the automation of such sub-routines.

[0018] Referring generally to Figure 1, an example of a well system 12 is illustrated as having a primary borehole 14 and a plurality of lateral boreholes 16 extending from the primary borehole 14. The well system 12 further comprises a coiled tubing system 18 comprising coiled tubing 20 and downhole equipment 22 which may include a bottom hole assembly (BHA) 24. The coiled tubing 20 is deployed downhole via surface equipment 26. Additionally, the well system 12 comprises a sensor system 28 having a plurality of sensors 30 which may be located downhole, at the surface, and/or at other suitable locations to monitor desired parameters. The data from sensors 30 (along with other data and information) is provided to a processing system 32, e.g. a surface control system, which may be located in whole or in part on site or at a remote location or locations. The data from sensors 30 and the processing, e.g. modeling, of data via processing system 32 enables application of the methodologies described below with reference to Figures 2-4.

[0019] Referring generally to Figure 2, an example of a workflow is illustrated for carrying out the methodology described herein. In this example, the workflow may be carried out on processing system 32 and includes a methodology for tubing force module (TFM) calculation and updating of the tubing force module based on real-time communication between the TFM modeling and wellsite measurements. The wellsite measurements may include surface measurements and downhole measurements obtained by, for example, sensors 30; and this “edge” data effectively enables edge computing to continuously update model parameters in a manner providing a more accurate and consistent TFM modeling.

[0020] As illustrated, the coiled tubing system 18 is moved downhole in a single run (Run 1) along a primary borehole to each lateral, e.g. multilateral 1 through multilateral N. Real-time data may be collected as the coiled tubing system 18 is running in hole (RIH) and pulled out of hole (POOH). At each lateral, edge computing data is collected which may include surface measurements, such as coiled tubing system weight, wellhead pressure, and flow back characteristics, as well as downhole measurements, such as pressure measurements, temperature measurements, coiled tubing system tension measurements, coiled tubing system compression measurements, and torque measurements. Historical data, e.g. cloud data, as well as the data collected at each lateral may be used to determine and update a coefficient of friction (COF). The COF in combination with the surface measurements and downhole measurements enables continuous updating of the TFM as the coiled tubing system is moved downhole from one lateral to the next. The updated information/model provides improved accuracy with respect to location and entry of the desired lateral boreholes.

[0021] Referring generally to Figure 3, another illustration of an example of a workflow-routine shows a methodology for real-time updating of the COF. For the first multilateral section (lateral 1), an initial TFM model and initial COF values are established, e.g. established based on values obtained from the cloud. In other words, the initial values may be based on historical data, such as job data from a similar well or the same well. For the second multilateral section (lateral 2), the COF values are compared and updated on the edge based on real-time data obtained from the first section and from database information for the second lateral. Such updating can be similarly continued during the job as the coiled tubing system 18 is moved from one lateral section to the next. In some applications, a depth interval may be set to a desired value, e.g. every 500 feet, depending on the parameters of a given operation, computation resources, and/or other job related factors.

[0022] It should be noted that updating of the COF can be very useful for determining the presence of specific laterals 16. Friction data may be used as indicative of specific laterals 16, thus enabling entry into the desired lateral 16 of multiple laterals 16 in a multilateral well. However, parameters other than the COF (and parameters in combination with the COF) also may be used in facilitating the accurate updating of the TFM and thus determination of the location of desired laterals. For real-time updating of the COF and/or other useful parameters, real-time job data is important. By way of example, a real-time job data set may include different data sources and measurements both on the edge and in the cloud (see Figure 4).

[0023] As illustrated by the diagram in Figure 4, real-time jobs data 34 may be created and updated based on a variety of data sets. By way of example, the data sets may include edge parameters obtained at least in part via sensors 30 and such edge parameters may be divided into different groups. In the illustrated embodiment, the edge parameters are divided into a first group 36 and a second group 38. Examples of edge parameters in the first group 36 include time, depth, wellhead pressure (WHP), pump rate, circulating pressure (CP), coiled tubing speed, coiled tubing system weight, load measurement, and/or other appropriate parameters. In this embodiment, examples of edge parameters in the second group 38 include downhole pressure (DHP), tension and compression (T&C) measurements, torque measurements, surface fluid return rates, and/or other appropriate parameters, e.g. wellbore tubing parameters and openhole geometry.

