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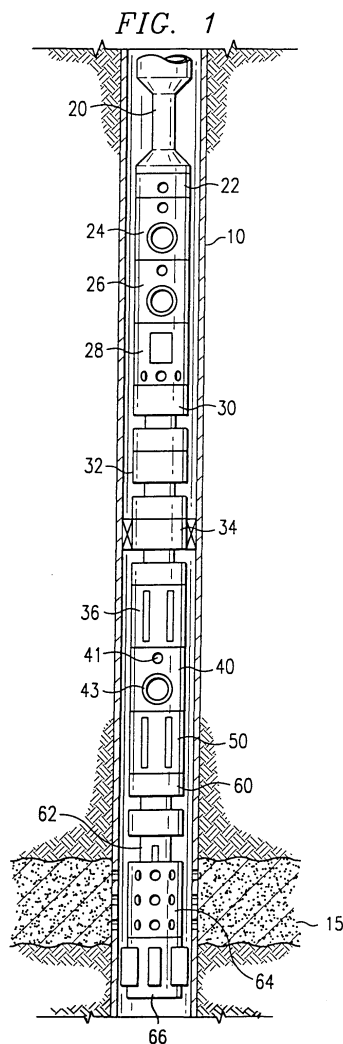
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(54) **Intelligent downhole testing system**

(57) An intelligent down hole testing system for conducting well testing has down hole flow. The system includes an apparatus for use in a wellbore having an annulus (10), the apparatus comprising a work string (20) placed in the annulus (10), a sensor (36) in said work string (20) and a control valve (40) in said work string (20), wherein said control valve (40) operates in response to reservoir measurements from said sensor (36). The system allows for flow and shut-in testing and fluid sampling down hole without the need for surface monitoring or control.



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Description

[0001] The present invention relates to an intelligent down hole testing system used to obtain reservoir information during a well test without the need for surface control. Specifically, the present invention allows for the down hole intelligent automation of flow and shut-in testing and sampling.

[0002] The expense of completing a petroleum producing well can quite frequently exceed the expense of actually drilling the well. As a result, it is critical that sufficient information be gathered on the well after drilling to accurately determine if it is economically feasible to complete the well. Testing can provide valuable information on the type of completion required to insure adequate production and proper reservoir maintenance procedures. Further, if a new formation is being explored, it is particularly critical that representative samples of the reservoir fluids be collected and analyzed from the first few wells drilled in order to evaluate the formation.

[0003] It is also important that any testing be accomplished as quickly as possible, since any testing performed will necessarily delay production during the test period. Development wells are drilled for their economic importance to production, and, therefore, the best testing strategies minimize time on the well site.

[0004] Important test data can be obtained by measuring the reservoir pressure and flow rate with the well in a stabilized flow condition and the pressure and temperature of the well down hole when the well is shut-in. A stabilized flow condition is reached when the well pressure remains unchanged over a period of time, resulting in steady-state flow, or the pressure changes linearly with respect to time while the well is being flowed at a constant rate. A common test regimen involves collecting flow rate, pressure, and temperature data while alternatively operating the well in stabilized flow and shut-in conditions. Typically, stabilized flow data is measured at the surface and interpolated to estimate the actual flow rate and pressure down hole. Calculating the flow rate and pressure at the surface, however, introduces two serious complications. First, the wellbore storage of production fluids introduces complications in the interpolation of the data to down hole rates and pressures due to the expansion or compression of wellbore fluids in response to changes in the wellbore pressure. Wellbore storage may also result in it taking several hours for a steady-state flow at the zone of interest to manifest itself at the surface. Consequently, the well has to be run at a steady-state for quite some time before data collection actually begins. When a limited amount of time has been set aside for testing, for example one day, it may be very difficult to run more than one or two stabilized flow and shut-in tests given the amount of time it takes to manifest stabilized flow conditions up hole. Further, a failure to timely recognize problems in flow testing parameters could lead to permanent damage to

the production capabilities of the well.

[0005] A second problem inherent in measuring pressures and flow rates at the surface is the fact that, with data thus collected, estimating true down hole conditions by interpolation techniques is difficult if the reservoir pressure drops below the bubble point. (The bubble point is the pressure below which gas evolves from an oil solution.) Further, fluid samples taken when the test well is below the bubble point can not be used to determine the hydrocarbon composition of the reservoir. Importantly, gas and liquid phases are typically not produced in a formation in the same proportion as they exist in a single phase above the bubble-point pressure.

