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(54) ANNULUS PLUGGING DETECTION USING A PRESSURE TRANSMITTER IN GAS-LIFT OIL PRODUCTION

(76) Inventors: **Kadir Kavaklioglu**, Karakoy (TR); **Marcos Peluso**, Chanhassen, MN (US)

Correspondence Address:
WESTMAN, CHAMPLIN & KELLY, P.A.
Suite 1600 - International Centre
900 Second Avenue South
Minneapolis, MI 55402-3319 (US)

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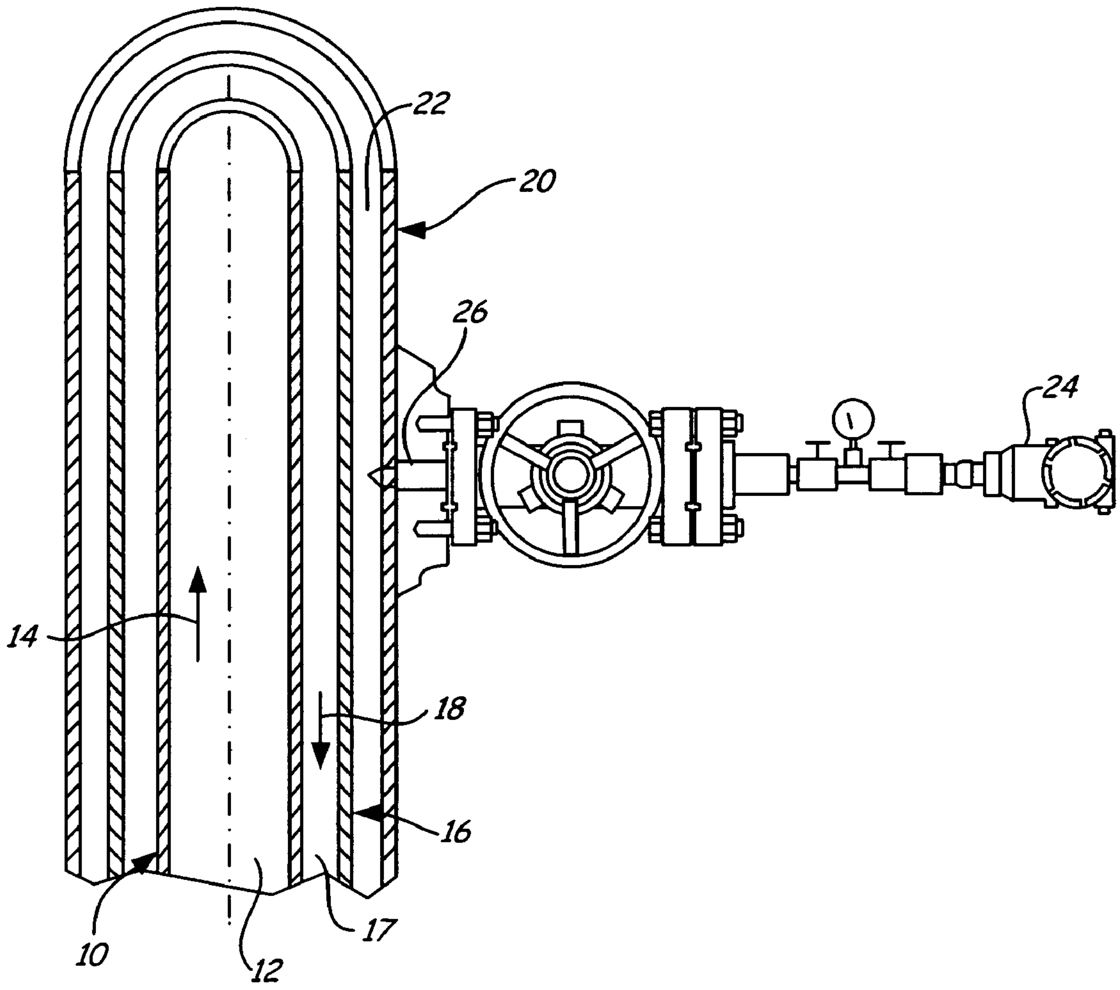
(57) **ABSTRACT**

Outer annulus plugging detection is provided for gas-lift oil wells. The outer annulus detection is effected using a pressure transmitter. The pressure transmitter provides an indication of pressure within an outer annulus of the oil well. A statistical parameter related to a plurality of outer annulus pressure readings is used to provide an indication of annulus plugging. Examples of the statistical parameter include mean and standard deviation.



