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(54) **DOWNHOLE USES OF PIEZOELECTRIC MOTORS**

(75) Inventors: **Rocco DiFoggio**, Houston, TX (US); **Jaedong Lee**, Houston, TX (US); **T. Rajasingham**, Dundalk (IE)

Correspondence Address:
GILBRETH ROEBUCK BYNUM
DERRINGTON SCHMIDT WALKER &
TRAN LLP
FROST BANK BUILDING
6750 WEST LOOP SOUTH, SUITE 920
BELLAIRE, TX 77401 (US)

(73) Assignee: **BAKER HUGHES, INCORPORATED**

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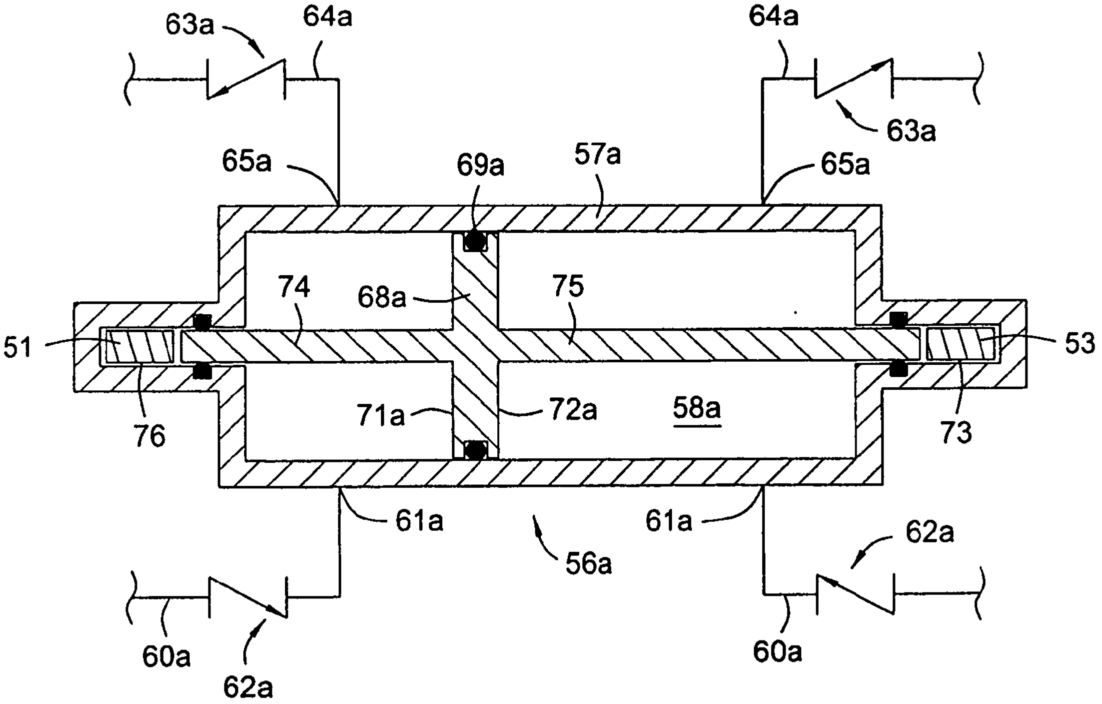
(57) **ABSTRACT**

A sampling system used in collecting samples of connate fluid from within hydrocarbon bearing formations. The sampling system comprises a sonde disposed within a wellbore formed proximate to the formation of interest. The sonde includes a sample probe insertable into the formation and a drawdown pump in fluid communication with the sample probe. The drawdown pump is motivated by an associated electrically responsive material, where the electrically responsive material can be comprised of a piezoelectric material, a electroactive polymer, or some other electrically responsive material.