[0006] While some prior art methods involve measuring pressures and temperatures down hole, the determination of whether the flow has reached steady-state is typically made at the surface, and fluid samples are often taken at the surface. Even a fluid sample taken down hole may not be of much use if the sample was taken below the bubble point, a fact that may not be determined until after the sample is painstakingly recovered.

[0007] Given the problems detailed above with these methods, a need exists for an intelligent down hole testing system that can flow and shut-in a well based on real time data taken down hole. Further, a need exists to collect samples of reservoir fluid at pressures above the bubble-point without the necessity of repeated sampling from the rig level and subsequent well flow manipulation. Such intelligent down hole testing system would save considerable rig time while greatly increasing the reliability and accuracy of well testing.

[0008] The present invention relates to an intelligent down hole testing system that can be run into the well on a work string along with many of the prior art components presently used for well testing. The intelligent down hole testing system assures that adequate reservoir information is acquired during a well test without the need for surface read-out. The invention is programmed on the surface to flow, shut-in, and sample the well pursuant to the particular test parameters best suited for each application. The system is then run in the well in the same way a prior art drill and testing string is presently run.

[0009] Once the testing string has been run into the well and everything is prepared down hole and at the surface for well testing, the intelligent down hole testing system is activated using a signal that is conveyed by wire line, telemetry, or hydraulic pulses. During the testing job, the invention interprets collected data and samples so as to make decisions about how the well testing should be carried out. For example, these decisions can include when to open the well for flow, when to shut-in the well, and when to choke the well for sampling. These decisions are based on pre-programmed information. However, if a change in decision making parameters is necessary, the intelligent down hole testing system can be re-programmed by a wire line probe, telemetry, or

hydraulic pulses. If the invention does not respond to these changes, a hydraulic override feature allows manual control of the intelligent down hole testing system. When the intelligent down hole testing system has completed its pre-programmed routine a multi-cycle safety circulating valve is activated to indicate that manual control of the system has been transferred. The operator on the surface then controls the system for well kill operations.

[0010] There are additionally two special logic features of the system that clearly distinguish the intelligent down hole testing system from prior art methods and apparatus. First, the invention's testing system has a flow and shut-in logic. During the flow periods, an intelligent control valve monitors the pressure/temperature sensors to determine stability of the flow period. Once a pre-determined stability is achieved, a timer is activated. When the timer completes its cycle, a ball valve in the intelligent control valve closes. When the intelligent control valve closes, the shut-in period commences and the intelligent control valve returns to monitoring the response from the pressure/temperature sensors. When pre-determined reservoir shut-in parameters are met, the timer is again activated. Once the timer completes this cycle the intelligent control valve opens, and the next flow period commences. The intelligent control valve continues to operate in this manner until programmed to change to a sampling mode (as described below) or to terminate the well test.

[0011] Second, the intelligent testing system comprises a sampling logic. If the intelligent control valve switches to the sampling mode, the ball valve is closed and a variable choke is opened for flow. Once a pre-determined stability is achieved, a timer in the intelligent sampling system is activated. When the timer completes its cycle, the intelligent sampling system captures a sample and checks the sample to determine if it was taken above or below the bubble-point. If the sample was taken below the bubble-point, the sample is discharged and the variable choke in the intelligent control valve is choked back a pre-determined amount. The intelligent control valve then monitors the pressure/temperature sensors to determine stability of the flow. Once a pre-determined stability is achieved, another sample is taken and tested. This cycle continues until the sample pressure is measured at the pre-determined pressure above the bubble-point. Once a correct sample has been taken the intelligent control valve opens the ball valve and closes the variable choke. The intelligent control valve can resume further flow and shut-in periods or can end the test.

[0012] According to another aspect of the invention there is provided a work string for use in well testing, comprising a packer isolating a lower portion of the work string, a control valve in said lower portion and at least one sensor in said lower portion, wherein said control valve operates in response to said sensor.

[0013] The sensor may be a pressure sensor or a tem-

perature sensor. The sensor may determine whether a fluid sample is taken above the sampled fluid's bubble point.

[0014] The control valve may include a variable choke valve and/or a ball valve.

[0015] In an embodiment, the work string further comprises a fluid sampling component in the lower portion thereof.