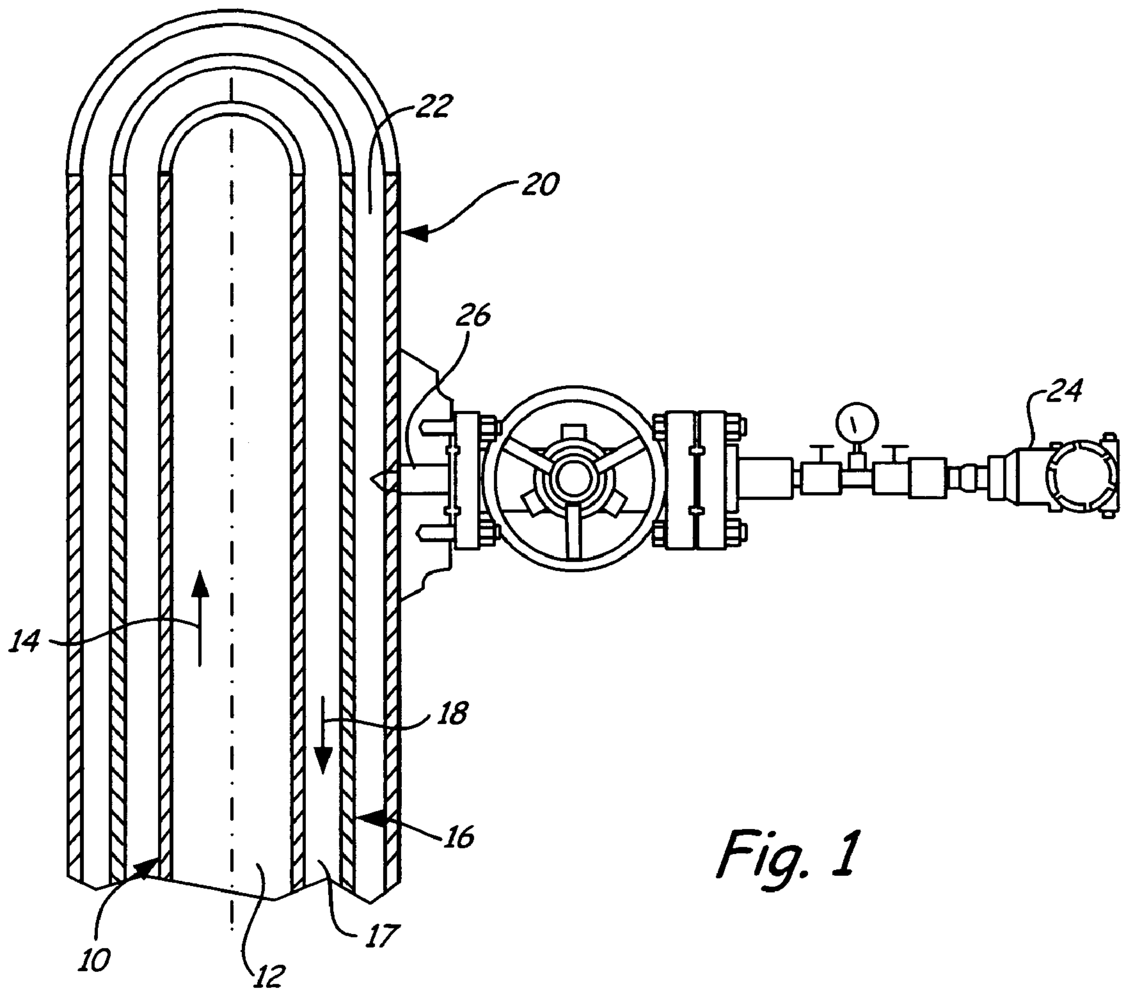


Fig. 1

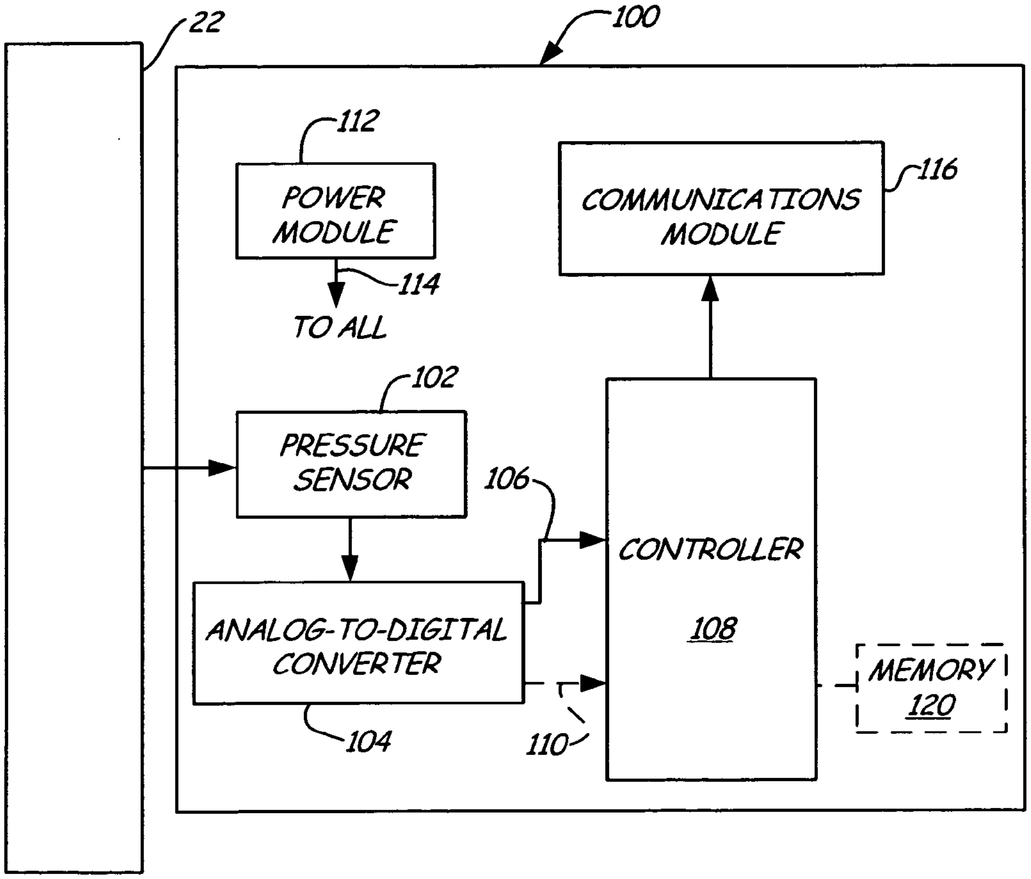

22
100
112
POWER MODULE
114
TO ALL
COMMUNICATIONS MODULE
116
102
PRESSURE SENSOR
106
CONTROLLER
108
ANALOG-TO-DIGITAL CONVERTER
104
110
MEMORY
120