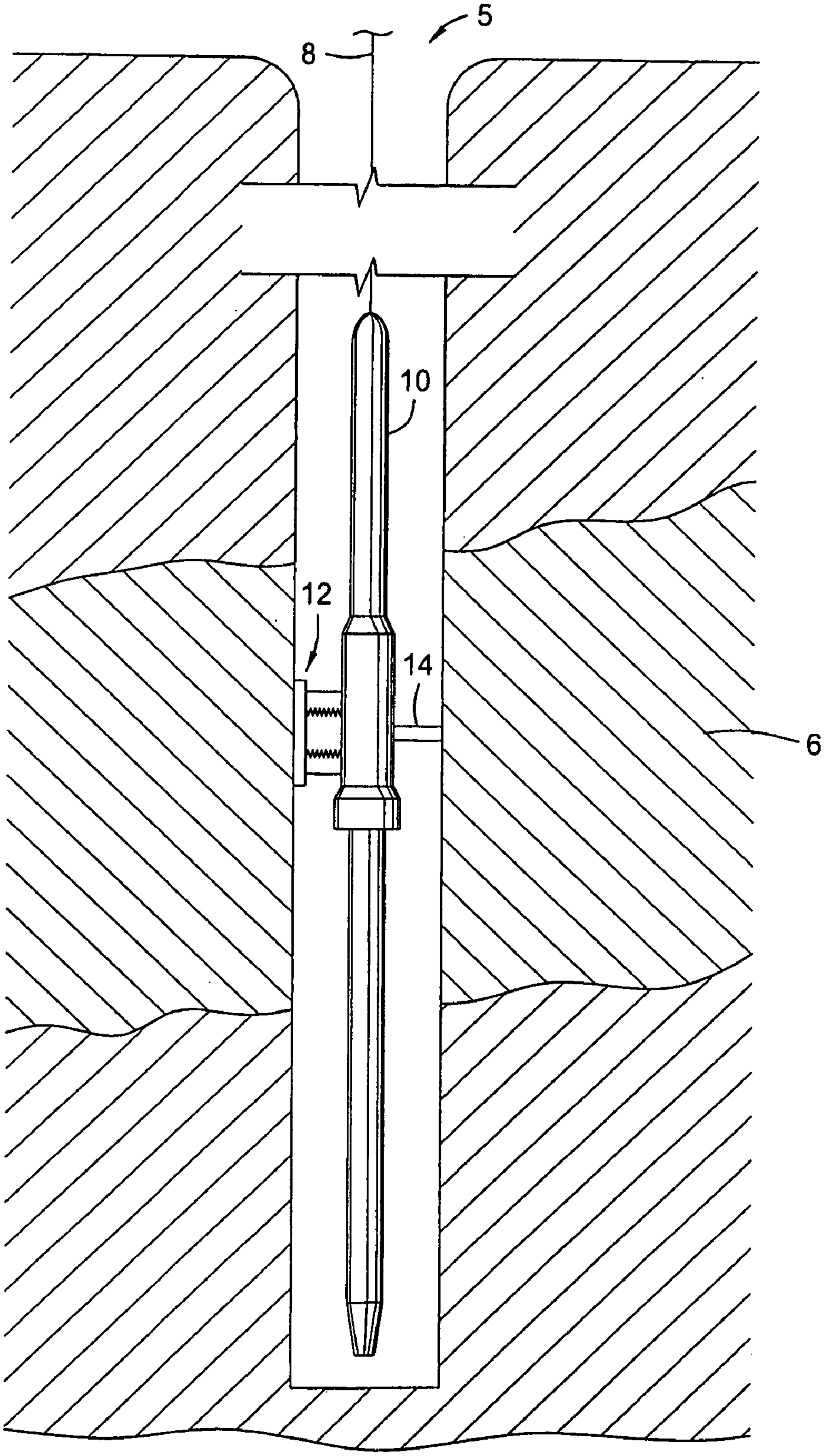


FIG. 1

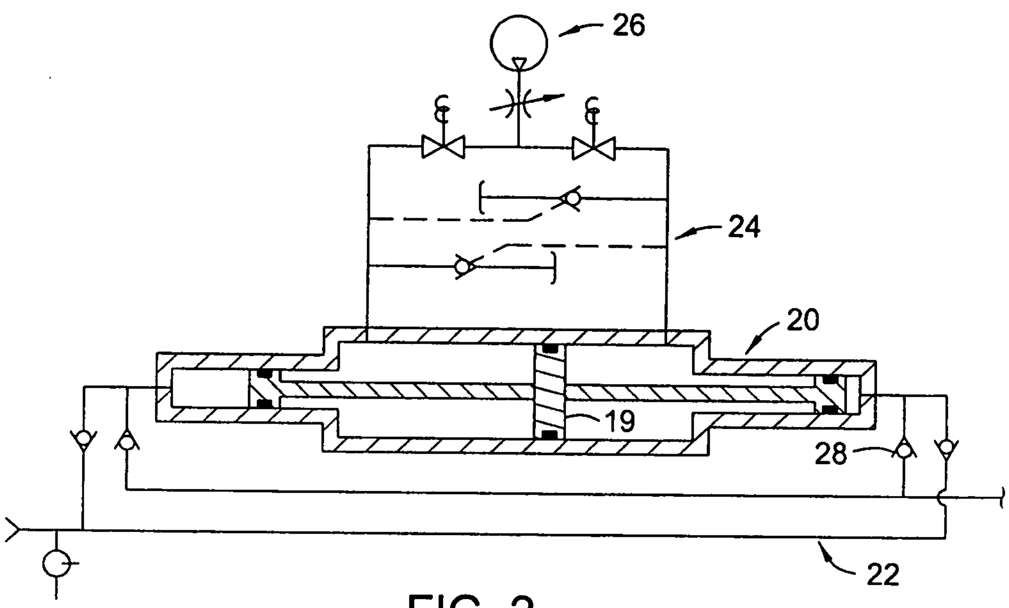


FIG. 2
(PRIOR ART)

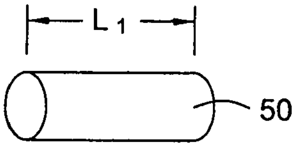


FIG. 3A

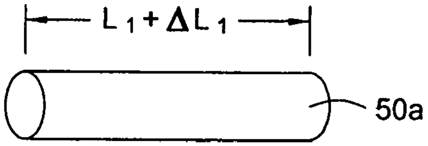


FIG. 3B

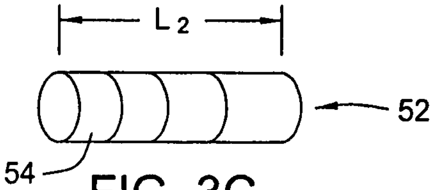


FIG. 3C

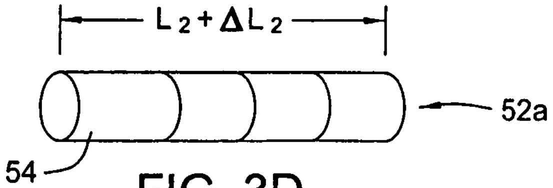


FIG. 3D

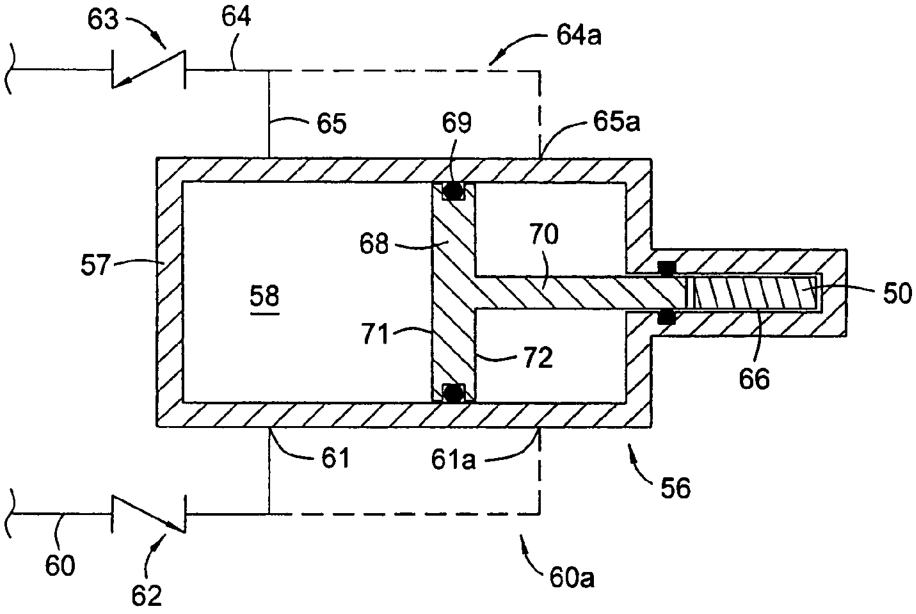
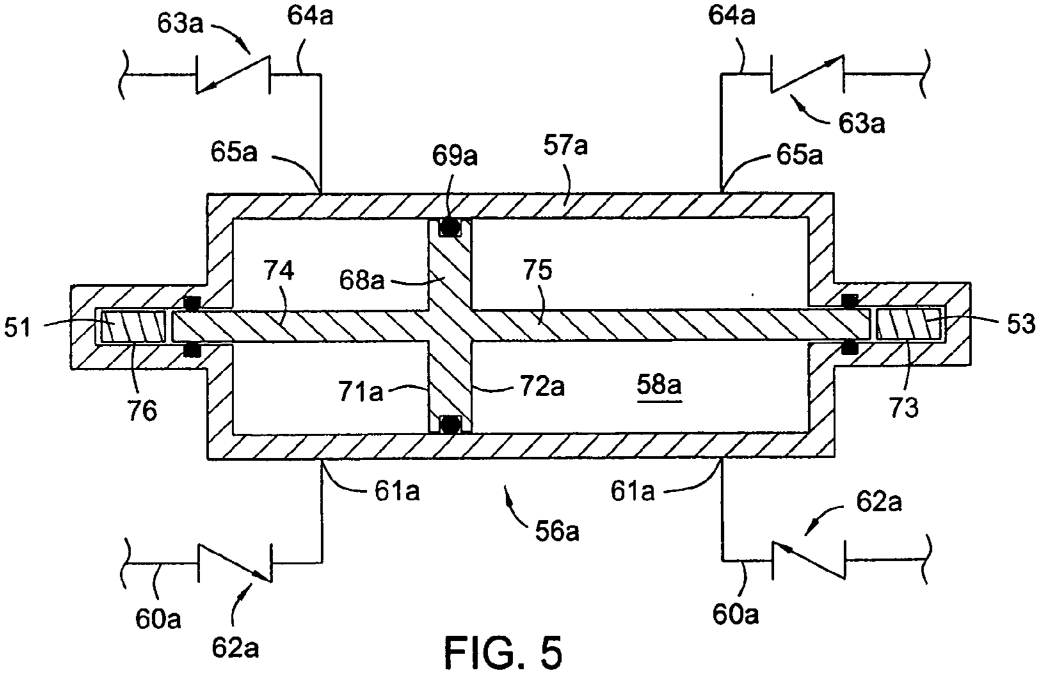

