

METHOD AND APPARATUS FOR USE OF ELECTRONIC PRESSURE GAUGE IN EXTREME HIGH TEMPERATURE ENVIRONMENT

CROSS-REFERENCE TO RELATED APPLICATIONS

None.

FIELD OF INVENTION

[0001] The invention relates, in general, to a method and apparatus for measuring pressure or installing a pressure gauge in a wellbore, and more particularly to use of an electric pressure gauge in extreme high temperatures.

BACKGROUND OF INVENTION

[0002] Pressure and temperature are the most widely measured physical parameters in a wellbore environment. Temperature sensors for high-temperature applications are readily available, but the availability of pressure sensors capable of reliable and prolonged use at high and extremely-high temperatures lags. With the advent of deeper hydrocarbon wells, ever harsher environments are encountered downhole. Conventional high-temperature pressure sensors are often limited in operation, as the overall pressure sensing system, which includes associated electronics, is limited to relatively low operating temperatures. Conventional electronic units used with pressure sensors are typically limited to operating temperatures below around 175 degrees C. (about 350 degrees F). Various attempts have been made to provide such an apparatus, however, there remains a need for an apparatus and method for measuring downhole pressure in a high or extremely-high temperature environment. It is desirable to provide a pressure sensing system suitable for use at high operating temperatures, greater than 450 degrees.

SUMMARY OF THE INVENTION

[0003] Methods and apparatus are presented for measuring pressure at a downhole location in a subterranean wellbore at high-temperatures. The invention provides for use of electronic pressure sensors to measure pressure at locations where the environmental temperature would typically damage the pressure sensor. In an exemplary method, a pressure gauge assembly having a pressure sensor and associated electronics for operating the pressure sensor is inserted into the wellbore at a location where pressure is to be sensed. The pressure sensor is exposed to the downhole wellbore pressure. The pressure gauge assembly is exposed to a potentially damaging, high, downhole temperature. A pressurized fluid, preferably a refrigerant, is flowed into a chamber proximate the pressure sensor and cools the pressure gauge assembly sufficiently to preclude damage from exposure to the downhole temperature. Preferably, the pressurized fluid is expanded, typically from a liquid to a gaseous phase, proximate or in the chamber, for example, by flowing the refrigerant through an orifice or evaporator, prior to flowing the refrigerant fluid into the chamber. To further protect the pressure sensor, the sensor can be exposed to the downhole pressure via a pressure communication passageway, preferably having a fluid isolation device, such as a membrane or diaphragm. The used refrigerant is returned uphole by a tubing and preferably condensed and circulated back downhole. The internal temperature of the pressure gauge assembly can be measured to insure that sufficient cooling occurs and to allow alteration of the cooling system parameters to increase or decrease cooling.

[0004] Another method for measuring pressure at a downhole location in a subterranean wellbore at high-temperatures is presented. An electronic pressure gauge assembly is positioned at an uphole location along the wellbore, where the environmental temperature is not expected to exceed the operating temperature of the pressure gauge. A pressure chamber is positioned downhole, at a location where the pressure is to be sensed and where environmental temperatures exceed the operating temperature of the pressure gauge assembly. The pressure chamber is exposed to a downhole pressure which is communicated to the uphole pressure gauge assembly, preferably by a pressure conduit filled with a pressurized fluid. The fluid is preferably an inert gas, but can be other fluids as well. The system can be isolated from pressure during run-in and actuated by removal of a temporary pressure isolation device such as a frangible disk, rupture disk, or eutectic plug. The temporary device can be actuated by thermal expansion of the pressurized fluid or by wellbore pressure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] For a more complete understanding of the features and advantages of the present invention, reference is now made to the detailed description of the invention along with the accompanying figures in which corresponding numerals in the different figures refer to corresponding parts and in which:

[0006] Figure 1 is an elevational schematic view of a wellbore extending through a subterranean formation and a high-temperature pressure gauge assembly according to an aspect of the invention;

[0007] Figure 2 is a schematic view of an exemplary high-temperature pressure gauge system according to an aspect of the invention;

[0008] Figure 3 is a schematic view of a preferred embodiment of a high-temperature pressure gauge system for use at downhole locations which have temperatures exceeding the design limits of electrical pressure sensors and their associated electronics; and

[0009] Figure 4 is a schematic detail view of an exemplary downhole pressure chamber assembly according to an aspect of the invention as seen in Figure 3.