Fig. 2

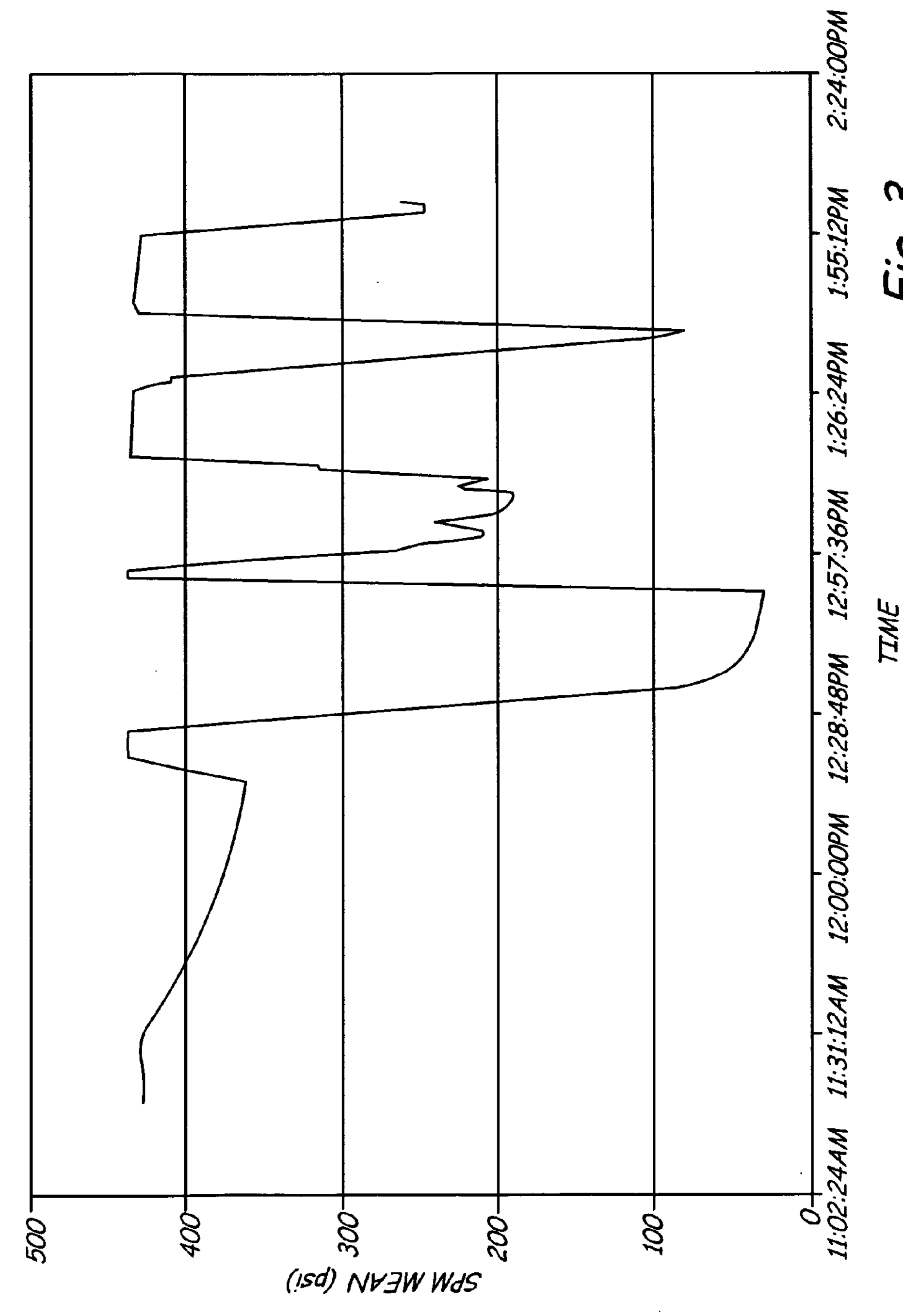

500
400
300
200
100
0
SPM MEAN (psi)
11:02:24AM
11:31:12AM
12:00:00PM
12:28:48PM
12:57:36PM
1:26:24PM
1:55:12PM
2:24:00PM
TIME