63
64
64a
65
69
65a
70
68
57
58
50
71
72
66
61
61a
56
60
62
60a

FIG. 4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51
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56a
60a
62a
60a

FIG. 5

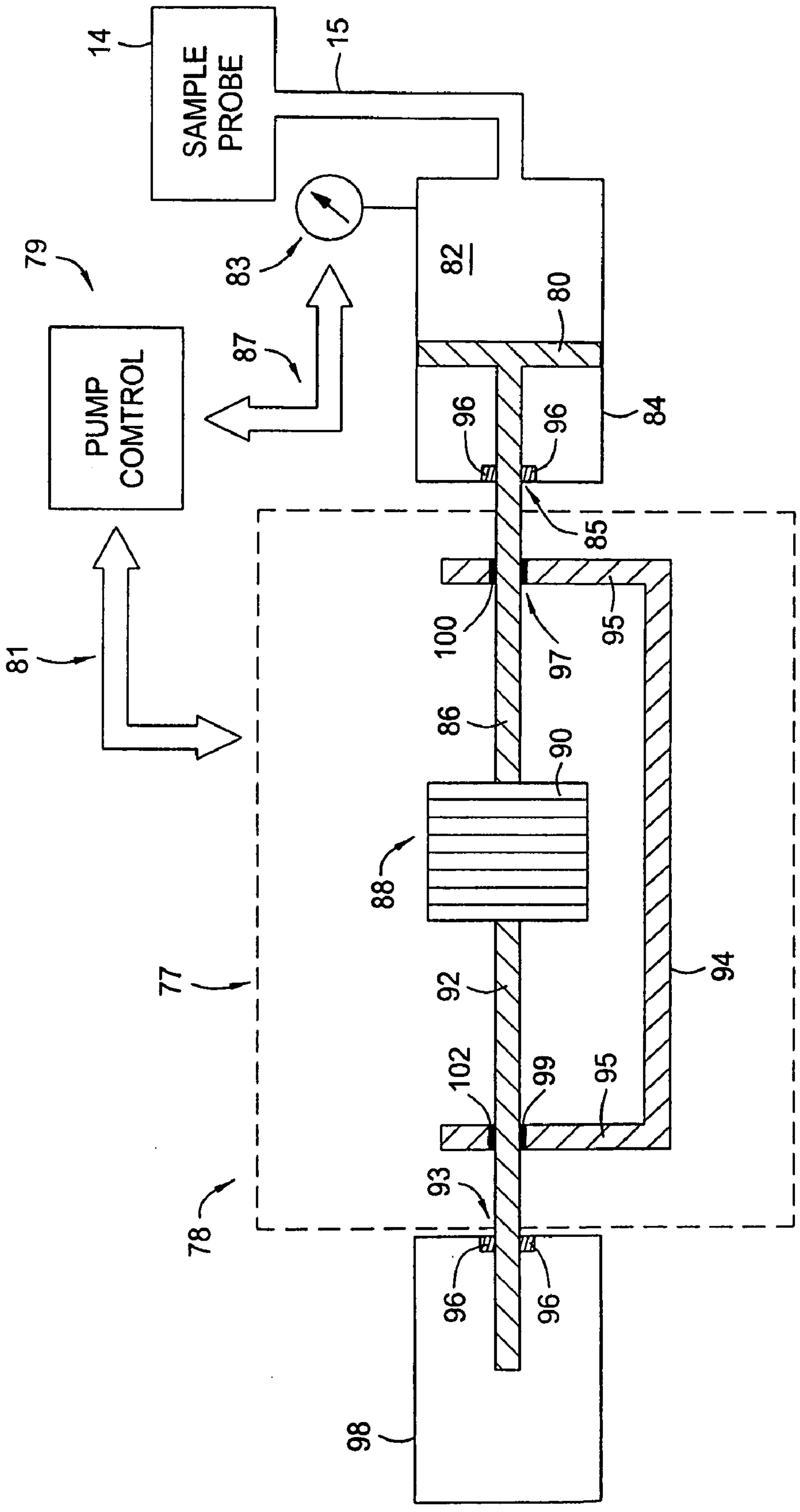
14
SAMPLE PROBE
15
79
83
82
80
87
PUMP COMTROL
84
96
96
85
81
100
97
95
86
90
88
77
92
94
102
99
95
93
78
96
96
98

FIG. 6

DOWNHOLE USES OF PIEZOELECTRIC MOTORS

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The invention relates generally to the field of hydrocarbon production. More specifically, the present invention relates to an apparatus for sampling connate fluid of a hydrocarbon bearing formation.

[0003] 2. Description of Related Art

[0004] The sampling of connate fluid contained in subterranean formations provides a method of testing formation zones of possible interest with regard to hydrocarbon bearing potential. This method involves recovering a sample of any formation fluids present for later analysis in a laboratory environment while causing a minimum of damage to the tested formations. The formation sample is essentially a point test of the possible productivity of subsurface earth formations. Additionally, a continuous record of the control and sequence of events during the test is made at the surface. From this record, valuable formation pressure and permeability data as well as data determinative of fluid compressibility, density and relative viscosity can be obtained for formation reservoir analysis.