[0024] The edge data may be combined with historical data 40, e.g. cloud data. Examples of cloud data 40 include deviation angle, deviation build rate, azimuth angle, azimuth build rate, pipe/coiled tubing inside diameter, pipe/coiled tubing outside diameter, and/or other suitable data related to the equipment, environment, and type of well. Such historical data may be obtained from various sources such as an original drilling survey. The edge data 36, 38 is combined with the historical data 40 and processed via the surface control system or other suitable processing system to enable the system to learn accurate indicators of specific laterals. As a result, a specific lateral or laterals may be reliably located. Once located, the coiled tubing system is directed into the selected lateral for performance of the desired lateral borehole servicing/intervention operation.

[0025] Depending on the parameters of a given lateral borehole servicing/intervention operation, the coiled tubing system may comprise a variety of constructions. For example, the BHA 24 may be coupled to a lower end of coiled tubing 20 and may comprise various components for injecting treatment fluids or performing other downhole services. In some applications, the BHA 24 may include or may be combined with a tractor which can be operated to facilitate movement of the coiled tubing system 18 along relatively long sections of lateral, e.g. horizontal, boreholes 16. The continued real-time updating of the data, e.g. updating of the TFM model, provides an ability to map the well and to navigate the BHA 24 into multiple different laterals in a multilateral well.

[0026] A variety of downhole measurements obtained by, for example, sensors 30 may be used to provide lateral access confirmation. For example, various casing collar locators, gamma instruments, direction and inclination sensors, and azimuth sensors may be used to confirm access into a desired lateral. The continually updated data also may be used to optimize tractoring operations. For example, changes in tractor operation may be made on command based on the processing of real-time data. The data may be transmitted uphole to processing system 32 via various techniques and telemetry systems. In some embodiments, tool power and telemetry may be combined with fiber optic sensing in a common stimulation fluid compatible tether, e.g. a cable or control line tether.

[0027] According to an operational example, the coiled tubing system 18 is initially run in hole to a target depth. In this example, the coiled tubing system 18 comprises BHA 24 which is run in hole with an electric circulation sub set to automatically allow fluid to pass through the BHA 24. The system may also comprise a tractor and fluid can be pumped through the tractor at lower rates to aid with the conveyance process by, for example, circulating debris. When the tractor is to be engaged, the pump rate is increased to meet the "tractoring" fluid/pressure requirements. Once the tractor is at a target well depth, the fluid pumping may be stopped while the lateral access process is initiated.

[0028] Subsequently, a profiling phase is implemented. The profiling phase is facilitated by the automatic, real-time processing of both edge data and historical/cloud data to continually update the TFM. Tubing force, torque, and coefficient of friction are examples of parameters which may be used in real-time to update the TFM and to thus enable consistent and accurate location of the desired lateral boreholes.

[0029] Following location of the desired lateral 16, depth correlation systems, e.g. a gamma system or a casing collar locator system also may be utilized to place the BHA 24 at a desired location in the borehole, e.g. just below the lateral junction of interest or at another suitable position. A bent sub may then be engaged on electronic command via an automated sequence as the coiled tubing system string is pulled out of hole past the lateral junction. A surface acquisition system also may be used to validate a change in the bent sub position which confirms a lateral junction contact. It should be noted that various other techniques may be used to position the BHA 24 via the coiled tubing 20 when locating and entering the desired lateral 16.

[0030] After locating the desired lateral 16, the BHA 24 may be moved into the lateral 16 and deployed to a target depth for a stimulation treatment or other downhole treatment. For example, the electric circulation sub may be activated to divert a fluid stream through an annular wellbore flow path, e.g. through a preselected nozzle sized to optimize a stimulation treatment, e.g. an acid stimulation treatment. The fluid exit to the annulus ensures that acid is not pumped through the tractor. Once the stimulation treatment (or other operation) is completed, the electric circulation sub may again be set to allow fluid to pass through the BHA 24.