Fig. 3

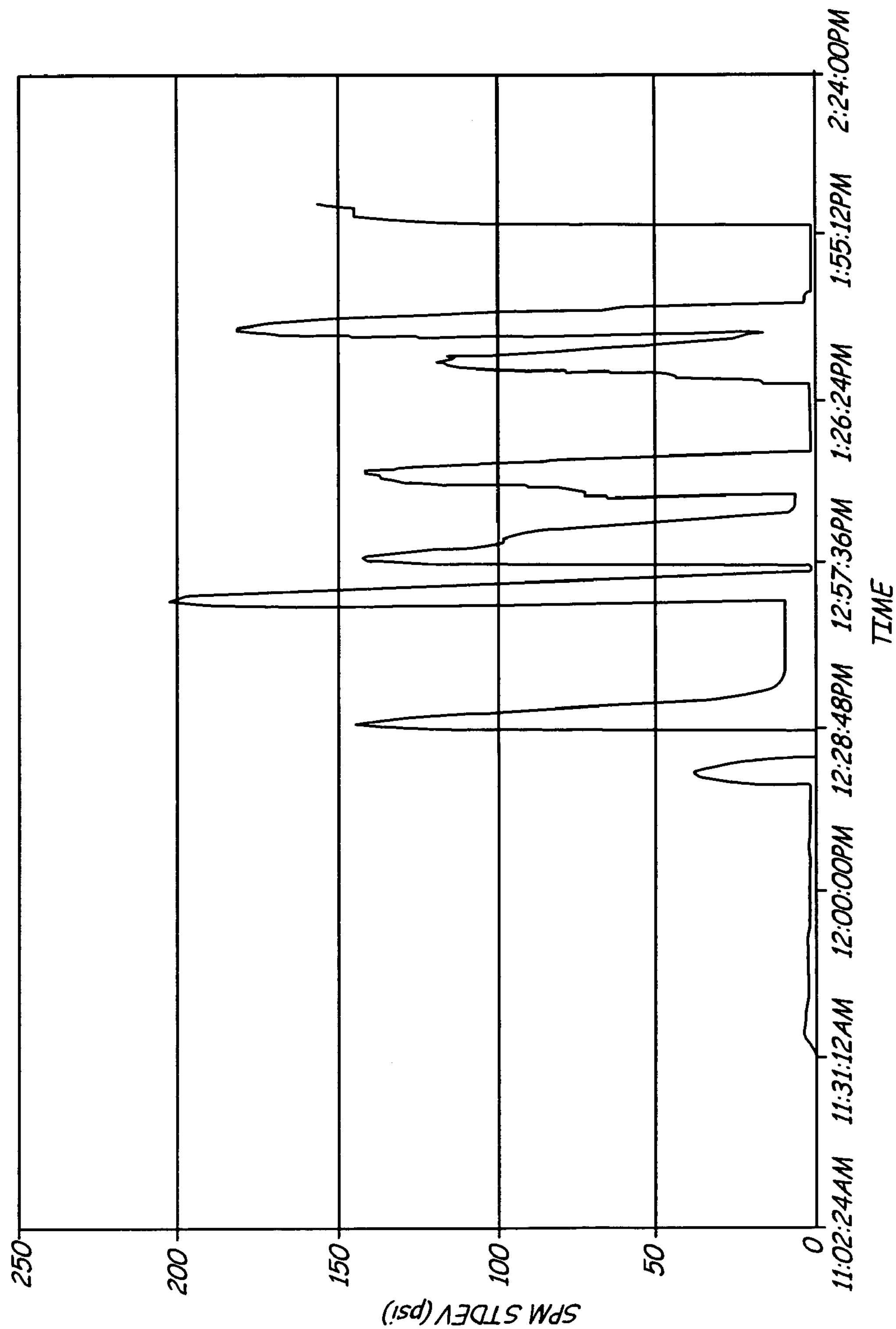

SPM STDEV (psi)
250
200
150
100
50
0
TIME
11:02:24AM
11:31:12AM
12:00:00PM
12:28:48PM
12:57:36PM
1:26:24PM
1:55:12PM
2:24:00PM

Fig. 4

ANNULUS PLUGGING DETECTION USING A PRESSURE TRANSMITTER IN GAS-LIFT OIL PRODUCTION

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application is based on and claims the benefit of U.S. provisional patent application Ser. No. 60/542,185, filed Feb. 5, 2004, the content of which is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] The present invention is related to gas-lift oil production operations. More particularly, the present invention is related to improved annulus plugging detection in such operations.

[0003] The gas-lift method of lifting crude oil is used in many of the world's oil wells. Indeed, in fields where significant quantities of associated gas are present and produced solids are involved, it is the preferred method of augmenting the natural reservoir pressure and thus increasing production.

[0004] Because the technique involves comparatively compact equipment at the well head, it is especially attractive where space is at a premium, such as offshore, and where access for maintenance is restricted.