[0005] Generally connate fluid sampling involves disposing a sonde **10** into a wellbore **5** via a wireline **8**. Oppositely located on the outer portion of the sonde **10** usually are a sample port **14** and an urging means **12**. When the sample port **14** is proximate to a formation of interest **6**, the urging means **12** is extended against the inner surface of the wellbore **5** thereby engaging the sample port **14** into the formation **6**. The engagement of the sample port **14** pierces the outer diameter of the wellbore **5** and enables fluid communication between the connate fluid in the formation **6** and the sample port **14**. As will be described in more detail below, after pushing the sample port **14** into the formation **6**, the connate fluid can be siphoned into the sonde **10** with a pumping means disposed therein.

[0006] Early formation fluid sampling instruments, such as the one described in U.S. Pat. No. 2,674,313, were not fully successful as a commercial service because they were limited to a single test on each trip into the borehole. Later instruments were suitable for multiple testing; however, the success of these testers depended to some extent on the characteristics of the particular formations to be tested. For example, where earth formations were unconsolidated, a different sampling apparatus was required than in the case of consolidated formations.

[0007] Down-hole multi-tester instruments have been developed with extendable sampling probes that engage the borehole wall and withdraw fluid samples from a formation of interest as well as measure pressure of the fluid within the formation. Traditionally these downhole instruments comprise an internal draw-down piston that is reciprocated hydraulically or electrically for drawing connate fluid from the formation to the instrument.

[0008] Generally, the down-hole multi-test sampling devices incorporate a fluid circuit for the sampling system which requires the connate fluid extracted from the formation, together with any foreign matter such as fine sand, rocks, mud-cake, etc. encountered by the sampling probe, to be drawn into a relatively small volume chamber and which is discharged into the borehole when the tool is closed. An example of such a device can be found in U.S. Pat. No. 4,416,152. Before closing, a sample can be allowed to flow into a sample tank through a separate but parallel circuit. Other methods provide for the sample to be collected through the same fluid circuit.

[0009] Another example of a circuit used in the sampling of connate fluid is shown in **FIG. 2**. Here connate fluid is motivated from the formation **6** via the sample port **14** and a sampling circuit **22** with a pump **20**. Reciprocating action of a piston **19** within the pump **20** causes pressure differentials that draw the connate fluid into the pump **20**. The actuation means for the pump **20** is, produced by a pressure source **26** and delivered to the pump **20** by a hydraulic circuit **24**. Check valves **28** strategically located within the hydraulic circuit **24** and the sampling circuit **22** direct the fluid flow within these circuits. A more detailed description of this circuit can be found in Michaels et al., U.S. Pat. No. 5,303,775.

[0010] Mud filtrate is forced into the formation during the drilling process. This filtrate must be flushed out of the formation before a true, uncontaminated sample of the connate fluid can be collected. Often this filtrate becomes lodged within the sample port **14** and hinders connate fluid flow to the sampling device. Prior art sampling devices have a first sample tank to collect filtrate and a second to collect connate fluid. The problem with this procedure is that the volume of filtrate to be removed is not known. For this reason it is desirable to pump formation fluid that is contaminated with filtrate from the formation until uncontaminated connate fluid can be identified and produced. Conventional down-hole testing instruments do not have an unlimited fluid pumping capability and therefore cannot ensure complete flushing of the filtrate; contaminant prior to sampling.

[0011] Estimates of formation permeability are routinely made from the pressure change produced with one or more draw-down piston. These analyses require that the viscosity of the fluid flowing during pumping be known. This can be achieved by injecting a fluid of known viscosity from the tool into the formation and comparing its viscosity with recovered formation fluid. The permeability determined in this manner can then be reliably compared to the formations in off-site wells to optimize recovery of fluid.

[0012] When exposed to an open hole, the fluid characteristics of formation fluid can change rapidly, thus it is important that the formation fluid be removed as quickly as possible. However, it is important that the formation flow rate be regulated in order to prevent dropping the fluid pressure below its "bubble-point" since measuring separated fluids does not result in a representative sample. After having these components come out of solution, they typically cannot be recombined which results in an unrepresentative sample having altered fluid properties.

[0013] Recently developed reservoir testing devices are capable of measuring the bubble-point pressures of the connate fluid at the time of sample collection. This can be accomplished using known techniques of light transmissibility to detect bubbles in the liquid. However this method has some drawbacks when particulate matter is present in the fluid thereby resulting in sometimes erroneous results. Other methods include trapping a known volume of formation fluid and increasing its volume gradually at a constant temperature. The measured changes in volume and pressure provide a plot of pressure vs. volume in order to ascertain the value of the bubble-point. This value is estimated within the region of the plot where the pressure and volume graph is no longer linear.

[0014] Unfortunately the pumping devices currently in use with the sampling devices have inherent drawbacks. For example, control of the electrical or hydraulic actuation means of the presently used pumping systems is not accurate that in turn results in an inability to fully control the speed of the pumps. Not being able to fully control pump speed prohibits the capability of ceasing pumping operations should the pressure of the connate fluid fall below its bubble point and also hinders the ability to accurately measure the bubble point. Since sampling connate fluid at pressures below its bubble point negatively affects the accuracy of the sampling data results. Therefore a need exists for a means of sampling connate fluid whereby the connate fluid can be obtained and analyzed at known pressures without altering the state of the sample.

BRIEF SUMMARY OF THE INVENTION

[0015] The device of the present disclosure includes a formation fluid testing drawdown pump comprising a piston, a cylinder formed to receive the piston therein, and a motive device operatively coupled to the piston. The motive device is comprised of material responsive to electrical stimuli. Alternatively the material responsive to electrical stimuli can be a piezoelectric composition or a electroactive polymer. Optionally the piezoelectric composition may be a single piezoelectric segment or at least two distinct piezoelectric segments. The motive device of the drawdown pump can optionally be a piezoelectric motor, where the piezoelectric motor is selected from the group comprising a linear piezoelectric motor and a rotary piezoelectric motor. The operative coupling of the drawdown pump may be comprised of a direct mechanical attachment between said motive device and said piston as well as a hydraulic circuit.

[0016] The formation testing drawdown pump may further comprise a feed back loop and a pump control, where the feed back loop comprises a pressure monitoring device in operative cooperation with the pump control. The pressure monitoring device provides data representative of fluid pressure within the cylinder and wherein the pump control is programmable for controlling the operation of said drawdown pump in response to the data representative of fluid pressure within the cylinder to ensure the fluid pressure within the cylinder remains above its bubble-point pressure.

