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(54) **DETERMINING FLUID BUBBLE POINT PRESSURE USING AN ADJUSTABLE CHOKE**

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(57) **ABSTRACT**

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

A method of determining the real time bubble point pressure of a fluid originating from a subsurface earth formation using an adjustable choke positioned downhole adjacent to the formation. The adjustable choke is placed into communication with the wellbore fluid flowing from the formation to the surface. The adjustable choke has a remotely adjustable choke opening for selectively restricting the flowrate of the fluid flowing through the choke. The adjustable choke has a pressure sensor for measuring the fluid pressure downstream of the choke opening. The method includes obtaining downstream fluid pressure data as a function of choke size for generating a plot of downstream pressure versus choke size data which exhibits substantially linear behavior having two different slopes. Extrapolating a best-fit line through the set of data having a first slope so as to intersect an extrapolation of a best-fit line through the set of data having a second slope thereby provides the bubble point pressure of the fluid as the pressure corresponding to the intersection of the two lines.

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(52) **U.S. Cl.** **73/64.54**; 166/264; 73/152.02

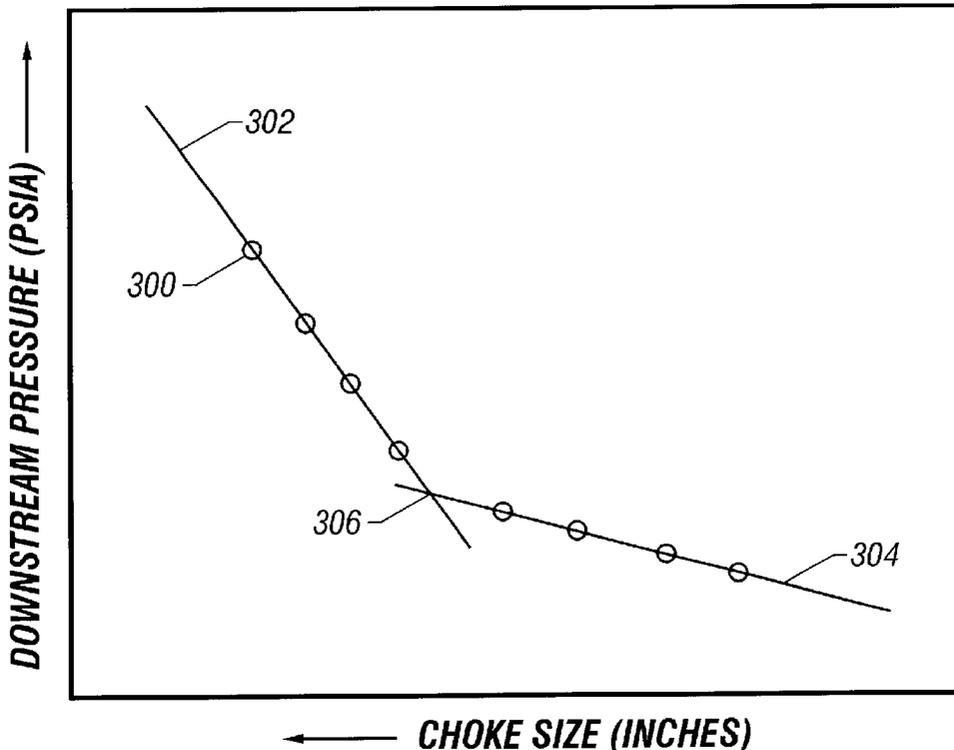
(58) **Field of Search** 73/61.46, 64.54, 73/64.46, 865.6, 152.02, 152.16, 152.24, 152.26, 152.51, 152.55; 166/264, 270.1, 401