[0016] In an embodiment, the control valve responses are programmed on the surface prior to well testing.

[0017] In an embodiment, the control valve operating responses are programmed from the surface by remote means while said work string is down hole.

[0018] According to another aspect of the invention there is provided a method of conducting a well test with a work string, comprising the steps of detecting a reservoir condition with at least one sensor and operating a control valve in response to said detected condition, wherein said sensor and said control valve operate down hole.

[0019] According to another aspect of the invention there is provided an apparatus for use in a wellbore having an annulus, said apparatus comprising a work string placed in the annulus, a sensor in said work string and a control valve in said work string, wherein said control valve operates in response to reservoir measurements from said sensor.

[0020] The reservoir measurements are down hole temperature data or down hole pressure data. The reservoir measurements may be fluid sample bubble point data.

[0021] In an embodiment, the apparatus further comprises: a fluid sampling component in said work string.

[0022] In an embodiment, the apparatus further comprises: a timer in said work string, the timer being electrically connected to said control valve and regulates the operation of said control valve.

[0023] According to another aspect of the invention there is provided an intelligent control valve for use in a well, comprising a valve positionable between an open and closed position and a sensor connected to said valve, wherein said valve operates in response to input from said sensor.

[0024] The intelligent control valve may be a variable choke valve and/or a ball valve. The sensor may be a pressure sensor or a temperature sensor. The sensor may determine if a fluid sample is taken above said sample's bubble point.

[0025] In an embodiment, the sensor is hydraulically connected to said valve.

[0026] In an embodiment, the sensor is electronically connected to said valve.

[0027] The present invention is a great improvement over prior art methods and assemblies by reducing the rig time required in running well tests and greatly increasing the reliability of such tests by taking measurements down hole. Further, test parameters can be changed to meet unique down hole conditions, thereby

efficiently gathering all necessary data while limiting the potential for well damage during testing.

[0028] Reference is now made to the accompanying drawings, in which:

[0029] Figure 1 is a schematic representation of an embodiment of the present invention.

[0030] Figure 2 is a flow diagram illustrating the overall functional sequence of an embodiment of the invention.

[0031] Figure 3a is a flow diagram illustrating the flow and shut-in logic of an embodiment of the invention.

[0032] Figure 3b is a flow diagram illustrating the sampling logic of an embodiment of the invention.

[0033] Figure 1 shows an embodiment of the present invention attached to a work string 20 and placed inside a wellbore annulus 10. Figure 1 shows a single zone of interest 15 to be tested. Many of the components illustrated in Figure 1 are typical of testing apparatus run on a work strings and are optional equipment that can be substituted with other equipment or can be left out of various embodiments of the present invention. For example, Figure 1 shows a radioactive tag 22 attached below the work string 20 for locating the work string in a hole. Below the radioactive tag 22 is shown both a rupture disc safety circulation valve 24 and a multi-cycle safety circulation valve 26. An optional, off the shelf, telemetry system 28 is shown immediately below the multi-cycle safety circulation valve 26. Next, Figure 1 shows a jar sub 30 which can be used to mechanically shock the work string 20 in the event the work string 20 and/or the packer 34 becomes stuck. Below the jar 30 is shown a safety joint 32, which is a relax point if the jar sub 30 does not work to free the work string 20.

[0034] One important component to the embodiment illustrated is an isolation packer 34. Such isolation packer 34, however, could be an off the shelf hydraulic packer typical of testing and completion assemblies. Other important components of the embodiment illustrated, although also off the shelf technology, include down hole pressure/temperature sensors 36. Unlike prior art apparatuses, however, the down hole pressure/temperature sensors 36 are electronically or hydraulically connected to and monitored by an intelligent control valve 40. The intelligent control valve illustrated in this embodiment comprises both a ball valve 43 and a variable choke 41. Also unique to the present invention is an intelligent sampling system 50, which is electronically integrated with the intelligence function of the invention.

[0035] Continuing down the work string, further optional equipment is shown such as a vertical shock absorber 60, a firing head 62, TCP guns 64, and radial shock absorbers 66, all of which are typical components of a perforation tool. The inclusion of these perforation tool components with the testing apparatus illustrates that the testing can be accomplished on the same work string, which performs the perforation of the zone of interest 15.

