Level Indicator for Underground Storage of Fluids

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This invention relates to the measurement of the level of a liquid body. In one aspect, this invention relates to a method and apparatus for determining the location of an interface between two substantially immiscible fluids of different specific gravities and different specific electrical resistivities. In another aspect, this invention relates to a method and apparatus for determining the location of the interface between two substantially immiscible fluids of different specific gravities and different specific electrical resistivities in an underground storage zone. In another of its aspects, this invention relates to a method of placing and locating electrical elements in an underground storage zone.

In another of its aspects, this invention relates to a method of removing the accumulation of deposits on electrical elements located in an underground storage zone without removing said elements from said zone. In still another of its aspects, this invention relates to a method and apparatus for making electrical connections between a zone of high fluid pressure and a zone of low fluid pressure without the leakage of pressure between said zones.

Constantly expanding production of fluids for the industries of this country and elsewhere has created a definite problem in providing suitable storage facilities for these fluids. In the petroleum industries, in particular, the problem of storage of liquefied petroleum gas is presently an urgent one due to the cost of storage in surface equipment, such as steel tanks, and due to the massive construction required to withstand the vapor pressure of such liquids. Also adding to this problem of adequate storage facilities is the fact that many industries experience seasonal peak loads in the requirements for their products and corresponding seasonal slack periods. These fluctuations in requirements require large storage facilities and the advantages of underground storage of fluids have lately come to the attention of the industry.

Underground storage caverns are generally formed in impermeable earth formations either by conventional mining methods or, in some cases, by dissolving out a soluble material to create a storage space with aqueous solutions in soluble formations, for example, in salt domes. The resulting caverns are less uniform in shape and size than would be an equal volume of orthodox surface storage space and have proven their value in the storage of LPG (liquefied petroleum gas). In addition to LPG, other liquefied gases can be stored underground, e.g., ammonia.

In the operation of these underground storage caverns, it is often convenient and desirable to remove the stored product from the cavern by displacing with water or brine. The product to be stored is pumped in above the water with sufficient pressure to force the water to the surface through a central pipe, commonly called an eductor pipe, which is located concentrically within an outer casing and which reaches the bottom of the cavern. The product is removed from storage by adding water, thus forcing the stored product out through the annulus between the eductor pipe and the outer casing. There is something of a problem in determining the volume of stored product in the storage cavern since the cavern contains both the stored product and water and each of these fluids is immiscible in the other. Usually, the stored product and water are metered into and out of the cavern; however, the errors in metering add up to a very large error over a period of time so that this method of determining the amount of stored product in the cavern is unreliable. In order to avoid making such large errors, it is desirable to check the amount of product in storage by determining the elevation of the interface between the stored product and water in the cavern. In a mined storage cavern, this is relatively simple because a float gauge can be installed in the storage cavern during its construction. However, this is not usually practical in solution storage caverns because only a small drill hole communicates with the cavern and there is not sufficient space to provide a suitable float gauge. Also, the extreme depth of some solution caverns makes the use of float gauges impractical. Furthermore, the small size of the drill hole makes placing, supporting and locating electrical devices in the underground cavern difficult.

One object of this invention is to provide an accurate and reliable indication of the elevation of the interface between two substantially immiscible fluids of different specific gravities and different specific electrical resistivities in an underground storage zone.

Another object of this invention is to provide an electrical means for testing and indicating the resistivity of the fluids in an underground storage zone at known elevations in the underground storage zone.

A further object of this invention is to provide a method and apparatus for readily and accurately placing electrical elements in an underground storage zone.

A still further object of this invention is to provide a method and apparatus for rigidly supporting electrical elements in an underground storage zone at specific locations within said zone.

Another further object of this invention is to provide a method of removing the accumulation of deposits from electrical elements located in an underground storage zone without removing said electrical elements from said underground storage zone.

An additional object of this invention is to provide a method and apparatus for making an electrical connection of conductors located in a high pressure zone and a low pressure zone without the loss of pressure between said zones of different pressure.

Other aspects, objects, as well as the several advantages of the invention are apparent from a study of the disclosure, the drawings, and the appended claims.

According to the present invention, there are provided a method and apparatus for ascertaining the elevation of the interface between two substantially immiscible fluids of different specific gravities and different specific electrical resistivities in an underground storage zone which comprises testing for the specific electrical resistivity of the fluid existing at specific elevations in said underground storage zone.