[0017] A method of sampling connate fluid from within a subterranean formation is disclosed herein comprising inserting a drawdown pump within a wellbore adjacent the subterranean formation, providing a fluid communicative path between the drawdown pump and the subterranean formation, and operating the drawdown pump with a motive device. The motive device of the present method is operatively coupled to the drawdown pump and comprises material responsive to electrical stimuli. The method further comprises providing electrical energy to the motive device. The material of the present method may be comprised of a piezoelectric composition that is a single segment or at least two distinct segments. The piezoelectric composition of the present method may comprise a piezoelectric motor, where the piezoelectric motor is selected from the group comprising a linear piezoelectric motor and a rotary piezoelectric motor. Optionally, the material responsive to electrical stimuli of the present method may be comprised of an electroactive polymer.

[0018] The operative coupling of the present method may be comprised of a direct mechanical attachment between the motive device and the piston and may also include a hydraulic circuit. The method may further comprise monitoring the pressure within the cylinder. The present method may further comprise controlling operation of the drawdown pump based on the monitored pressure within the cylinder thereby ensuring the pressure within the cylinder remains above the bubble-point pressure of the sampled fluid. The drawdown pump may operate under constant pressure or under constant volumetric flow.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING.

[0019] **FIG. 1** depicts in a partial cutaway side view of a sampling sonde disposed in a wellbore.

[0020] **FIG. 2** illustrates a prior art drawdown pump.

[0021] **FIGS. 3A-3D** portray electrically responsive materials in a perspective view.

[0022] **FIG. 4** shows a cutaway view of one embodiment of a drawdown pump in accordance with the disclosure herein.

[0023] **FIG. 5** illustrates an embodiment of a drawdown pump in accordance with the disclosure herein.

[0024] **FIG. 6** depicts a partial cutaway view of an embodiment of a drawdown pump in accordance with the disclosure herein.

DETAILED DESCRIPTION OF THE INVENTION

[0025] With reference now to the drawings herein, one embodiment of a drawdown pump **56** in accordance with the present invention is illustrated in a cutaway view in **FIG. 4**. In this embodiment the drawdown pump **56** comprises a housing **57** that encompasses a cylinder **58** on one end and having a cavity **66** on its other end. The cylinder **58** should be substantially cylindrical and formed to receive a piston **68** within. The piston **68**, having a disklike configuration, should likewise have an outer diameter that is substantially circular and formed for reciprocating axial travel within the cylinder **58**. The cavity **66**, while shown as substantially cylindrical, can have other shapes and can also have a varying cross sectional area along its length. As will be described in more detail later, the cavity **66** should be formed to receive a section of electrically responsive material.

[0026] A seal **69** can be provided on the outermost circumference of the piston **68**. The seal **69** should preferably be comprised of a resilient pliable material, such as a polymer, that is capable of providing a pressure seal across the outer diameter of the piston **68**. This pressure seal should thereby isolate the pressure within the cylinder **58** on the side of the piston face **71** from the cylinder pressure along the piston rod **70**.

[**0027**] The drawdown pump **56** of **FIG. 4** further comprises a fluid inlet line **60** that terminates on one of its ends at an inlet port **61** formed in the pump housing **57**. Since the inlet port **61** traverses the through the outside of the housing **57** and into the cylinder **58**, the fluid inlet line **60** is therefore in fluid communication with the cylinder **58**. The other end of the fluid inlet line **60** is in fluid communication with a sample probe **14**. An inlet check valve **62** is included with the fluid inlet line **60**. Fluid can flow across the inlet check valve **62** only in the direction towards the inlet port **61** but is prevented from flowing across the inlet check valve **62** from the inlet check valve **62** towards the sample probe **14**.

[**0028**] This embodiment of the drawdown pump **56** further includes a fluid exit line **64** connected on one of its ends at an outlet port **65** and in fluid communication on its other end with a fluid storage tank (not shown). An outlet check valve **63** resides on the fluid exit line **64** whose orientation allows fluid flow from the drawdown pump **56** to fluid storage, but prevents flow from the fluid storage tank to the drawdown pump **56**. Like the inlet port **61**, the outlet port **65** is formed through the outer surface of the housing **57** thereby allowing fluid communication between the fluid exit line **64** and the cylinder **58**.

[**0029**] With reference now to **FIGS. 3A-3D**, examples of electrically responsive material (ERM) are shown in a perspective view. Electrically responsive material converts electrical energy into mechanical energy and can expand or contract when exposed to electrical stimuli. The electrically responsive material can include piezoelectric composites, electroactive polymers, artificial muscles and the like.

[**0030**] When a voltage is applied to the piezoelectric material, the material will experience a strain that causes it to expand. When the voltage is removed, the strain is removed and the material contracts. A non-limiting list of potential piezoelectric materials for use with embodiments of the present invention includes ceramics, quartz, polycrystalline piezoelectric ceramics, and quartz analogue crystals like berlinite (AlPO4) and gallium orthophosphate (GaPO4), ceramics with perovskite or tungsten-bronze structures (BaTiO3, KNbO3, LiNbO3, LiTaO3, BiFeO3, NaxWO3, Ba2NaNb5O5, Pb2KNb5O15).

[**0031**] Suitable electroactive polymer materials include any substantially insulating polymer or rubber (or combination thereof) that deforms in response to an electrostatic force or whose deformation results in a change in electric field. More specifically, exemplary materials include silicone elastomers, acrylic elastomers such as VHB 4910 acrylic elastomer, polyurethanes, thermoplastic elastomers, copolymers comprising PVDF, pressure-sensitive adhesives, fluoroelastomers, polymers comprising silicone and acrylic moieties, and the like. Polymers comprising silicone and acrylic moieties may include copolymers comprising silicone and acrylic moieties, polymer blends comprising a silicone elastomer and an acrylic elastomer, for example.

[**0032**] With regard to the electrically responsive material of the embodiment of **FIGS. 3A-3D** and **FIG. 4**, the electrically responsive material expands with the application of an electrical stimulus. This expansion is illustrated with reference to a comparison of **FIGS. 3A and 3B**. An example of an ERM **50** of length L_1 is shown in **FIG. 3A** in its relaxed or unresponsive state. Illustrating the expansive nature of electrically responsive material, **FIG. 3B** depicts an ERM **50***a* illustrating how the material responds to an applied electrical stimuli. In **FIG. 3B**, the ERM **50** a has expanded over that of the ERM **50** of **FIG. 3A** and its length has increased from L_1 to $L_1+\Delta L_1$; where $L_1+\Delta L_1$ is greater than L_1. The increase is a function of the dimensions of the un-stimulated material as well as the amount of current or voltage applied to the material. It is believed that it is well within the capabilities of those skilled in the art to determine appropriate dimensions and applied electrical power in order to attain the desired means and ends of the present invention.