[0031] The methodology and system for utilizing edge data and historical data, as described herein, enables automated sequences for operations in as many laterals as desired without pulling the coiled tubing system to the surface for BHA redress. Use of the edge data and historical data in real-time enables the automation of a variety of sub-routines on the surface control system 32 or other processing system. Examples of such automated sub-routines include controlling or steering a downhole apparatus into a lateral borehole based on electrical signals sent from the surface control system or other processing system for a desired well intervention treatment.

[0032] The technique also may be used for automating a sub-routine to map dimensions of a lateral junction by determining the status and positioning of the BHA 24 or other downhole apparatus, thus facilitating a well intervention treatment. According to another example, the technique may be used to automate a sub-routine for controlling or directing the path of fluid pumped from the surface. The pumped fluid may be directed through a desired lateral junction based on electrical signals sent from the surface control system or other processing system to facilitate the desired well intervention treatment.

[0033] Additionally, the real-time use of edge data and historical data enables automation of a sub-routine for controlling or directing a path of fluid pumped from the surface and through a wellbore lateral junction. The selected path of fluid and the specific lateral may be selected based on suitable edge data such as distributed sensor measurements, e.g. distributed temperature measurements. This ability facilitates efficient and accurate well intervention treatments. In other applications, the real-time edge data and historical data processing technique may be used to automate a sub-routine for controlling or steering a downhole tractor apparatus into a lateral junction. Again, the lateral junction may be reliably located based on, for example, downhole load measurements and/or other edge measurements to thus facilitate a desired well intervention treatment. The automated ability to reliably locate and enter desired laterals may be combined with many types of treatment operations, monitoring operations, well evaluation operations, and/or other desired well operations.

[0034] It should be noted the coiled tubing system 18 may comprise a variety of equipment, including a variety of downhole equipment 22, e.g. various types of bottom hole assemblies, bent subs, sensor systems, tractors, and/or other types of downhole systems and components. Additionally, the data acquired downhole, at the surface, from the cloud, and/or from other storage media may vary from application to application. Similarly, the processing systems 32 used to process the real-time data may comprise single processing systems, plural processing systems, processing systems located at the wellsite, and/or processing systems at remote locations. The coiled tubing system 18 also may be used to implement many types of servicing and/or intervention operations in one or more of the lateral boreholes 16 of a given multilateral well.

[0035] Although a few embodiments of the disclosure have been described in detail above, those of ordinary skill in the art will readily appreciate that many modifications are possible without materially departing from the teachings of this disclosure. Accordingly, such modifications are intended to be included within the scope of this disclosure as defined in the claims.

CLAIMS

What is claimed is:

1. A method for use in a well, comprising:

moving a coiled tubing system downhole into a well having a primary borehole and a plurality of lateral boreholes extending from the primary borehole;

using historical data to locate a first lateral borehole of the plurality of lateral boreholes;

processing historical data and edge data in real-time to locate subsequent lateral boreholes of the plurality of lateral boreholes; and

updating a model for determining lateral borehole location based on the edge data acquired during location of each subsequent lateral borehole.

2. The method as recited in claim 1, wherein using historical data comprises using cloud-based data.

3. The method as recited in claim 1, wherein updating the model comprises updating a tubing force module.

4. The method as recited in claim 3, further comprising using the tubing force module in conjunction with a coefficient of friction of the coiled tubing system as the coiled tubing system is moved downhole.

5. The method as recited in claim 1, further comprising entering a selected lateral borehole, of the plurality of lateral boreholes, with the coiled tubing system.

6. The method as recited in claim 1, further comprising entering each lateral borehole with the coiled tubing system.

7. The method as recited in claim 1, wherein processing comprises using edge data obtained from surface measurements and from downhole measurements.

8. The method as recited in claim 1, wherein moving the coiled tubing system comprises moving a bottom hole assembly coupled to coiled tubing.

9. The method as recited in claim 8, further comprising providing electrical control signals downhole to control the bottom hole assembly based on the processed historical data and edge data.

10. The method as recited in claim 9, wherein moving comprises moving the bottom hole assembly with a tractor.

11. A method, comprising:

combining edge data and cloud data by integrating downhole data, surface measurement data, and historical well data related to use of a coiled tubing system downhole;

processing in real-time the edge data and the cloud data on a processor system to update a tubing force module used for making tubing force predictions with respect to movement of the coiled tubing system downhole in a well; and

using the tubing force module to accurately locate a lateral borehole in the well.