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10 Claims, 3 Drawing Sheets



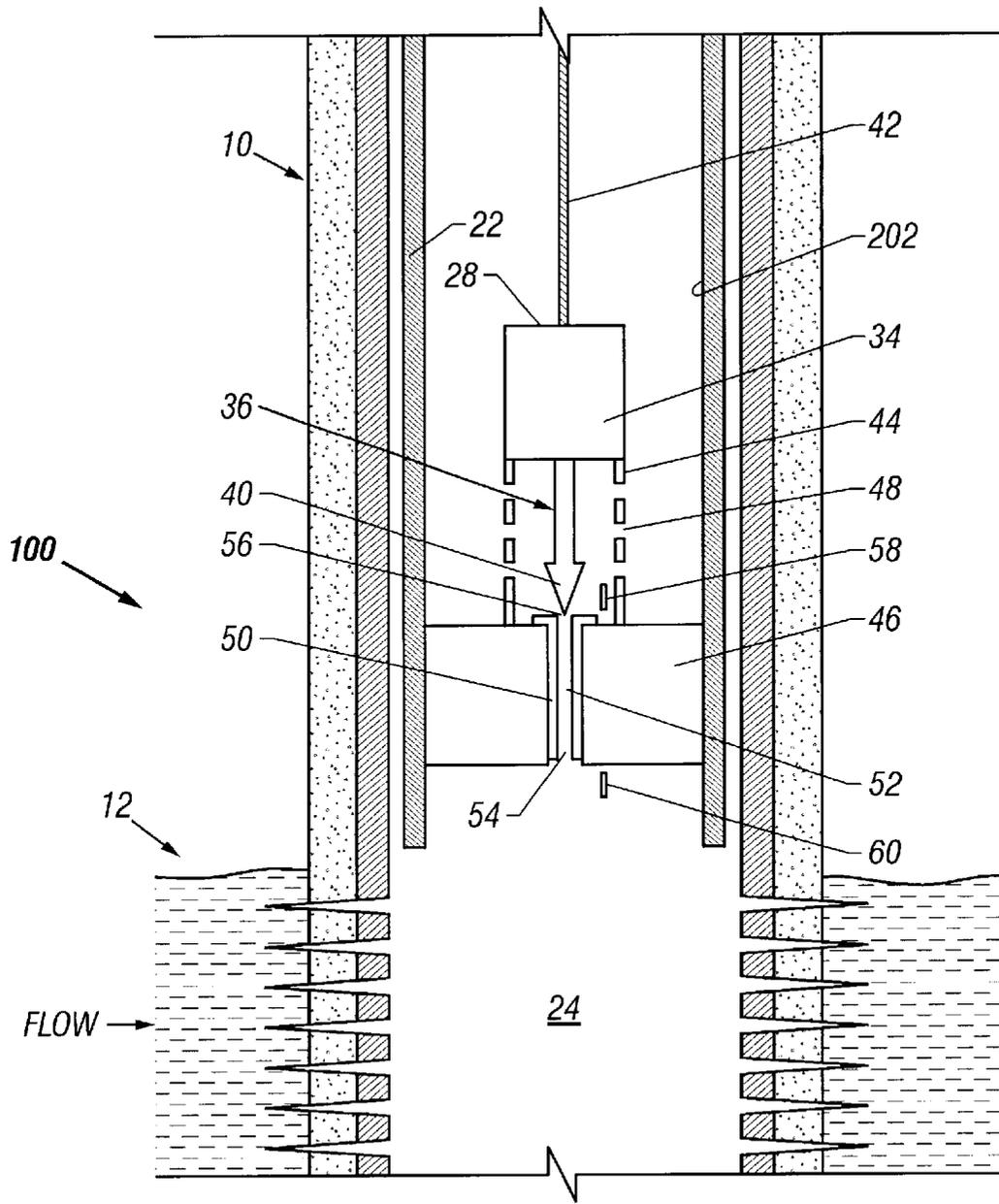


FIG. 2

DETERMINING FLUID BUBBLE POINT PRESSURE USING AN ADJUSTABLE CHOKE

Background of the Invention

This invention relates generally to the field of wireline tools used for subsurface earth formation testing, and more particularly to wireline tools used for determining the bubble point pressure of fluid flowing from a subsurface formation.