[**0033**] Alternatively, with reference now to **FIGS. 3C and 3D**, the electrically responsive material can be a segmented ERM **52** comprised of at least two segments **54** sequentially stacked in an axial configuration. **FIG. 3C** depicts in perspective view a segmented ERM **52** in a relaxed state, upon application of applied electrical energy to the segmented ERM **52** it expands to an expanded ERM **52***a* (**FIG. 3D**) from a length L_2 to a length $L_2+\Delta L_2$, where $L_2+\Delta L_2$ is greater than L_2. An advantage of greater control and flexibility of ERM expansion can be realized by the segmented embodiment. Here a single segment **54** can be expanded by selectively applying electrical energy, or the collective segments **54** can be sequentially expanded to affect a manner of the expansive stroke applied by expansion of the segmented ERM **52**. It should be pointed out that while linear expansion is illustrated in **FIGS. 3A-3D**, the ERMs (**50**, **52**) can expand in a radial fashion as well.

[**0034**] In operation, connate fluid resident within the formation of interest **6** enters the sample probe **14**, travels through the fluid inlet line **60** and into inlet port **61**, thereby filling the cylinder **58**. Generally when the cylinder **58** is being filled with connate fluid the piston **68** is in the downstroke mode and moving towards the cavity **66**. This movement of the piston **68** can be produced by the pressure differential across the piston **68** caused by the presence of the fluid, or by a spring (not shown) disposed within the cylinder **58** driving the piston backwards.

[**0035**] When a desired amount of fluid fills the cylinder **58**, an electrical stimulus is applied to the ERM **50** disposed within the cavity **66**. It should be pointed out that the segmented ERM **52** can be used in lieu of the ERM **50**, or these varying embodiments can be used concurrently. As previously discussed, the electrical stimulus causes the ERM **50** to expand; this expansion in turn pushes against the piston rod **70** and urges it out of the cavity **66**. As the piston rod **70** is moved out of the cavity **66** (the upstroke mode) the piston **68** travels across the cylinder **58** thereby imparting a motivating force onto the fluid within the cylinder **58**. This motivating force pressurizes the fluid thereby causing it to move from the cylinder **58** through the outlet port **65** onto the fluid storage tank via the fluid exit line **64**. As is well known, the strategic positioning and orientation of the inlet and outlet check valves (**62**, **63**) allows fluid flow into the cylinder **58** from the formation **6** during the downstroke mode and from the cylinder **58** to fluid storage during the upstroke mode.

[**0036**] Optionally, as shown in dashed lines in **FIG. 4**, the connate fluid inlet line **60***a* connects to the housing **57** at the inlet port **61**a. Here the inlet port **61***a* pierces the connate pump **56** in an area of the housing **57** proximate to the ERM cavity **66**. In this configuration urging the piston **68** into the cylinder **58** by expansion of the ERM **50** reduces the pressure on the backside of the piston **68** thus drawing fluid in from the formation **6**. Furthermore, like the inlet port **61***a*, the outlet port **65***a* of this alternative embodiment is similarly positioned proximate to the ERM cavity **66**. Thus the fluid drawn into the cylinder **58** during expansion of the ERM **50** is urged out of the cylinder **58** on the downstroke of the piston **68**.

[0037] The embodiment of the drawdown pump **56**a shown in **FIG. 5** comprises an elongated housing **57***a* having a substantially cylindrical cylinder **58***a* formed to receive a piston **68***a* axially therein. Like the piston **68** of the embodiment of **FIG. 4**, the piston **69***a* has a disk-like configuration suitable for axial travel within the cylinder **58***a*. However the associated piston rods (**74**, **75**) of this embodiment extend respectively from both the first and the second piston face (**71***a*, **72***a*). The piston rods (**74**, **75**) extend into corresponding forward and rearward cavities (**76**, **73**) disposed at the opposite ends of the cylinder **58***a*. Further, in this embodiment, fluid inlet lines **60***a* connect to the cylinder **58***a* via inlet ports **61***a* on both sides of the piston **68***a*. Similarly, fluid outlet lines connect to the cylinder **58***a* via outlet ports **65***a* that are also situated on both sides of the piston **68***a*. The inlet lines **60***a* are in fluid communication on their other end with the sample probe thereby enabling connate fluid to flow into the cylinder **58***a* through these lines. As in the case of the embodiment of **FIG. 5**, in this embodiment the other end of the fluid exit lines **64***a* connects to a fluid sample tank. Inlet check valves **62***a* are included within the inlet line **60***a* that limit fluid flow direction only to the cylinder **58***a*. Outlet check valves **63***a* are also provided with the exit lines **64***a* that allow fluid flow from the cylinder to the fluid sample tank but prevents flow reverse directional flow. A quantity of ERM **50** is included within each cavity (**76**, **73**).

[0038] In the operation of the embodiment of **FIG. 5** axial movement of the piston **68***a* is effectuated by stimulating one of either ERM **51** within the forward cavity **76**, or ERM **53** within the rearward cavity **73**. As noted above, stimulation of any electrically responsive material can cause it to expand. In the case of the drawdown pump **56***a*, expansion of either ERM **51** or ERM **53** urges the piston **68***a* along the axis of the cylinder **58***a*. Movement of the piston **68***a* in either direction increases the fluid pressure within the cylinder **58***a* in the portion that the piston **68***a* is moving towards, thus urging any fluid within that portion to the fluid storage tank via the corresponding fluid exit line **64***a*. Moreover, in the other portion of the cylinder **58***a*, the fluid pressure is decreasing, thus drawing the connate fluid out of the formation **6**, into the sample port **14**, and into that portion of the cylinder **58***a*. When the piston **68***a* reaches the end of its stroke, the electrical power stimulating the expanded ERM (**51** or **53**) is terminated and electrical power is then applied to the other ERM (**51** or **53**) to repeat the process of simultaneously urging fluid from one portion of the cylinder **58***a* and drawing fluid into the other portion. Accordingly, the electrical stimulus should not be applied to both ERM **51** and ERM **53** simultaneously, but instead should be applied in discrete sequences. Use of the present invention thereby enables samples of connate fluid to be drawn, at pressure, from a formation of interest **6** and stored within a storage tank for later analysis. Sustaining the connate fluid at pressure maintains the sample above its bubble point thereby preserving all the constituents within the sample.