12. The method as recited in claim 11, wherein the well is a multilateral well and further comprising continually collecting edge data to update the tubing force module for subsequent lateral boreholes.

13. The method as recited in claim 12, further comprising collecting edge data comprising depth data, wellhead pressure data, pump rate data, load data,

circulating pressure data, coiled tubing speed data, and coiled tubing system weight.

14. The method as recited in claim 12, further comprising collecting edge data comprising downhole pressure data and fluid return rate data.

15. The method as recited in claim 12, further comprising collecting edge data comprising coiled tubing system tension and compression data, wellbore tubing data, and openhole geometry data.

16. The method as recited in claim 12, further comprising collecting edge data comprising coiled tubing system torque data.

17. The method as recited in claim 12, further comprising collecting data from the cloud comprising lateral borehole deviation data, lateral borehole deviation rate data, lateral borehole azimuth data, and lateral borehole azimuth rate data.

18. A system for use in a well, comprising:

a coiled tubing system having a bottom hole assembly coupled with coiled tubing, the bottom hole assembly being positioned for movement downhole into a well having a primary borehole and a plurality of lateral boreholes extending from the primary borehole;

surface equipment coupled with the coiled tubing system to convey the coiled tubing and the bottom hole assembly downhole and to retrieve the coiled tubing and the bottom hole assembly;

a sensor system working in cooperation with the coiled tubing system to obtain data on a plurality of parameters; and

a processing system configured to process the data in combination with historical data to locate a first lateral borehole of the plurality of lateral boreholes and subsequently to locate additional lateral boreholes of the plurality of lateral boreholes.

19. The system as recited in claim 18, wherein the data comprises edge data and wherein the processing system is configured to update a model for determining lateral borehole location based at least in part on edge data acquired during location of each subsequent lateral borehole.

20. The system as recited in claim 19, wherein the processing system is configured to update the model by updating a tubing force module.