[0010] It should be understood by those skilled in the art that the use of directional terms such as above, below, upper, lower, upward, downward and the like are used in relation to the illustrative embodiments as they are depicted in the figures, the upward direction being toward the top of the corresponding figure and the downward direction being toward the bottom of the corresponding figure. Where this is not the case and a term is being used to indicate a required orientation, the Specification will state or make such clear.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0011] While the making and using of various embodiments of the present invention are discussed in detail below, a practitioner of the art will appreciate that the present invention provides applicable inventive concepts which can be embodied in a variety of specific contexts. The specific embodiments discussed herein are illustrative of specific ways to make and use the invention and do not limit the scope of the present invention. The description is provided with reference to a vertical wellbore; however, the inventions disclosed herein can be used in horizontal, vertical or deviated wellbores.

[0012] As described above, the invention is drawn to an apparatus and method for measuring pressure at a downhole location under extreme temperature conditions using an electrical pressure gauge. The system is designed to allow operation of the pressure gauge at locations having high temperatures that would otherwise damage or destroy the gauge. That is, the system allows for effective operation of the pressure gauge, over extended periods of time, at temperatures above the maximum operating temperature of the pressure sensor or gauge. “Maximum operating temperature” refers to the design standard or temperature rating of the sensor, set by the manufacturer.

[0013] At Figure 1 is shown an elevational schematic view of an exemplary wellbore 10 extending through a subterranean formation 12 having at least one hydrocarbon-bearing zone 14. The wellbore is shown as having casing 15, although the invention herein can be used in uncased bores. The wellbore is shown as vertical, although it can also be used in deviated and horizontal bores. The wellbore is shown as extending from the surface, however, the invention can be used in subsea applications as well. A tubing string 16 is shown run-in to the wellbore and having a high-temperature pressure sensing system 20 according to an embodiment of the invention.

[0014] Figure 2 is a schematic view of an exemplary high-temperature pressure gauge system according to an aspect of the invention. Like numbers are used for like parts throughout.

[0015] With reference to Figures 1 and 2, the system includes a refrigerant flow loop 22 wherein a fluid control assembly 50 is provided, including a pressure supply 24, such as a pump. The pressure supply sends a refrigerant R downhole through a fluid outlet 29 and into a first tube 30. The refrigerant is preferably a high-pressure refrigerant and the system is operated at adequate pressure for the refrigerant. Acceptable refrigerants for use in the system include R-113 or R-611, which are commercially available from Refrigerant Supply, Inc., for example. Additional refrigerants are acceptable as well and are known to those of skill in the art.

[0016] In a preferred embodiment, the refrigerant undergoes liquid to gas phase change to cool the downhole components. However, a suitable compressed gas can be used as a refrigerant, wherein the compressed gas does not undergo a phase change. In fact, even compressed air would provide cooling, just not as efficiently as a phase-change refrigerant.

[0017] The first tube 30 conveys the refrigerant under pressure from the uphole portion 78 to a downhole portion 80 of the system. Preferably, the first tube is of a relatively small inner diameter. The system is designed to minimize pressure drop flow losses without using larger

diameter, more expensive tubing. In the art, such small ID tubing is often referred to as “capillary” tubing although the system does not rely on significant capillary action. The refrigerant is forced through an orifice 32 once downhole. Fluid then passes from the orifice to an evaporator tube 34 positioned in a pressure sensor housing 36. A pressure drop is induced across the orifice and evaporator tube. In a preferred embodiment, the refrigerant is in a liquid state while in the first, small-diameter tube 30, and upon passing through the orifice 32 and evaporator tube 34, expands to a vaporous state. The refrigerant operates to remove heat from the pressure sensor 38 and surrounding housing.