Electric wireline tools are used for determining bubble point pressure of fluid originating from a subsurface earth formation in order to determine properties of the fluid used in calculating the total fluid content within the formation. One of the methods of determining in situ bubble point pressure of formation fluid involve the use of downhole electric wireline tools capable of withdrawing a sample of fluid from a subsurface earth formation into a sample chamber and incrementally expanding the volume of the sample chamber while measuring the pressure. The bubble point pressure of the fluid is then extracted from a plot of the pressure versus volume data. These conventional tools are used only in the exploration stage, are not useable during well production, and are removed from the wellbore prior to flowing the well.

Other conventional methods of determining bubble point pressure of a formation fluid involve withdrawing a sample of fluid from the earth formation into a chamber of a testing tool. Then, the bubble point pressure measurement is done at the well site or laboratory by measuring the pressure and volume of the sample, while expanding the volume of the sample. Such conventional tools are not permanently installed, and do not permit the determination of in situ fluid bubble point pressure during well production.

Conventional methods and apparatus for remotely controlling well production employ the use of various downhole electromechanical devices coupled with computer based surface systems. One such device is an adjustable choke with pressure sensors located upstream and downstream of the choke for attaining desired wellbore pressure by controlling fluid flow during the life of the well. However, such devices do not use the adjustable choke in determining a bubble point pressure of the fluid.

Therefore, a need exists for a method for determining fluid bubble point pressure during well production.

The present invention is directed to overcoming one or more of the limitations of the existing devices.

Summary of the Invention

According to one aspect of the present invention, an apparatus for determining a bubble point pressure of a fluid originating from a subsurface earth formation is provided that includes production tubing, an adjustable choke, and a controller. The production tubing is adapted for placement within the subsurface earth formation. The adjustable choke is coupled to the production tubing. The adjustable choke includes a remotely adjustable choke opening adapted to selectively restrict a flow rate of a fluid flowing through the choke opening, and a pressure sensor adapted to measure a fluid pressure downstream of the choke opening. The controller is operably coupled to the adjustable choke and is adapted to control the adjustable choke opening, monitor the fluid pressure downstream of the choke opening, and calculate the bubble point pressure.

According to another aspect of the present invention, a method of determining a bubble point pressure of a fluid originating from a subsurface earth formation is provided

that includes placing an adjustable choke in communication with the fluid flowing from the subsurface formation. The size of the adjustable choke is selectively adjusted to vary the flow rate downstream from the adjustable choke. The fluid pressure downstream from the adjustable choke is measured for a range of choke sizes. The plot of the fluid pressure downstream against choke size will indicate fluid phase change from one phase (liquid), as shown by a first line, into two phases (liquid and gas), as shown by a second line. The intersection of these two best fit lines indicates the bubble point pressure for the fluid.

According to another aspect of the present invention, a method of determining a bubble point pressure of a fluid originating from a subsurface earth formation using an adjustable choke positioned downhole adjacent to the formation is provided that includes placing the adjustable choke in communication with the fluid flowing from the formation to the surface during well production. The adjustable choke has a selectively operable actuator for remotely adjusting the size of an opening of the choke in order to vary the downstream flowrate of the fluid flowing through the opening. The choke also includes a pressure sensor located adjacent to the choke opening for measuring the downstream pressure of the fluid after flowing through the choke opening. The pressure sensor communicates the pressure measurements to a controller. The size of the adjustable choke is selectively adjusted to varying the downstream fluid flowrate while simultaneously measuring the downstream fluid pressure. Downstream fluid pressure data at several choke sizes is obtained to generate a first plot of downstream pressure vs choke size data which contains data exhibiting substantially linear behavior having a first slope and a second plot of downstream pressure vs choke size data which contains data exhibiting substantially linear behavior having a second slope. The plotted data are then extrapolated to determine the intersection of the first and second plots to determine the bubble point pressure of the fluid.

Brief Description of the Drawings

FIG. 1 depicts a view, partly in cross-section, of an embodiment of an adjustable choke positioned inside an inverted pocket of a production tubing with pressure transducers positioned above and below an opening of the choke for measuring the downstream and upstream pressures, respectively, of fluid flowing through the fully open choke.

FIG. 2 depicts a view, partly in cross-section, of an alternate embodiment in which an adjustable choke is positioned inside a primary bore of a production tubing, illustrating a means of adjusting the choke size by physically displacing area available for the passage of fluid.