[0039] The embodiment of the drawdown pump **78** of **FIG. 6** comprises a piston **80**, a cylinder **82**, a piston rod **86**, an ERM segment **88**, an anchor rod **92**, a base **94**, an expansion stroke pinch brake **100**, a compression stroke pinch brake **102**, and an optional dashpot **98**. The base **94** further includes legs **95** that extend perpendicularly away from the main body of the base **94**. The legs **95** contain a first aperture **97** and a second aperture **99** in which the pinch brakes (**100**, **102**) are respectively disposed. The cylinder **82** is elongated and is formed within a generally cylindrical cylinder housing **84**. The inner diameter of the cylinder **82** is formed to axially receive the piston **80** therein and allow for axial reciprocation of the piston **80**. The piston **80** has a disklike configuration with a circular outer diameter that should match the dimensions and configuration of the inner diameter of the cylinder **80**. Preferably the respective dimensions of the outer circumference of the piston **80** and the inner diameter of the cylinder **82** are sufficiently close to create a pressure seal along the outer diameter of the piston **80**. Seals (not shown) may be disposed on the outer diameter of the piston **80** for providing the pressure seal.

[0040] The piston rod **86** is attached to the rearward side of piston **80** and extends outside of the cylinder housing **84** through an opening **85** formed on the rear face of the housing **84**. The piston rod **86** is connected to the forward side of the ERM **88** on its other end. An annular seal **96** can be included around the piston rod **86** within the cylinder **82** and adjacent the opening **85** for preventing fluid flow through the opening **85**.

[0041] Between the cylinder housing **84** and the ERM **88**, the piston rod **86** passes through the expansion stroke pinch brake **100**. The expansion stroke pinch brake **100** fits within a first aperture **97** formed through one of the legs **95**. The inner diameter of the first aperture **97** is greater than the outer diameter of the piston rod **86** thus providing a space for the pinch brake **100** to reside therein. As shown, the pinch brake **100** is a single annularly shaped element circumscribing a portion of the length of the piston rod **86**; but the pinch brake **100** can also be comprised of one or more elements radially disposed within the space between the piston rod **86** and the diameter of the first aperture **97**.

[0042] Selective activation of the pinch brake **100** impinges the brake **100** upon the piston rod **86** with sufficient force to effectively bind the piston rod **86** to the leg **95** thereby preventing movement of the piston rod **86** with respect to the leg **95**. Examples of suitable material for the brake include an inflatable packer, extending members, and electrically responsive materials, such as piezoelectric material and electroactive polymers.

[0043] The anchor rod **92** is connected to the rearward side of the ERM **88** on one end and passes through the compression stroke pinch brake **102** before terminating within the optional dashpot **98**. Optionally, the other end of the anchor rod **92** is inserted into the dashpot **98** via an opening **93** formed through the wall of the dashpot **98**. The dashpot **98** should contain a compressible fluid, such as for example but not limited to silicone oil, brine, or formation fluid. Seals **96** are provided adjacent the opening **93** for retaining the fluid within the dashpot **98**.

[0044] The ERM segment **88** is preferably comprised of an electrically responsive material such as a piezoelectric composite, an electroactive polymer, or any other substance responsive to external electrical stimuli. The ERM segment **88** of the embodiment of **FIG. 6** is shown as a series of stacked elements **90**, where each element has substantially the same dimensions. However, the ERM segment **88** can alternatively be comprised of a single non-segmented portion of electrically responsive material. Further, the stacked elements **90** can also be of varying dimensions. Additionally, the specific material of the individual elements **90** can vary, for example, one or more of the elements **90** might be comprised of a piezoelectric material while the remaining elements **90** may be comprised of an electroactive polymer.

[**0045**] In operation, the embodiment of the drawdown pump **78** of **FIG. 6** operates in a similar fashion to the above described drawdown pumps (**56**, **56***a*), that is the drawdown pump **78** is in fluid communication with the sample probe **14** via a conduit **15**. Connate fluid is drawn into the cylinder **82** by the pressure differential that exists between the cylinder **82** and the formation **6**. The differential pressure can be created by lowering the pressure within the cylinder by urging the piston **80** axially rearward through the cylinder housing **84**. Movement of the piston **80** is accomplished by selectively activating the ERM segment **88** in combination with both the expansion stroke pinch brake **100** and the compression stroke pinch brake **102**. For example, stimulating the ERM segment **88** while simultaneously releasing the compression stroke pinch brake **102** allows the ERM segment **88** to expand in response to the applied external electrical stimulus. Expansion of the ERM segment **88** thereby slides the anchor rod **92** through the compression stroke pinch brake **102** in a direction away from the ERM segment **88**. Upon completion of the expansion stroke of the ERM segment **88** the compression stroke pinch brake **102** is activated thereby clamping the anchor rod **92** therein. Then the external stimulus is removed from the ERM segment **88** while the expansion stroke pinch brake **100** is in the release mode. Removing the electrical stimulus from the ERM segment **88** allows the ERM segment **88** to contract in size to its normal or relaxed state. Contraction of the ERM **88** in combination with the release of the expansion stroke pinch brake **100** pulls the piston rod **86** in the direction of the ERM segment **88** thereby urging the piston **80** through the cylinder **82** in a rearward direction.

[**0046**] The piston stroke length realized during each sequence of release/activation steps is dependent upon the amount and type of the electrically responsive material of the ERM segment **88** as well as the amount and type of external stimulus applied. Consecutively repeating the above described release/activation and stimulus steps produces an "inch-worm" effect on the piston travel enabling the drawdown pump **78** to draw in a suitable amount of connate fluid within the cylinder **82** for subsequent analysis. Typical fluid sampling volumes can range from about 30 cc to in excess of 900 cc, and often in the range of about 56 cc. However the actual amount of fluid sampled is dependent on the particular formation from which the fluid is being drawn, thus the volume of the cylinder **82** should be able to accommodate the amount of fluid to be sampled.

[**0047**] Due to the highly responsive qualities of electrically responsive materials, the speed and stroke of the piston **80** can be tightly controlled to ensure that the pressure within the cylinder **82** remains above the bubble point pressure of the connate fluid. Accordingly one of the many advantages realized by the drawdown pump of the present disclosure is that the measured discrete movements of the piston **80** does not produce the large dynamic forces caused by the acceleration/deceleration of typical currently used drawdown pump motors. Furthermore, due to the highly responsive nature of electrically responsive material, the speed of operational cycles of drawdown pumps of the present disclosure is well within acceptable limits of operational usage.

[**0048**] The pressure within the cylinder **82** may be monitored with the attached pressure monitoring device **83**. Implementation of the pressure monitoring device **83** also provides the ability to control the actuation of the drawdown pump **78** to ensure the pressure within the cylinder **82** remains above the bubble point of the sampled fluid therein. The drawdown sequence can occur under constant pressure or under constant volumetric flow rate. The pressure measured by the pressure monitoring device **83** is conveyed via a feed back loop **87** to the pump control **79**. The pressure monitoring device **83** can be a pressure gauge, and can detect the pressure in any currently known or later developed means of pressure monitoring. For example, the pressure monitoring device **83** can monitor pressure pneumatically or with transducers that convert mechanical energy to electrical, such as a quartz element or piezoelectric component. The measured pressure can be measured and obtained in digital or analog form.