[0005] **FIG. 1** is diagrammatic view of a typical gas-lift oil well. Central pipe **10** defines a passageway **12** through which crude oil flows in the direction of arrow **14** up to the ground and ultimately to one or more collection stations. The middle section includes middle conduit **16** disposed preferably, concentrically, about pipe **10** to define an inner annulus **17** between conduit **16** and pipe **10**. Pressurized gas is injected into inner annulus **17** and travels down, in the direction of arrow **18**, to the bottom of the piping. The pressurized gas then enters the middle section that contains the crude oil through a special section. This creates lift for the crude oil to ascend via pipe **10** to the surface. By the nature of this process, inner annulus **17** is highly pressurized and often has temperatures exceeding that of ambient. An outer shell **20** defines an outer annulus **22** between shell **20** and conduit **16**. Outer annulus **22** and shell **20** help protect the environment against leaks and any thermal impacts of the pumping operation. In an ideal situation, the pressure within outer annulus **22** is slightly below atmospheric pressure and would not have any materials, such as oil or gas, disposed therein. However, in actual operations, outer annulus **22** may become pressurized due to leaks from inner annulus **17** or cracks in conduit **16** defining the barrier between inner annulus **17** and outer annulus **22**. The pressure within outer annulus may sometimes reach levels on the order of 2000 pounds per square inch. In these cases, a special permit may be required from the state, or other suitable regulatory authority, to operate the well. In such situations, the pressure within outer annulus **22** must be monitored to comply with regulations.

[0006] One factor that complicates monitoring the pressure within outer annulus **22** is material disposed within annulus **22**, which may become filled (partially or fully) with materials such as water, mud, oil from the surroundings or from the reservoir. The presence of these materials can create a significant problem for pressure measurement because they may freeze at relatively high temperatures due to the significant pressures involved. As illustrated in **FIG. 1**, a pressure transmitter, such as transmitter **24** is sometimes operably coupled to outer annulus **22** in order to monitor the pressure therein.

[0007] During normal oil pumping operations, the well temperature may be around 160° F., which is induced by the relatively high-pressure gas injection to the system. Due to various reasons, the well may stop operation occasionally. In this case, the well temperature close to ground and well head above ground will drop in temperature to that of ambient. In these cases, the material inside outer annulus **22** can freeze creating a plug in annulus **22** and/or instrument piping **26**. When this happens, pressure measurements taken using transmitter **24** will no longer reflect the actual pressures in outer annulus **22**. When the well starts to operate again, the temperature in the well starts to rise. This temperature rise will cause expansion of the material in the bottom sections of annulus **22**. Since there may be a frozen plug at the top section, significant increases in pressure in annulus **22** below the plug can occur. Outer annulus pressures exceeding 4000 pounds per square inch have been observed during this process. Due to the frozen plug at the top of annulus **22**, pressure measured using transmitter **24** will not indicate this severe pressure rise. Therefore, routine pressure monitoring at the well head may not help detect the issue. If the pressure in the well rises too much, it may cause an explosion at the top with leakage to the environment and potentially serious injury or even death.

[0008] Accordingly, it is extremely important to determine whether the outer annulus is becoming, or has become plugged. Further, in order to ensure that additional costs are not required in this monitoring process, it would be beneficial if such monitoring could be done without adding significant hardware, or technician time.

SUMMARY OF THE INVENTION

[0009] Outer annulus plugging detection is provided for gas-lift oil wells. The outer annulus detection is effected using a pressure transmitter. The pressure transmitter provides an indication of pressure within an outer annulus of the oil well. A parameter related to a plurality of outer annulus pressure readings is used to provide an indication of annulus plugging. Examples of the statistical parameter include mean and standard deviation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] **FIG. 1** is diagrammatic view of a typical gas-lift oil well.

[0011] **FIG. 2** is diagrammatic view of a pressure transmitter operably coupled to an outer annulus in accordance with an embodiment of the present invention.

[0012] **FIG. 3** shows results from a test performed in accordance with an embodiment of the present invention.