[0018] The refrigerant R is then moved up a second tube 40 towards the surface, as indicated by an arrow, and back to the fluid control assembly 50, through inlet 37. The control assembly preferably includes a condenser 52. The condenser returns the refrigerant fluid to a liquid state. The fluid control assembly 50 includes other parts, such as tubing, valves, motors, etc., as are known in the art for fluid control loops, and will not be discussed herein in detail. The control assembly further includes appropriate electronics and processors 51 for monitoring and operating the control assembly and its constituent parts.

[0019] The first and second tubes are run from the surface to the pressure gauge by methods known in the art. For example, the tubes can be positioned internal or external to the tubing string (or other work or production string). Further, the first and second tubes can be positioned in an interior space of a protective conduit 33. The electrical cables 70, discussed below, can also be positioned within the protective conduit 33 or may be separately housed.

[0020] At the downhole location, the pressure housing 36, in a preferred embodiment, further includes a pressure sensor 38 with a maximum operating temperature below that of the wellbore environmental temperature at the downhole location. The pressure gauge 35 also includes an electronics package 60 for operating the pressure sensor and other electrical equipment in the housing. The electronics packages associated with pressure and temperature sensors and gauges are well known in the art and will not be discussed here in detail and typically include wiring, components, filters, amplifiers, rectifiers, etc., and can also include memory storage, interrogation electronics, electronic circuits, and sometimes microprocessor, etc. As used herein, the term “electronic pressure gauge,” and similar, means a pressure sensor and the associated electronics to operate the sensor. Electronic pressure sensors include, but are

not limited to, piezoelectric, piezoresistive, magnetic, potentiometric, resistance-based, semiconductor, etc., sensors.

[0021] The pressure sensor 38 is preferably positioned entirely within the housing 36, as shown. Alternately, portions of the pressure sensor can be exposed into the wellbore environment, such as a pressure face (for example, a diaphragm). Preferably the pressure sensor 38 is positioned within the housing 36. In such a case, a pressure communication passageway 62 is used to convey wellbore pressure to the sensor. The pressure communication passageway can further employ a bladder, diaphragm, membrane, fluid filled spaces, or other known fluid isolation devices 64 which convey pressure without direct contact of the wellbore fluids with the sensor.

[0022] In a preferred embodiment, an internal temperature sensor 66 is positioned within the housing to measure the temperature therein. By measuring the internal temperature of the housing, and therefore of the pressure sensor and electronics package, the system can be controlled to maintain a selected operational temperature or a temperature below the maximum operational temperature of the pressure gauge. For example, where the internal temperature rises above a selected amount, the fluid loop system can be controlled, manually or automatically, to increase refrigerant flow to reduce the temperature. Similar temperature sensors can be used elsewhere, such as along the first and second tubes, at locations in the control assembly, etc., to monitor the fluid temperature.

[0023] Further, an optional external temperature sensor 68, or wellbore temperature sensor, can extend into the wellbore environment, as shown, or be located in the wellbore environment at another location and connected electrically to the housing 36 and electronics package 60 therein. The pressure sensor, temperature sensors, etc., are operably connected to the electronics package as is known in the art.

[0024] The electronics package communicates sensor signals and data to the surface via electrical cables 70 which extend from the surface to the housing, typically in a protective conduit. It is possible to use the cooling methods of the invention with a battery-powered sensor, however, since the first and second tubes are required to run downhole, it is a simple matter to also run cables. The cables 70 transmit the signals and data to a monitoring station 72 which can include processors, electronic components, etc., as is known in the art. The monitoring station 72 is preferably connected for communication with the control system 50 as well.

[0025] The electronics and internal temperature sensors make it possible to dynamically operate the cooling system to maintain a steady ambient temperature in the housing. As the internal temperature rises above a selected temperature, the system is operated to provide additional cooling, for example.

[0026] In a preferred embodiment, the housing 36 constitutes an insulating flask 74. The flask 74 is designed for reducing heat inflow from the wellbore environment and further protects the pressure sensor and reduces the work required by the cooling system. The flask can constitute multiple reflective and insulating layers, as is known in the art.