[**0049**] The pump control **79**, as is known in the art, may be comprised of a programmable circuit, such as a computer or microprocessor, having been programmed to analyze the value of the measured pressure within the cylinder **82** and compare it to the connate fluid bubble point pressure. Should these two pressures both reside within a predetermined pressure range, the pressure control **79** may be programmed to adjust the operation of the drawdown pump **78** to ensure the pressure of the fluid in the cylinder **82** remains above its bubble point pressure. The data commands are preferably in digital form and are transferred to the operational components **77** of the drawdown pump **78** via the control loop **81**. The operation components **77** include the items enclosed by the dashed line of **FIG. 6**, as well as the components used to supply and control the electrical signal(s) applied to the items within the dashed line. Those skilled in the art are capable of establishing a proper pressure range above that which the cylinder pressure should remain. It is also within the capabilities of those skilled in the art to program a control system for comparing measured pressures with bubble point pressures and affecting pump controls when these pressures fall within the specified range.

[**0050**] Furthermore, an additional advantage realized by the responsive material of the ERM segment **88** is that the discrete inch-worm movements of the drawdown pump **78** simulate a continuous or analog movement of the piston **80** that minimizes or eliminates the dynamic pumping effects experienced by current drawdown pumps. When it is desired to empty the cylinder **82** of fluid, the release/activation sequence may be reversed to urge the piston **80** into the cylinder **82** and thus force the fluid through a cylinder outlet (not shown) for storage and/or fluid analysis.

[**0051**] Inclusion of the optional dashpot **98** with its compressible fluid therein provides a resistive force to the movement of the anchor rod **92** for pressure compensation with regard to the piston **80**. The resistive force produced within the compressible fluid can be useful in situations when the applied force of the pinch brakes (**100**, **102**) is limited and may not possess sufficient clamping force to support the piston rod **86** against the fluid force imparted onto the piston **80**. Yet further optionally, the free end of the anchor rod **92** may include a piston (not shown) for increasing the resistive force provided by the dashpot **98**. Additionally, the resistive force is stored within the compressive fluid and can be transferred into a translational force for pushing the piston **80** back into the cylinder **82** after the fluid sampling stroke is completed. Alternatives to the fluid can include a spring or other elastic device or material in which kinetic energy can be converted to potential energy and temporarily stored therein.

[**0052**] The present invention described herein, therefore, is well adapted to carry out the objects and attain the ends and advantages mentioned, as well as others inherent therein. While a presently preferred embodiment of the invention has been given for purposes of disclosure, numerous changes exist in the details of procedures for accomplishing the desired results. For example, the electrically responsive material can be used for pressurizing hydraulics, where the produced hydraulic pressure is utilized to operate a drawdown pump as disclosed herein. Moreover, the embodiments of the pumping devices disclosed herein can be utilized for measuring fluid physical properties such for example fluid density and fluid viscosity. Poiseuille's Law may be implemented with regard to measuring fluid viscosity, fluid viscosity can be determined by flowing a known amount of fluid through a length of tube and measuring the pressure drop along the tube. Other ways of determining viscosity include rotating a cylinder within the fluid and measuring a corresponding torque produced within the fluid. Rotation of the cylinder can be effectuated by adding a rotary piezo-electric motor. These and other similar modifications will readily suggest themselves to those skilled in the art, and are intended to be encompassed within the spirit of the present invention disclosed herein and the scope of the appended claims.

What is claimed is:

1. A formation fluid testing drawdown pump comprising:

a piston;

a cylinder formed to receive said piston therein; and

a motive device operatively coupled to said piston, wherein said motive device is comprised of material responsive to electrical stimuli.

2. The formation testing drawdown pump of claim 1, wherein said material is comprised of a piezoelectric composition.

3. The formation testing drawdown pump of claim 2, further comprising a piezoelectric motor.

4. The formation testing drawdown pump of claim 3, wherein said piezoelectric motor is selected from the group comprising a linear piezoelectric motor and a rotary piezoelectric motor.

5. The formation testing drawdown pump of claim 1, wherein said material is comprised of an electroactive polymer.

6. The formation testing drawdown pump of claim 1, wherein said operative coupling is comprised of a direct mechanical attachment between said motive device and said piston.

7. The formation testing drawdown pump of claim 1 wherein said operative coupling is comprised of a hydraulic circuit.

8. The formation testing drawdown pump of claim 3, wherein said piezoelectric composition comprises at least two distinct piezoelectric segments.

9. The formation testing drawdown pump of claim 1 further comprising a feed back loop and a pump control, said feed back loop comprising a pressure monitoring device in operative cooperation with the pump control.

10. The formation testing drawdown pump of claim 9 wherein said pressure monitoring device provides data representative of fluid pressure within the cylinder and wherein the pump control is programmable for controlling the operation of said drawdown pump in response to the data representative of fluid pressure within the cylinder to ensure the fluid pressure within the cylinder remains above its bubble-point pressure.

11. A method of sampling connate fluid from within a subterranean formation comprising:

inserting a drawdown pump within a wellbore adjacent the subterranean formation;

providing a fluid communicative path between said drawdown pump and the subterranean formation; and

operating said drawdown pump with a motive device, wherein said motive device is operatively coupled to said drawdown pump and comprises material responsive to electrical stimuli.

12. The method of claim 11 further comprising providing electrical energy to said motive device.

13. The method of claim 11, wherein said material is comprised of a piezoelectric composition.

14. The method of claim 13, wherein said piezoelectric composition comprises a piezoelectric motor.

15. The method of claim 14, wherein said piezoelectric motor is selected from the group comprising a linear piezoelectric motor and a rotary piezoelectric motor.

16. The method of claim 11, wherein said material is comprised of an electroactive polymer.

17. The method of claim 11, wherein said operative coupling is comprised of a direct mechanical attachment between said motive device and said piston.

18. The method of claim 11 wherein said operative coupling is comprised of a hydraulic circuit.

19. The method of claim 13, wherein said piezoelectric composition comprises at least two distinct piezoelectric segments.

20. The method of claim 13 further comprising monitoring the pressure within the cylinder.

21. The method of claim 20 further comprising controlling operation of the drawdown pump based on the monitored pressure within the cylinder thereby ensuring the pressure within the cylinder remains above the bubble-point pressure of the sampled fluid.

22. The method of claim 11, wherein the operating mode of said drawdown pump is selected from the group consisting of operating at a constant pressure and operating at a constant volumetric flow rate.

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