[0036] Figure 2 shows a flow diagram of the testing

sequence of one embodiment of the invention. The process begins by programming 210 the intelligent down hole testing system at the surface. This programming 210 includes the flow, shut-in, and sample testing protocol, which will be described in reference to Figures 3a and 3b. After the system has been programmed 210, the invention is then run in 220 the well for testing. The run in step 220 can be accomplished exactly as prior art drill stem testing strings are presently run in wells. The intelligent down hole testing system ("IDHTS") is then activated 230 using a signal that is conveyed from the surface to the down hole components by wire line, telemetry, or hydraulic pulses. Once the invention is activated 230 the intelligent testing 240 takes place down hole. This testing includes collecting data (for example, pressure, temperature, and flow rates), during shut-in conditions, stabilized flow and testing and sampling the well fluids. The parameters of all these tests are performed pursuant to the programming initiated at the programming step 210. If during the test 240 it becomes necessary to change the programming parameters, the intelligent down hole testing system can be re-programmed 250 by a wire line probe, telemetry, or hydraulic pulses. If the invention does not respond to these programming changes, a hydraulic override feature 270 allows the surface operator to revert to manual control of the testing components. However, if the re-programming step 250 is successfully accepted by the intelligent down hole testing system, the testing step 240 is resumed. Once all of the intelligent down hole testing has been completed 260 a multi-cycle safety circulating valve, or other like component, can be activated to indicate manual control of the system has been transferred to the surface 280. The operator on the surface would control the intelligent down hole testing system for well kill operations.

[0037] Referring now to Figures 3a and 3b, these flow diagrams illustrate the flow and shut-in logic and the sampling logic, respectively. Consequently, Figures 3a and 3b provide greater detail of the intelligent testing step 240 illustrated in Figure 2.

[0038] The flow and shut-in logic begins with the step of opening the ball valve 300. This allows for the well to begin flowing back up the work string. While the well is flowing, the invention monitors down hole pressure and temperature sensors 305 in order to identify a stabilized flow. Once the invention has determined that a stabilized flow has been achieved 310, pursuant to the parameters programmed at step 210 of Figure 2, a timer is activated 315 in order to conduct stabilized flow testing during a predetermined time period. Pressure and temperature data is collected during this timed stabilized flow. Once the stabilized flow time period expires, the next step involves closing the ball valve 320. The system again monitors the pressure and temperature 325 until the pre-programmed shut-in parameters for testing 330 are met. At this point, the timer is again activated 335 so that pressure and temperature data can be collected for

the shut-in condition over a predetermined time period. After this shut-in test is complete, the system performs an iteration check 340, again pursuant to the previous programming, to determine if additional well flow and shut-in tests are required. If so, the process begins again with the step of opening the ball valve 300. Otherwise, the intelligent down hole testing system can revert to the sampling logic mode, as illustrated in Figure 3b, by first closing the ball valve 345.

[0039] With the ball valve closed 345, a variable choke is opened 350 a pre-determined amount. The initial choke can be based either on previous surface programming or can be influenced by the data collected during the previous flow and shut-in logic testing. Opening the variable choke 350 allows the well fluids to again flow up the work string, but at a pressure that can be regulated by increasing or decreasing the choke. The system again performs a pressure and temperature monitor step 355 until stabilized flow parameters are met 360. A timer is then activated 365 to regulate the period of stabilized flow. The invention then captures a sample of the well fluid 370. This sample is captured 370 and evaluated 375 down hole in very close proximity to a reservoir. Consequently, the data obtained from this sample is extremely accurate.

[0040] The sample evaluation step 375 determines whether the sample was taken above or below the bubble point pressure. If the sample was taken below the bubble point pressure, the sample is discharged 380 and the choke on the variable choke valve is increased 385. The invention then again monitors the pressure and temperature 355 until stabilized flow parameters are met 360, thus starting the sampling process all over again. If, however, the sample evaluation 375 determines that the sample was taken at a pressure acceptably above the bubble point pressure, the sample is retained for further analysis and the choke valve is closed 390. The invention then returns to the beginning of the flow and shut-in logic illustrated in Figure 3a by opening the ball valve 300. If additional flow and shut-in testing is required or programmed, this process is again initiated by the pressure/temperature monitoring step 305. The entire system reverts to the manual mode 395, however, if no further testing is required.