Further, according to the present invention, there are provided a method and apparatus for ascertaining the elevation of the interface between two substantially immiscible fluids of different specific gravities and different specific electrical resistivities in an underground storage zone which comprises locating a series of electrodes insulated from each other at different elevations in said underground zone, supplying said electrodes with electrical energy; and determining by an indicating means which electrodes are located in a fluid which provides a path of low electrical resistance through said fluid and a conductor, for example, an eductor pipe as a return electrical conductor.
As an important feature of this invention, an electrical circuit is provided for ascertaining the elevation of said interface in said underground storage zone with accuracy and reliability, by maintaining the indicating means in an inoperative condition until the current flow in the resistivity testing circuit reaches a value which is greater than the maximum current flow permitted by the resistance of the electrical conductors of various lengths.

Still further, according to the present invention, there are provided a method and apparatus for placing electrical elements at spaced elevations in an underground storage zone, comprising attaching the electrical elements to an eductor pipe and lowering said eductor pipe, with said electrical elements attached thereto, into said underground storage zone.

Also, according to the present invention, there are provided a method and apparatus for removing the accumulation of deposits from electrical elements located in an underground storage zone comprising applying a direct current electrical potential of a particular polarity to said electrical elements.

In addition, according to the present invention, there are provided a method and apparatus for ascertaining the elevation of the interface between two substantially immiscible fluids of different specific gravities and different specific electrical resistivities in an underground storage zone wherein an electrical current transfer zone is provided comprising electrical conductors and a pressure retaining member arranged so as to permit the conductors to pass therethrough yet retaining the pressure existing in the storage zone, said electric current transfer zone being positioned at a point removed from the storage zone. Further, in event of leakage of fluid pressure, there is provided a blanking means to shut-in the pressure of the underground storage system. Also, with this arrangement, another blanking means is provided in the electric current transfer zone positioned at a point removed from the storage zone to cut-off the high pressure acting on the pressure retaining member and permit an inspection of said pressure retaining member and the conductors passing therethrough.

The invention is further illustrated in the accompanying drawings.

Figure 1, which is an elevation of a typical underground storage system formed by the solution method and an electrical circuit in schematic form for testing and indicating the electrical resistivity of fluids at various levels, shows the location of two typical electrodes in the storage zone with the electrical conductors of these electrodes attached to the eductor pipe and passed through the instrument outlet assembly at the well head to the testing and indicating circuits.

Figure 2 is a partial vertical view of a portion of the eductor pipe showing one method of attaching an electrical conductor and electrode to the eductor pipe.

Figure 3 is a partial cross-section of the instrument outlet assembly attached to the outer casing at the well head above the surface of the ground and shows, in detail, the method of making electrical connections through the pressure retarding member and the arrangement of the valve for shutting-in the pressure whenever leakage of fluid occurs from around the electrical connections.

Referring to Figure 1, storage zone 10, containing water layer 11 and stored product 12, is dug through the surface through the drill hole in which is set outer casing 13. Eductor pipe 14, having a diameter substantially smaller than the internal diameter of casing 13, is mounted concentrically within casing 13 so as to form an annulus between the outer wall of eductor pipe 14 and the inner wall of casing 13. Eductor pipe 14 extends into storage zone 10 at a point near the surface of storage zone 10 but casing 13 is placed to extend only a short distance into storage zone 10. At the well head on the surface, outlet conduit 15 carries stored product 12 to the distribution system, not shown, and conduit 16 provides an inlet for water into storage zone 10 through eductor pipe 14. Also, at the well head, instrumentation outlet assembly 17, which is described in detail in Figure 3, is attached to outer casing 13 and provides for passage of typical insulated conductors 20 and 21 from storage zone 10 to the resistivity testing and indicating means without escape of fluid from within the underground storage system.

As shown in Figure 1, electrodes 18 and 19 are located in storage zone 10 attached to eductor pipe 14 at different levels within storage zone 10. Although only two typical insulated conductors are shown in Figure 1, it should be understood that an indication of conductors can be used depending upon the number of locations where it is desirable to test the resistivity of the contained fluids. Insulated conductors 20 and 21, of electrodes 18 and 19, respectively, are attached to eductor pipe 14 at spaced intervals along its length by tape 22, or other attaching means, with eductor pipe 14 serving as a support. The attachment of an insulated conductor to eductor pipe 14 and the arrangement of an electrode attached to eductor pipe 14 are shown in detail in Figure 2.