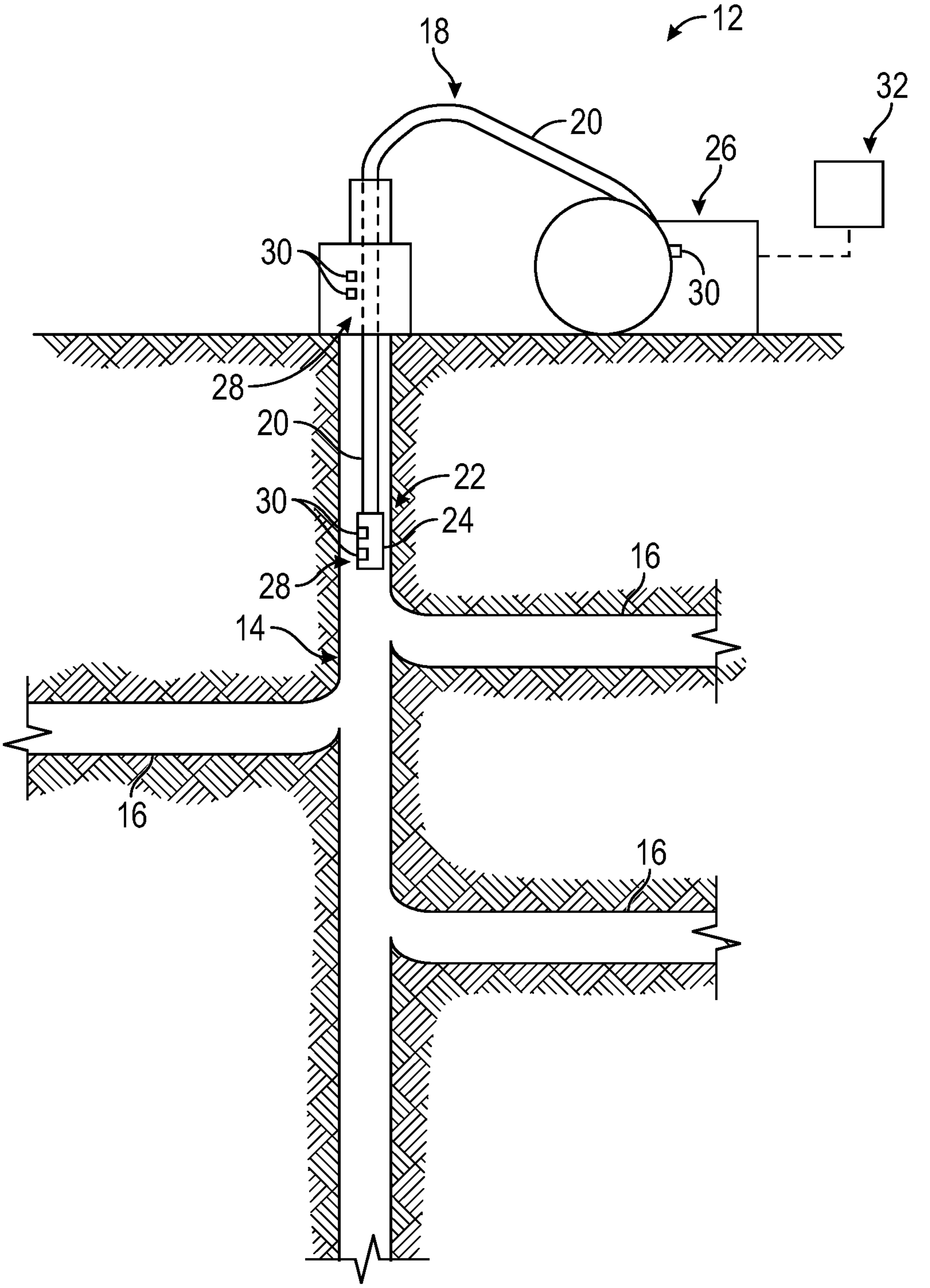
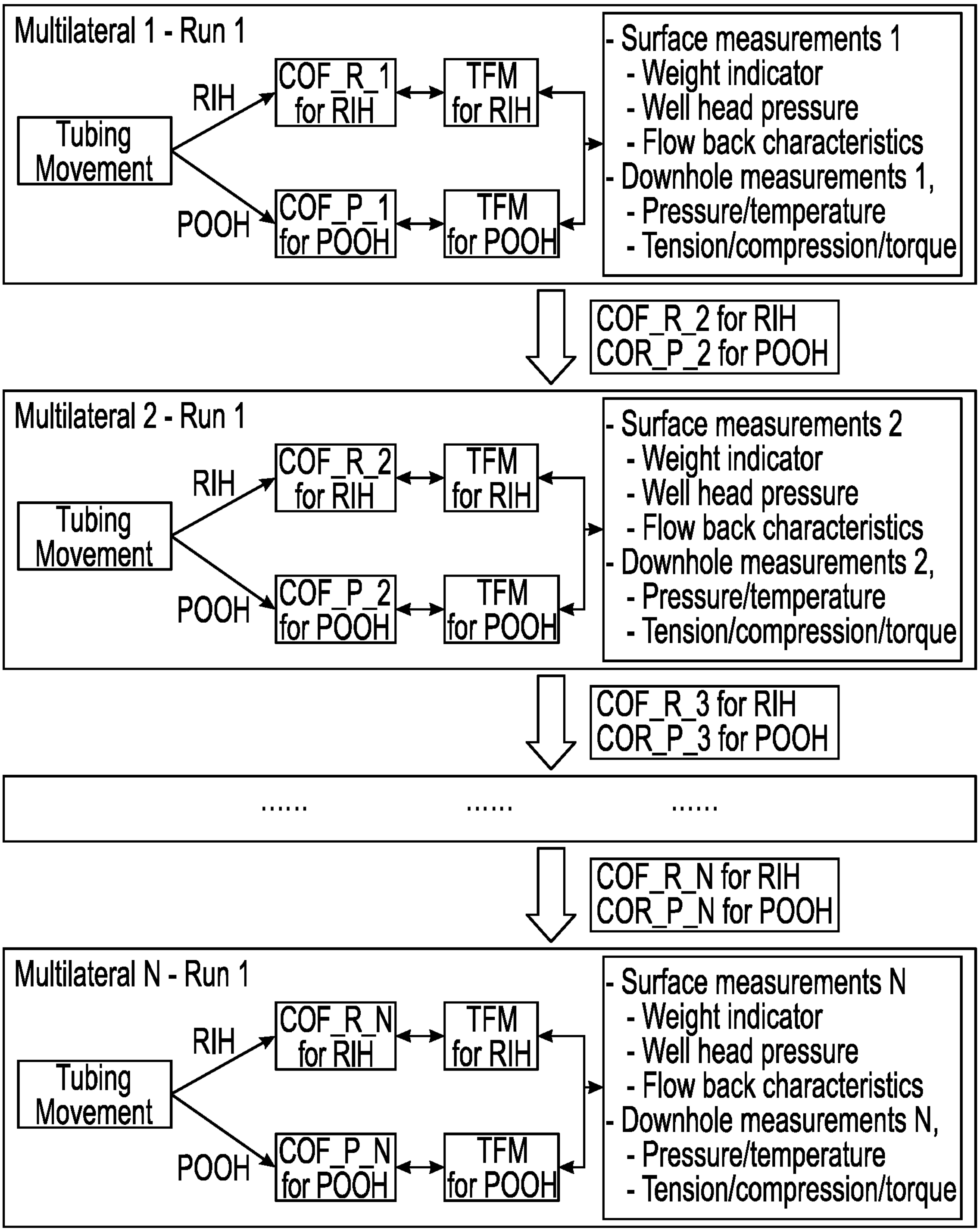