[0041] While Figures 3a and 3b illustrate separate flow and shut-in logic and sampling logic, another embodiment of the invention initially combines the two logic functions so that they are accomplished simultaneously. This can be accomplished by performing the first sample capture 370 while a stabilized flow test is being timed 315. If the sample then evaluates 375 to be above the bubble point, no further sampling logic is required.

[0042] It will be appreciated that the invention described above may be modified.

Claims

1. A work string (20) for use in well testing, comprising a packer (34) isolating a lower portion of the work string (20), a control valve (40) in said lower portion, and at least one sensor (36) in said lower portion, wherein said control valve (40) operates in response to said sensor.
2. A work string (20) according to claim 1, wherein said sensor (36) is a pressure sensor.
3. A work string (20) according to claim 1, wherein said sensor (36) is a temperature sensor.
4. A method of conducting a well test with a work string (20), comprising the steps of detecting a reservoir condition with at least one sensor (36) and operating a control valve (40) in response to said detected condition, wherein said sensor (36) and said control valve (40) operate down hole.
5. A method according to claim 4, wherein said sensor (36) is a pressure sensor.
6. A method according to claim 4, wherein said sensor (36) is a temperature sensor.
7. An apparatus for use in a wellbore having an annulus (10), comprising a work string (20) placed in the annulus (10), a sensor (36) in said work string (20) and a control valve (40) in said work string (20), wherein said control valve (40) operates in response to reservoir measurements from said sensor (36).
8. Apparatus according to claim 7, wherein said reservoir measurements are down hole temperature data.
9. An intelligent control valve for use in a well, comprising a valve (40) positionable between an open and closed position and a sensor (36) connected to said valve (40), wherein said valve (40) operates in response to input from said sensor (36).
10. An intelligent control valve according to claim 9, wherein said valve (40) is a variable choke valve (41).

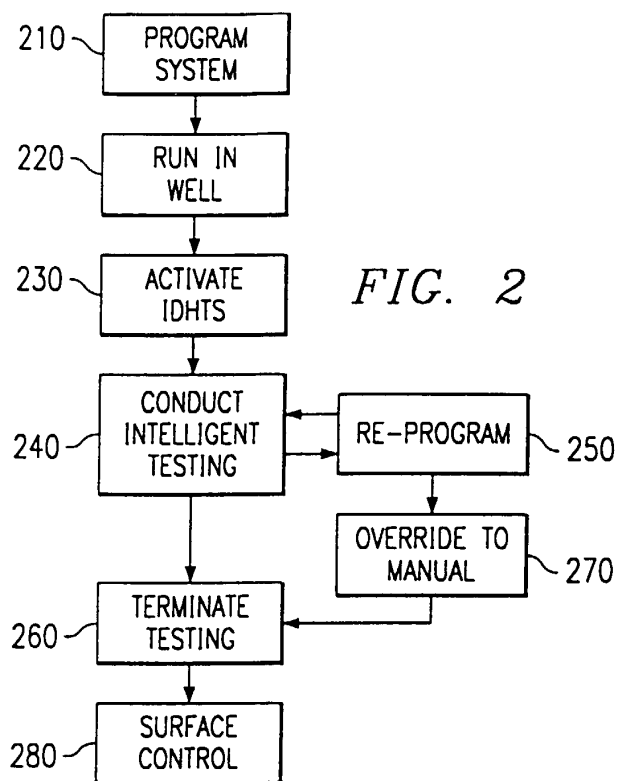
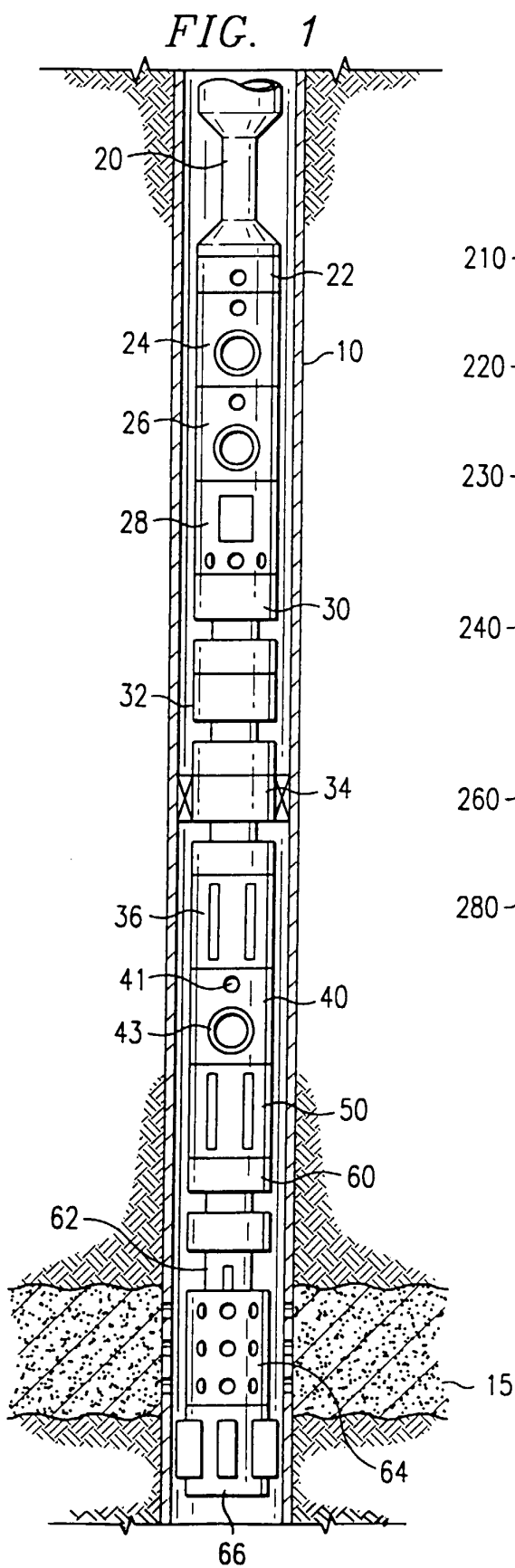