[0027] Further, a eutectic alloy can be deployed proximate to the electronics package or within a space in the housing (particularly if in a flask). The melting temperature of the eutectic is selected to be between the targeted cooled electronics temperature and the maximum electronic operating temperature. Therefore, if the cooling system was temporarily shut down, the melting of the eutectic material would provide cooling while waiting for the cooling system to be restarted.

[0028] In a preferable method, the cooling system and gauge are operational while the tubing is run into the wellbore. In such a manner, the pressure sensor, gauge electronics package, and other sensitive equipment are prevented from temporary exposure to high temperatures during run-in.

[0029] Figure 3 is a schematic of an exemplary embodiment according to an aspect of the invention. The system 100 shown here can be used in a wellbore, in conjunction with tubing, conduits, and electrical connections, as described above with respect to the embodiment in Figures 1 and 2, and as is known in the art.

[0030] Figure 3 shows a schematic view of a preferred embodiment of a high-temperature pressure gauge system 100 for use at downhole locations which have temperatures exceeding the design limits of electrical pressure sensors and their associated electronics. The system 100 is deployed on a tubing string 102 or similar. Insulated pipe joints 104 are used to insulate the joints and equipment positioned thereon or therein. To keep the gauge from overheating due to flow, insulated pipe could be used at, above and below the gauge. A tester valve 106 is positioned in the tubing string, as is known in the art.

[0031] At an uphole location 108, where the static wellbore temperature is low enough to operate a pressure gauge having electronics without damage, an uphole assembly 110 is

positioned mounted to the tubing string or insulated joint. The uphole assembly 110 includes a pressure gauge assembly 112. Typical components of a pressure gauge assembly are discussed above and will not be repeated here. The pressure gauge assembly includes a pressure sensor 114, associated electronics, preferably a temperature sensor, and other components. This gauge can be a conventional DST gauge, a DynaLink (trademark) gauge or a wired permanent gauge, for example.

[0032] The pressure sensor 114 is operably attached to a pressure communication conduit 116, preferably a relatively small inner diameter tube, which communicates pressure from the downhole assembly 120 to the uphole pressure sensor 114. The pressure conduit 116 is filled with a suitable fluid 122, such as helium. A light, inert gas such as helium can be used to purge the system and acts as a fluid pressure column in the pressure communication conduit 116. The pressure communication conduit terminates at a pressure chamber assembly 124 positioned at the downhole location. Helium is a preferred fluid for the system, as its corresponding hydrostatic pressure is very low. Consequently, any errors in calculating the correction factor to determine actual downhole pressure are small. Nitrogen gas or other gases can be used as well. Even a liquid can be used with sufficiently accurate knowledge of the density properties of the fluid at the anticipated downhole conditions (temperature and pressure), and accurate measurement of differences in “true vertical depth” (TVD) between the gauge and the sensing location.

[0033] Figure 4 is a schematic detail view of an exemplary downhole pressure chamber assembly according to an aspect of the invention. The pressure chamber assembly 124 is a part of the downhole assembly 120 and is positioned at a downhole location having environmental temperatures which typically exceed the operational parameters of the pressure gauge and electronics. The pressure chamber assembly 124, as shown, has a pressure chamber 126 positioned adjacent a tubing bore 128 and in fluid communication therewith, such as via communication port 130. A pressurized fluid 126, such as helium, is contained in the chamber and a fluidly attached pressure communication conduit 116. The conduit 116 is preferably a capillary tube. Wellbore fluid 136, and its pressure, is communicated from the tubing bore 128 to the chamber by port 130. The pressure of the wellbore fluid, F , in turn, condenses or transmits pressure to the inert fluid 126. The pressure is transmitted through the pressure communication conduit 116 to the pressure sensor 114 at the uphole assembly 110. The pressure chamber

assembly can include additional elements, as are known in the art, such as membranes, bladders and other fluid isolation devices, liners, mountings, etc.