[0013] **FIG. 4** shows the standard deviation as a function of time for the same test cases as that of **FIG. 3**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0014] **FIG. 2** is diagrammatic view of a pressure transmitter **100** operably coupled to outer annulus **22**. Pressure sensor **102** of transmitter **100** is fluidically coupled to annulus **22** and has an electrical characteristic that varies with the pressure in annulus **22**. Pressure sensor **102** can be a capacitive-type pressure sensor, a resistance-based strain gauge-type sensor, or any other suitable type of sensor. Pressure sensor **102** is electrically coupled to analog to digital converter **104**. Converter **104** converts an analog signal from sensor **102** into a digital value that it provides, via line **106**, to controller **108**. Additionally, in accordance with one embodiment of the invention, converter **104** may provide an auxiliary output **110**, illustrated in phantom, that simply reflects a digital bitstream indicative of the analog reading. The use of a digital bitstream allows higher resolution, which is useful for some types of statistical processing. For example, while a traditional analog to digital converter may provide digital conversions on line **106** at approximately 22 times per second, the frequency of the digital bitstream on line **110** may be over 100 kHz.

[**0015**] Power module **112** can include any suitable circuitry for receiving and conveying power to the components of transmitter **100**. Module **112** is coupled to all components requiring power as indicated at line **114**. Module **112** may include an energy storage cell, or may include suitable circuitry to couple to a source of energy. It is known for some process industry standard protocols to provide operating power. Examples of such protocols include HART, and FOUNDATION™ Fieldbus. Power module **112** may also include one or more suitable transducers for converting potential energy into electrical energy for transmitter **100**. Thus, module **112** may include one or more solar cells, for example.

[**0016**] Communications module **116** is coupled to controller **108** and allows transmitter **100** to communicate to one or more external devices. In embodiments where transmitter **100** is expected to communicate using an industry standard process communication protocol, module **116** will be suitably adapted. For example, if transmitter **100** is to communicate using the FOUNDATION™ fieldbus protocol, module **116** may include any suitable known fieldbus communications circuitry. Transmitter **100**, in some embodiments, can provide a first signal indicative of pressure within annulus **22**, and a second signal indicative of annulus plugging. Known protocols allow such signals to be provided over the same communication lines. For example, one signal could be provided in analog format, and the second signal could be a superimposed digital signal.

[**0017**] Controller **108** is preferably a microprocessor. Controller **108** could be part of transmitter **100**, or may reside in a remote location from transmitter **100**. Controller **108** may include internal memory (not separately illustrated) and/or may be coupled to external memory **120**. Using internal memory, external memory **120**, or any combination thereof, controller **108** will store pressure measurement data related to readings from pressure sensor **102** over time. In accordance with embodiments of the present invention, it has been determined that secondary calculations based upon a plurality of temporally spaced readings related to pressure sensor **102** can reveal the plugging of annulus **22**. Much of the remainder of the description will focus upon the use of statistical parameters. However, embodiments of the present invention can be practiced using other analytical techniques such as fuzzy logic, neural networks, learning techniques, trend analysis, and any other suitable methods, or any combination thereof.

[**0018**] In order to understand the effects of plugging, various simulations were performed both on real oil wells and on simulated laboratory rigs. In these simulations, various valves on instrument piping were used to artificially induce a plugged annulus condition by isolating the measurement device from the process. A commercially available pressure transmitter sold under the trade designation 3051 S T, available from Rosemount, Inc., of Eden Prairie, Minn., was used as the pressure-measuring device. This transmitter was equipped with an auxiliary data channel **110** for providing fast updating diagnostics for statistical calculations. The two statistical calculations used in the simulations were mean and standard deviation of the pressure measurement. However, embodiments of the present invention should not be considered to be limited to such statistical calculations.

[**0019**] **FIG. 3** shows results from one of the test performed. This plot presents the mean parameter as a function of time. In this particular case, the normal operating pressure in outer annulus **22** is approximately 426 pounds per square inch. Every time that a valve was closed to simulate annulus plugging, the mean parameter pressure reading showed a significant drop in value compared to normal operating pressure. It has been concluded that the temperature changes and pipe/valve leaks contribute to this change as a result of plugging. Accordingly, pressure transmitter **100** can be characterized, or otherwise calibrated to a known non-plugged condition. Then, if the mean of the pressure sensor readings deviates beyond an allowable threshold from the baseline "good" condition, an alarm, or other suitable indication, is provided from pressure transmitter **100** indicating annulus plugging.