FIG. 3a

FROM FIG. 3b

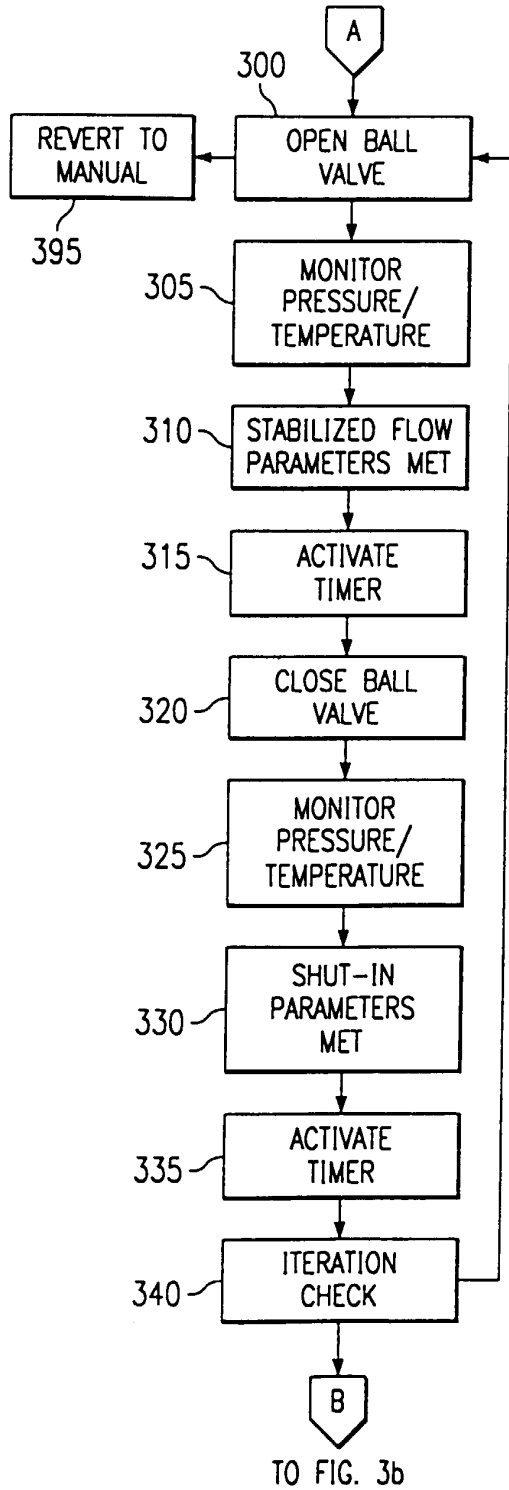


FIG. 3b

FROM FIG. 3a