FIG. 3 illustrates the use of downstream pressure vs choke size for determining a bubble point pressure of a fluid.

Detailed Description of the Illustrative Embodiments

Referring initially to FIG. 1, a preferred embodiment of an apparatus **100** for determining bubble point pressure positioned in a wellbore **10** is illustrated. The wellbore **10** includes a hole drilled through the earth penetrating a subsurface earth formation **12** containing formation fluid **14**. The wellbore **10** is lined with annular regions of cement **16** and a casing **18**. Perforations **20** adjacent to the formation **12** provide a passage permitting formation fluid **14** to flow from the formation **12** into a lower end of production tubing **22**. The production tubing **22** provides a conduit for facilitating the flow of wellbore fluid **24**, originating from the formation **12**, to the surface.

The apparatus **100** includes an adjustable choke **28** disposed within an inverted pocket **26** of the tubing **22**. The adjustable choke **28** controllably restricts the flow of wellbore fluid **24** in the pocket **26** and thereby induces a loss in the fluid flowrate and pressure across the choke **28**. Wellbore fluid **24** flows from the tubing **22** into an inlet port **30** of the pocket **26**, through the adjustable choke **28**, and out of the pocket **26** through an outlet port **32**.

The adjustable choke **28** includes a motor **34** for vertically translating a bidirectional conical needle **36** which extends from a bottom side of the motor **34**. The bidirectional conical needle **36** incorporates a vertical linear spindle **38** and a right circular cone **40** wherein the cone **40** opens upward and has an axis of symmetry coincident with the longitudinal axis of the spindle **38**. The spindle **38** connects on an upper end to the bottom side of the motor **34**, and on a lower end the spindle **38** connects to a top side of the cone **40**.

The motor **34** is powered by an armored electrical cable or wireline **42** attached to a top side of the motor **34**. In addition, the motor **34** is supported by a cylindrical support member **44** which connects on an upper end to the bottom side of the motor **34**, and on a lower end connects to a top side of an annular mounting block **46**. The support member **44** is perforated with holes **48** to enable the fluid to flow out of the choke **28** toward the upper end of the pocket **26**. An outer diameter surface of the annular mounting block **46** attaches along an inner surface of the pocket **26**. A needle seating **50** attaches along the top side of the annular mounting block **46** and extends downwardly along an inner diameter surface of the annular mounting block **46**.

The needle seating **50** includes a constant diameter passage **52** having an inlet opening **54** at the passage **52** on a lower end of the needle seating **50** and an outlet opening **56** at the passage **52** on an upper end of the needle seating **50**. A pressure transducer **58** located in an immediate area above the outlet opening **56** measures a downstream pressure of the wellbore fluid **24** after flowing through the outlet opening **56** of the adjustable choke **28**.

Another pressure transducer **60** located in an immediate area below the inlet opening **54** measures the fluid pressure upstream of the adjustable choke **28**.

Referring to FIG. 2, an alternate embodiment **200** in which the adjustable choke **28** is disposed within a primary bore **202** of the tubing **22** is illustrated. In this embodiment, an annular mounting block **46** is sized so that an outer diameter surface of the annular mounting block **46** attaches along an inner surface of the primary bore **202**. The adjustable choke **28** controllably restricts the flow of wellbore fluid **24** in the tubing **22** and thereby induces a loss in the fluid flowrate and pressure across the choke **28**.

In a preferred embodiment, the adjustable choke **28** including elements **34**, **36**, **38**, **40**, **42**, **44**, **46**, **48**, **50**, **52**, **54**, **56**, **58** and **60** comprises the adjustable choke included in the commercially available product entitled "The Cobra System" manufactured and sold by DataLine Petroleum Services in Houston, Tex. modified in accordance with the teachings of the present disclosure.