[0034] Preferably the chamber assembly 124 includes a temporary fluid isolation device 136, such as a eutectic plug, frangible disk, rupture disk operated valve, or similar. The pressure fluid 126 is preferably pressurized prior to run-in. The isolation device 136 is preferably operated by thermal expansion of the fluid 126, typically an inert gas, which increases fluid pressure and ruptures the temporary isolation device 136 as the chamber assembly is lowered to the downhole location. This valve could also be simply operated by the well hydrostatic pressure. This valve could also be a eutectic plug that turns to liquid at the elevated downhole temperature.

[0035] In a preferred embodiment, no pump-out device is required. The fluid chamber is filled with helium (or other selected fluid) during installation of the pressure gauge. The chamber will then have a hydrostatic pressure, which in turn places the helium column at this pressure. The volume of the chamber is enough greater (perhaps 50 times) than the volume in the first tube, so further compression of the helium due to increasing hydrostatic pressure during run-in will not result in wellbore fluid entering the first, small diameter tubing.

[0036] The pressure chamber discussed herein is similar to that of the commercially available EZ-Gauge (trademark) permanent pressure monitoring system, provided by Halliburton Energy Services, Inc. Further information regarding the system can be easily located on-line or through Halliburton.

[0037] Exemplary methods of use of the invention will be described, with the understanding that the invention is determined and limited only by the claims. Those of skill in the art will recognize additional steps, different order of steps, and that not all steps need be performed to practice the inventive methods described.

[0038] A method of measuring pressure at a downhole location in a subterranean wellbore at high-temperatures is presented with the following steps: inserting into the wellbore a pressure gauge assembly having a pressure sensor and associated electronics for operating the pressure sensor; exposing the pressure sensor to a downhole wellbore pressure; exposing the pressure gauge assembly to a downhole temperature; flowing a pressurized refrigerant fluid into a chamber proximate the pressure sensor; and cooling the pressure gauge sufficiently to preclude damage from exposure to the downhole temperature. Further and additional steps can include: expanding the pressurized fluid in the chamber; expanding the refrigerant fluid from a liquid to a

vaporous state; flowing the refrigerant fluid through an orifice prior to flowing the refrigerant fluid into the chamber; flowing the refrigerant fluid through an evaporator tube after flowing the fluid through the orifice; communicating the downhole wellbore pressure through a passageway extending from the pressure sensor; providing a pressure sensor further comprising a fluid isolation device capable of transmitting pressure; flowing the refrigerant fluid uphole; circulating the refrigerant fluid between the surface and the downhole pressure gauge assembly; flowing the fluid downhole through a capillary tube; measuring the internal temperature of the pressure gauge assembly; altering the flow of the refrigerant fluid in response to measuring the internal temperature of the pressure gauge assembly; inserting the pressure gauge assembly into the wellbore while the refrigerant fluid is pressurized.

[0039] In another preferred embodiment, the following method is disclosed. A method of measuring downhole pressure in a wellbore extending through a subterranean formation, the method comprising the steps of: positioning an electronic pressure gauge assembly at an uphole location along the wellbore; positioning a pressure chamber at a downhole location along the wellbore; exposing the pressure chamber to a downhole temperature above the maximum operational temperature of the pressure gauge assembly; communicating the downhole wellbore pressure to the pressure chamber; communicating the pressure in the pressure chamber to the pressure gauge assembly positioned uphole; and measuring the pressure communicated to the pressure gauge assembly using the pressure sensor. The method may further include the following steps and limitations: communicating pressure from the pressure chamber to the pressure gauge assembly via a pressure conduit filled with a pressurized fluid; wherein the fluid is an inert gas; actuating a temporary pressure isolation device; wherein the pressure isolation device is selected from the group consisting of: frangible disks, rupture disks, and eutectic plugs; wherein the temporary pressure isolation device is actuated by thermal expansion of a pressurized fluid in the chamber; wherein the temporary pressure isolation device is actuated in response to a change in wellbore pressure; wherein the pressure gauge assembly is a wired, permanent gauge assembly.

[0040] Persons of skill in the art will recognize various combinations and orders of the above described steps and details of the methods presented herein. While this invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Various modifications and combinations of the illustrative

embodiments as well as other embodiments of the invention, will be apparent to persons skilled in the art upon reference to the description. It is, therefore, intended that the appended claims encompass any such modifications or embodiments.