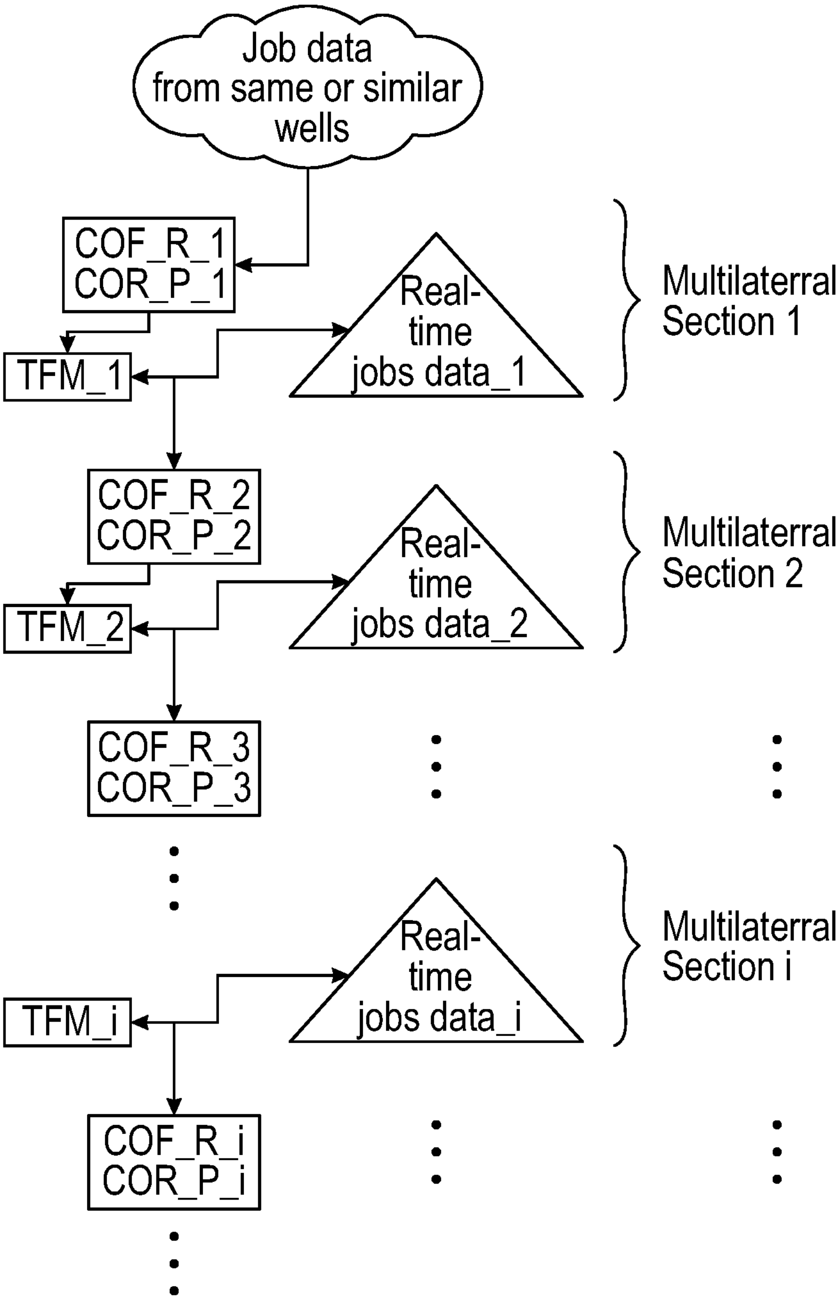