In operation, the adjustable choke **28** is placed into communication with the wellbore fluid **24**, as illustrated in both FIGS. 1 and 2. A controller (not illustrated) remotely adjusts the choke size of the adjustable choke **28** by sending electrical control signals through the wireline **42** to the motor **34** for controlling the penetration depth of the bidirectional conical needle **36** into a plane of the outlet opening **56**. Extending a vertex of the conical needle **36** so as to penetrate the outlet opening **56** physically displaces an area

in the plane of the outlet opening **56** by the presence of a circular cross-sectional area of the cone **40**. In a preferred embodiment, the plane of the outlet opening **56** is perpendicular to the axis of the cone **40**. Increasing the penetration depth of the cone **40** into the outlet opening **56**, increases the cross-sectional area of the cone **40** in the plane of the outlet opening **56** and thereby decreases the choke size or effective open area of the outlet opening **56** available for the passage of wellbore fluid **24**. Generally, the smaller the choke size, the smaller the flowrate of wellbore fluid **24** through the outlet opening **56** and, consequently, the smaller the corresponding downstream pressure, as pressure is proportional to flowrate. The pressure transducer **58** located downstream of the outlet opening **56** is used to measure the downstream fluid pressure for several different choke sizes ranging from completely open to nearly completely closed. When the choke size is adjusted such that the corresponding downstream pressure is equal to or less than a bubble point pressure of the wellbore fluid **24**, gas releases from solution and separates from the liquid phase thereby forming a two-phase mixture of liquid and gas.

Referring to FIG. 3, a method for determining the bubble point pressure of the wellbore fluid from the monitored downstream pressure will be described. In FIG. 3 a plot of downstream pressure versus choke size data **300** exhibiting two different linear slopes is illustrated. The downstream pressure is monitored using the pressure transducer **58**. A first best-fit line **302** drawn through the substantially linear data exhibits a first slope. A second best-fit line **304** drawn through the substantially linear data exhibits a second slope. The first best-fit line **302** corresponds to pressures at which the wellbore fluid is a single phase liquid wherein gas remains in solution. The second best-fit line **304** corresponds to pressures at which gas releases from solution and the wellbore fluid is a two-phase gas-liquid mixture. The bubble point pressure **306** of the wellbore fluid is the pressure that corresponds to the intersection of the two extrapolated best-fit lines **302** and **304**. In a preferred embodiment, the determination of the bubble point pressure **306** is performed by the controller using conventional curve-fitting software.

Referring back to FIG. 2, the adjustable choke **28** may also be used for conducting a downhole build up pressure transient test while minimizing wellbore storage effects. Upon shut in of the wellbore **10**, the pressure transducer **60** located in an immediate area below the inlet opening **54** measures the fluid pressure upstream of the adjustable choke **28** as the pressure builds up. Anomalies in the pressure data due to wellbore storage effects are minimized by positioning the adjustable choke **28** downhole so as to minimize the volume or length of the wellbore **10** between the location of shutting in the wellbore **10** and the formation **12**.

A method of determining a bubble point pressure of a production fluid using an adjustable choke positioned downhole adjacent to a subsurface earth formation has been described. The adjustable choke is placed in communication with the fluid flowing from the formation to the surface in order to vary the pressure of the fluid flowing through the choke. Adjusting the choke size by selectively restricting the area of the choke available for the passage of fluid induces losses in the fluid flowrate and pressure across the choke. A pressure transducer in an immediate area downstream of the choke provides a means of measuring the pressure of the fluid as a function of choke size. A plot of downstream pressure versus choke size data exhibits substantially linear behavior having a first slope corresponding to pressures at which the fluid is a single phase liquid and a second, smaller slope corresponding to pressures at which the fluid is a

two-phase liquid-gas mixture. Extrapolating a best-fit line drawn through the single phase fluid data so as to intersect an extrapolation of a best-fit line drawn through the two phase fluid data thereby determines the bubble point pressure of the fluid as the pressure corresponding to the intersection of the two lines.

Although illustrative embodiments of the invention have been shown and described, a wide range of modification, changes and substitution is contemplated in the foregoing disclosure. In some instances, some features of the present invention may be employed without a corresponding use of the other features. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the invention.