Insulated conductors 20 and 21 terminate at terminals 24 and 25, respectively, of selector switch 26 which includes conductor 27 and other terminals 28, 29, and 30 for connecting additional electrodes located in underground storage zone 10. Any number of electrodes may be located in the storage zone and the number of terminals 26 will be determined by the number of electrodes employed. Conductor 31, solenoid coil 32 of solenoid switch 33, and conductors 34 and 35 complete the electrical path to the source of electrical energy. Thus, with one side of the source of electrical energy grounded by conductor 37, the complete path for the flow of electrical energy to typical electrode 18 located in underground storage zone 10 is through conductors 34 and 35, solenoid coil 32, conductor 31, conductor 27 and terminal 24 of selector switch 26, insulated conductor 20, electrode 18, water layer 11 in storage zone 10, eductor pipe 14, and conductor 36 which grounds eductor pipe 14 at the well head.

In Figure 2, typical insulated conductor 20 is attached to eductor pipe 14 with insulated tape 23 and 43 which is wrapped around eductor pipe 14 and conductor 20. The insulating tape used may be any of the types well known in the art made of rubber, synthetic resins, plastics, or the like and should be of a type which is not soluble in the fluids placed in the storage system. Conductor 20 is insulated along its complete length except for the lower portion from which the insulation has been removed so as to form electrode 18. Eductor pipe 14 is wrapped with insulated tape 44 in order to prevent an electrode 18 from touching eductor pipe 14 and shorting the electrical circuit. The electrical path is completed by the flow of electrons from electrode 18 through water layer 11 and eductor pipe 14.

In Figure 3, the instrument outlet assembly is incorporated in the arrangement of weld outlet 45, weld necks 46, 47, and 48, pressure plate 49, valve 50, T-fitting 51, and junction box 52 to which is attached electrical conduit 53. The whole instrument outlet assembly is attached to casing 13 by means of weld outlet 45 which is welded to casing 13 at circular opening 54 in casing 13. Weld neck 46 is connected to weld outlet 45, and pressure plate 49 is mounted between weld necks 46 and 47. In this embodiment, pressure plate 49 is shown as being bolted to weld necks 46 and 47 so that it can be easily replaced when necessary. Pressure plate 49 is of sufficient thickness to withstand the elevated pressures in the storage system and is provided with a number of holes 55 which are drilled and tapped. Holes 55 are shown drilled and tapped in pressure plate 49, there are as many such holes as there are electrical conductors of which conductors 20 and 21 are typical. Electrical connector 56, which is an externally threaded in-
sulated bolt with a terminal at each end, is tightly screwed into pressure plate 49 so that there is no escape of fluid pressure from within casing 13. The number of electrical connectors, of which connector 56 is typical, depends upon the number of holes in pressure plate 49 since there is one connector for each hole. Conductor 20 is attached to each end of typical connector 56 to make a fluid-pressure-tight electrical connection through pressure plate 49. The off-set chamber 57, obtained by the location of weld outlet 45 and weld neck 46 between casing 13 and pressure plate 49, providing a conductor 20 to connector 56 out of the path of flow of fluid from the storage zone so that connector 56 is not subjected to lateral forces which tend to loosen or erode connector 56 in pressure plate 49 and cause leakage. Also, by locating connector 56 in off-set chamber 57, there is no restriction to the flow of fluid from the storage zone and, therefore, the pressure required to remove fluid from the storage zone is kept to a minimum. Further, the circular welded joint between circular opening 54 in casing 13 and weld outlet provides greater strength than other types of construction.