FIG. 1



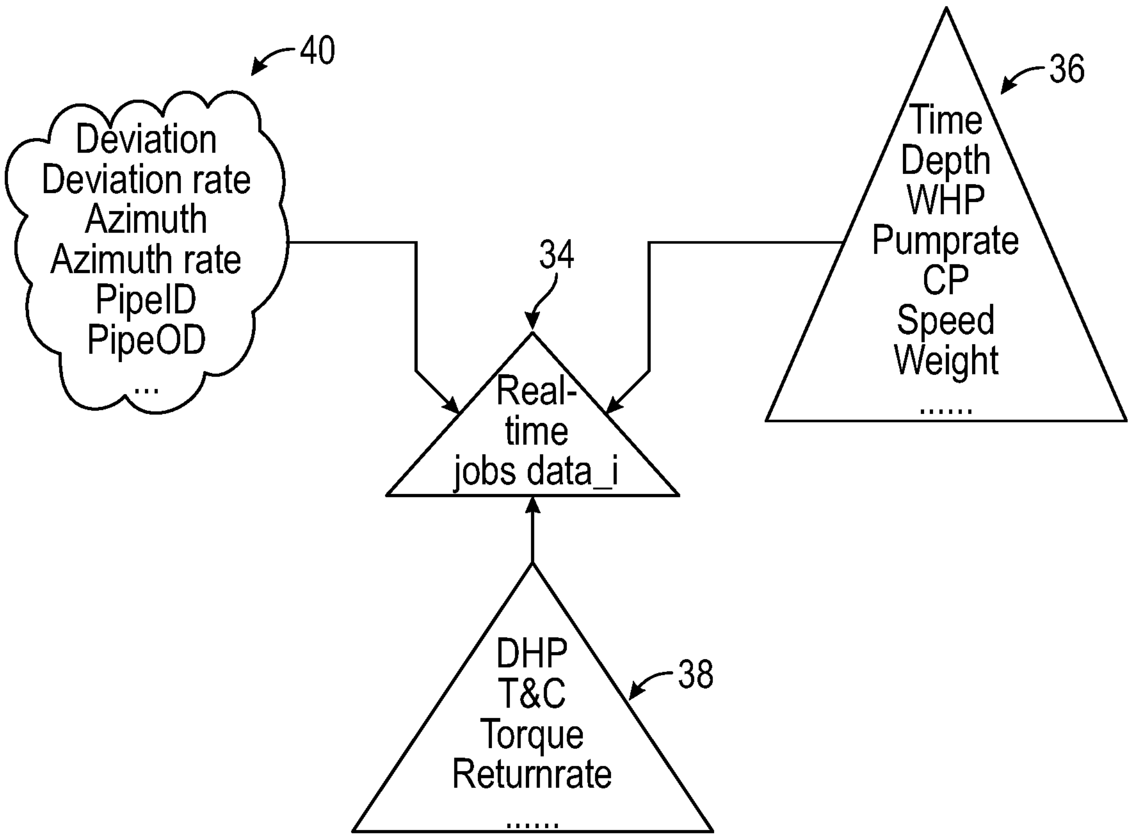
Realtime TFM Modeling

FIG. 2



Realtime updating of the COF values for TFM modeling

FIG. 3



Compositions and sources of real time job data

FIG. 4