[**0020**] **FIG. 4** shows the standard deviation as a function of time for the same test cases of that of **FIG. 3**. The standard deviation parameter presents a significantly more distinctive signature for plugging indications. Each time the system was plugged, a peak was observed in the standard deviation. As is apparent from the results illustrated in **FIG. 4**, standard deviation may be used alone, or in combination with the mean to provide annulus plugging detection.

[**0021**] Another challenging situation for annulus plugging detection is when a well is stopped and started. In this case, the pressures in outer annulus **22** will not be as high as during normal operation. However, statistical process monitoring may still be used in this case. If training has been performed on the pressure transmitter before the pumping operation is shut down, then the outer annulus mean pressure and its standard deviation can be recorded as baseline. When the well is started again, it is expected that the pressure measurements are expected to rise from its shutdown levels if there is no plugging. If there is plugging, the pressure measurements will not significantly rise, thus indicating plugged annulus. Thus, in accordance with one embodiment of the present invention, pressure transmitter **100** is provided with a notification regarding pumping operations, either stopping, starting, or both. Thus, when pressure transmitter **100** receives a notification that pumping is starting again, it may wait a pre-selected duration before expecting measurements to be acceptable.

[**0022**] While it is preferred that monitoring of a statistical parameter related to the outer annulus pressure be done continuously, embodiments of the present invention can be practiced by accessing the outer annulus pressure at selected intervals, or even in response to technician requests. However, sufficient numbers of pressure measurements must be taken by pressure sensor **102** in order to provide statistical computations.

[**0023**] Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

What is claimed is:

1. A system for detecting outer annulus plugging in a gas-lift oil well, the system comprising:

a pressure transmitter operably coupleable to the outer annulus of the gas-lift oil well, the pressure transmitter being adapted to provide a signal related to pressure within the outer annulus; and

a controller configured to receive the signal and obtain a plurality of pressure measurements relative to the outer annulus, which measurements are temporally spaced, the controller being configured to calculate a parameter indicative of annulus plugging based on the plurality of pressure measurements.

2. The system of claim 1, wherein the controller is a component of the pressure transmitter.

3. The system of claim 1, wherein the pressure transmitter is adapted to provide a first signal indicative of pressure within the outer annulus, and a second signal indicative of plugging.

4. The system of claim 3, wherein the pressure transmitter communicates over a digital process communication loop.

5. The system of claim 1, wherein the pressure transmitter is powered by a digital process communication loop.

6. The system of claim 1, wherein the pressure transmitter further comprises an analog-to-digital converter providing digital conversions to the controller.

7. The system of claim 1, wherein the pressure transmitter further comprises an analog-to-digital converter providing a high-speed bitstream to the controller.

8. The system of claim 1, wherein the parameter is a statistical parameter.

9. The system of claim 8, wherein the statistical parameter is mean.

10. The system of claim 8, wherein the statistical parameter is standard deviation.

11. The system of claim 8, wherein the statistical parameter is a combination of mean and standard deviation.

12. The system of claim 1, wherein the parameter is calculated using fuzzy logic.

13. The system of claim 1, wherein the parameter is calculated using a neural network.

14. A method of determining whether an outer annulus of a gas-lift oil well is at least partially plugged, the method comprising:

obtaining a plurality of temporally spaced pressure measurements within the outer annulus;

calculating a statistical parameter using the plurality of measurements; and

providing an indication of plugging based upon the statistical parameter.

15. The method of claim 14, wherein the method is performed by a pressure transmitter.

16. The method of claim 14, wherein the statistical parameter is mean.

17. The method of claim 14, wherein the statistical parameter is standard deviation.

18. A gas-lift oil well comprising:

a first pipe having a first pipe wall defining an interior adapted to convey pressurized crude oil;

a second pipe having a second pipe wall defining an inner annulus with the first pipe wall;

an outer shell defining an outer annulus with the second pipe wall; and

means for detecting plugging of the outer annulus.

* * * * *