What is claimed is:

1. An apparatus for determining a bubble point pressure of a fluid originating from a subsurface earth formation, comprising:

- a production tubing adapted for placement within the subsurface earth formation; an adjustable choke coupled to the production tubing, the adjustable choke including:
 - a remotely adjustable choke opening for selectively restricting a flow rate of a fluid flowing through the choke opening; and
 - a pressure sensor for measuring a fluid pressure downstream of the choke opening; and
- a controller operably coupled to the adjustable choke for controlling the adjustable choke opening, monitoring the fluid pressure downstream of the choke opening, and calculating the bubble point pressure during the flowing of fluid from the subsurface formation through the production tubing by:
 - generating a first plot of downstream pressure vs. choke size which exhibits substantially linear behavior having a first slope and a second plot of downstream pressure vs. choke size which exhibits substantially linear behavior having a second slope; and
 - determining the intersection of the first plot and the second plot.

2. The apparatus of claim 1, wherein the production tubing includes an inner fluid passage and an outer surface, and wherein the adjustable choke is in fluidic communication with the inner fluid passage.

3. The apparatus of claim 2, wherein the adjustable choke is positioned on the outer surface of the production tubing.

4. The apparatus of claim 2, wherein the adjustable choke is positioned within the inner fluid passage of the production tubing.

5. A method of determining a bubble point pressure of a fluid originating from a subsurface earth formation, comprising:

- placing an adjustable choke in communication with the fluid flowing from the subsurface formation;
- selectively adjusting the size of the adjustable choke to vary the flow rate downstream from the adjustable choke;
- measuring the fluid pressure downstream from the adjustable choke and the corresponding choke size for a range of choke sizes;
- generating a first plot of downstream pressure vs. choke size which exhibits substantially linear behavior having a first slope and a second plot of downstream pressure vs. choke size which exhibits substantially linear behavior having a second slope; and

determining the intersection of the first plot and the second plot.

6. The method according to claim 5, wherein the adjustable choke is positioned downhole within an inverted pocket of a production tubing, the tubing having a primary bore and a pocket which is laterally separated from the primary bore by an inner wall, the pocket having an inlet port at a lower end of the pocket for the entrance of fluid flowing from inside the primary bore and an outlet port at an upper end of the pocket for the fluid to exit the pocket.

7. The method according to claim 5, wherein the adjustable choke is positioned downhole within a primary bore of a production tubing.

8. The method according to claim 6, wherein a longitudinal axis of the pocket is substantially parallel to a longitudinal axis of the tubing.

9. A method of determining a bubble point pressure of a fluid originating from a subsurface earth formation using an adjustable choke positioned downhole adjacent to the formation, comprising:

- placing the adjustable choke in communication with the fluid flowing from the formation to the surface during well production, the choke having a selectively operable actuator for remotely adjusting the size of an opening of the choke in order to vary the downstream flowrate of the fluid flowing through the opening, the choke including a pressure sensor located adjacent to the choke opening for measuring the downstream pressure of the fluid after flowing through the choke opening, the pressure sensor communicating the pressure measurements to a controller;
- selectively adjusting the choke size for varying the downstream fluid flowrate and simultaneously measuring the downstream fluid pressure;
- obtaining downstream fluid pressure data at several choke sizes for generating a plot of downstream pressure vs choke size data which contains data exhibiting substantially linear behavior having a first slope and data exhibiting substantially linear behavior having a second slope; and

extrapolating the data demonstrating a first slope by a best-fit line so as to intersect an extrapolation of the data demonstrating a second slope, thereby determining the bubble point pressure of the fluid as the pressure corresponding to the intersection of the two lines.

10. An apparatus for determining a bubble point pressure of a fluid originating from a subsurface earth formation, comprising:

- means for placing an adjustable choke in communication with the fluid flowing from the subsurface formation;
- means for selectively adjusting the size of the adjustable choke to vary the flow rate downstream from the adjustable choke;
- means for measuring the fluid pressure downstream from the adjustable choke and the corresponding choke size for a range of choke sizes;
- means for generating a first plot of downstream pressure vs. choke size which exhibits substantially linear behavior having a first slope and a second plot of downstream pressure vs. choke size which exhibits substantially linear behavior having a second slope; and
- means for determining the intersection of the first plot and the second plot.