It is claimed:

1. A method of measuring pressure at a downhole location in a subterranean wellbore, the method comprising:

inserting into the wellbore a pressure gauge assembly comprising a pressure sensor;

exposing the pressure sensor to a downhole wellbore pressure;

exposing the pressure gauge assembly to a downhole temperature;

flowing a fluid to the pressure gauge assembly from a fluid control assembly at a surface location;

cooling the pressure sensor sufficiently to preclude damage from exposure to the downhole temperature by flowing the fluid through an evaporator at least partially in the pressure gauge assembly and expanding the fluid in the evaporator;

returning the evaporated fluid to the fluid control assembly;

condensing the evaporated fluid at the surface location; and

returning the condensed fluid downhole to the evaporator to cool the pressure sensor.

2. A method as in claim 1, further comprising the step of expanding the fluid from a liquid to a gaseous phase.

3. A method as in claim 1, further comprising the step of flowing the fluid through an orifice prior to flowing the fluid through the evaporator.

4. A method as in claim 1, wherein the step of exposing the pressure sensor to a downhole wellbore pressure further comprises the step of communicating the downhole wellbore pressure through a passageway extending from the pressure sensor.
5. A method as in claim 4, wherein the pressure sensor further comprises isolation device capable of transmitting pressure.
6. A method as in claim 1, wherein flowing the fluid to the pressure gauge assembly further comprises the step of circulating the fluid, in a closed circuit, between the surface location and the pressure gauge assembly.
7. A method as in claim 1, wherein the step of flowing the fluid to the pressure gauge assembly further comprises the step of flowing the fluid downhole through a capillary tube.
8. A method as in claim 1, further comprising the step of measuring the internal temperature of the pressure gauge assembly.
9. A method as in claim 8, further comprising altering the rate of flow of the fluid in response to measuring the internal temperature of the pressure gauge assembly.
10. A method as in claim 1, further comprising the step of pressurizing the fluid in the pressure gauge assembly prior to insertion into the wellbore.
11. A method as in claim 1, wherein the fluid comprises a refrigerant.
12. A method of measuring downhole pressure in a wellbore extending through a subterranean formation, the method comprising:

positioning an electronic pressure gauge assembly comprising a pressure sensor at an uphole location along the wellbore;

positioning a pressure chamber at a downhole location along the wellbore;

exposing the pressure chamber to a downhole temperature greater than a maximum operational temperature of the electronic pressure gauge assembly;

flowing a fluid to the electronic pressure gauge assembly from a fluid control assembly at a surface location;

cooling the pressure sensor sufficiently to preclude damage from exposure to another downhole temperature by flowing the fluid through an evaporator at least partially in the pressure gauge assembly and expanding the fluid in the evaporator;

returning the evaporated fluid to the fluid control assembly;

condensing the evaporated fluid at the surface location; and

returning the condensed fluid downhole to the evaporator to cool the pressure sensor;

communicating the downhole wellbore pressure to the pressure chamber;

communicating a pressure in the pressure chamber to the pressure gauge assembly positioned uphole; and

measuring the pressure communicated to the pressure gauge assembly using the pressure sensor; and

wherein communicating pressure from the pressure chamber to the pressure gauge assembly comprises communicating pressure via a conduit filled with a pressurized fluid.

13. A method as in claim 12 wherein the pressurized fluid is an inert gas.
14. A method as in claim 12 wherein the conduit comprises a capillary tube.

15. A method as in claim 12, wherein the step of communicating the downhole pressure to the pressure chamber further comprises actuating an isolation device.
16. A method as in claim 15, wherein the isolation device comprises at least one selected from the group consisting of: frangible disks, rupture disks, and eutectic plugs.
17. A method as in claim 15, wherein the isolation device comprises a temporary fluid isolation device configured to be actuated by thermal expansion of a pressurized fluid in the pressure chamber.
18. A method as in claim 15, wherein the isolation device comprises a temporary fluid isolation device configured to be actuated in response to a change in downhole pressure.
19. A method as in claim 12 wherein the pressure gauge assembly comprises a wired permanent gauge assembly.