Valve 50 is mounted on weld neck 48 which is fixed to weld neck 47. T-fitting 51 is attached to the other end of valve 50 and junction box 52 is connected to one arm of T-fitting 51. The other arm of T-fitting 51 is connected to a short pipe 58 for detecting, either by sight or odor, the build-up of fluid resulting from leakage past electrical connector 56 in pressure plate 49. If desired, other means, such as a sensitive pressure gauge, for detecting a build-up of pressure can be used and automatic apparatus for detecting leakage and closing valve 50 can be employed. The electrical conductors, of which conductor 20 is a typical one, are housed within weld necks 47 and 48, valve 50, and T-fitting 51 and pass from junction box 52, by conduit 53, to the resistivity and indicating means shown in Figure 1. Conduit 53 has a sealing fitting (not shown) which is filled with a sealing compound which holds any escaped fluid within the instrument outlet assembly and prevents the passage of such escaped fluid from the vicinity of the well head through conduit 53. Whenever leakage is detected, valve 50 is closed to effectively shut-in the pressure until the source of leakage can be repaired. The closing of valve 50 may result in the cutting of the electrical conductors passing therethrough, in which case the resistivity testing and indicating circuits are inoperative; however, valve 50 may be closed by an operator without cutting the electrical conductors. For instance, the gate of the valve or the valve seat is arranged to accommodate the insulated conductors when the gate is closed against the seat without cutting the conductors. In another construction, the insulated conductors are arranged to pass through the packing of the valve without affecting the seal. With some types of insulated conductors, a special valve is not necessary because the insulation is sufficiently deformable to permit the valve gate to be closed without loss of pressure. Although this feature is not shown in the drawing, a valve may be located at the junction of weld outlet 45 and weld neck 46 so that the pressure can be shut-in while valve 50 is removed from the assembly and leaks around the connectors repaired. Of course, the valve used for this purpose would also have to be of a type which would not result in a cutting of the electrical conductors whenever it is closed. Also, if this valve is used, valve 50 is not necessary since this valve can be used to shut-in the pressure in the storage zone as well as cut-off the pressure acting on pressure plate 49.

In operation, electrical energy is applied to the various electrodes located in storage zone 10 as determined by the operation of selector switch 26. Each of these electrodes is located in the storage zone at different elevations and the resistance of each of the electrical circuits containing an electrode is primarily dependent upon the electrical resistance of the fluid surrounding the electrode which acts as a barrier to the flow of electrons from the electrode to the eductor pipe 14. Ordinarily, the stored product will offer high resistance to the flow of electrons in comparison to the water layer which will provide a path of relatively low electrical resistance because of the presence of dissolved minerals, very often sodium chloride, present in the water layer. As the electrical energy is applied to each of these circuits by the operation of selector switch 26, the flow of electrical current in each circuit will be either large or small, depending upon the resistance of the fluid surrounding each electrode. A large volume of current flow through solenoid coil 32 operates solenoid switch 33 to close contacts 39 and complete the electrical circuit which applies electrical energy to indicating light 41, causing it to burn brightly and indicate that the fluid surrounding that particular electrode has very low electrical resistance. In comparison, a small value of current flow does not affect operation of solenoid switch 33, so that contacts 39 remain open, and indicating light 41 remains unlighted. By this indication, the fluid surrounding this electrode is known to have a high electrical resistance. The location of the interface between the fluid layers in storage zone 10 is determined by testing for the electrical resistance of the fluid surrounding each electrode at each elevation in sequence and the location of the elevation of the interface is known when indicating light 41 first lights or first goes out, depending on the direction in which the resistivity is tested at the different elevations. If desired, a voltmeter or other electromotive force measuring device can be used in place of indicating light 41 to indicate the resistivity of the fluid at the various elevations in storage zone 10. Also, the source of electrical energy is not restricted to the use of 110 volts A.C. as shown in Figure 1 but electrical energy of other voltage levels can be used. In addition, under certain conditions, direct current (D.C.) can be used in place of alternating current (A.C.).

One important feature of this invention is the use of solenoid switch 33 as the resistivity testing and indicating circuit shown in Figure 1. In many underground storage installations, the difference in the lengths of the electrical conductors to each electrode located at different elevations in the storage zone is sufficiently large to cause a substantial difference in current flow in each circuit. Even though this difference in current flow may not be sufficient to cause indicating light 41 to light or to go out completely, when solenoid switch 33 is removed from the circuit and indicating light 41 is connected in the circuit in series with the particular electrode and the resistance of the fluid surrounding the electrode, it will often be sufficient to affect the brilliance of indicating light 41 and give an unreliable and difficultly ascertainable indication of the resistivity of the fluids in storage zone 10. Also, the stored product may have a relatively low electrical resistivity, because of either the particular nature of the material or the presence of an aqueous solution in admixture with the stored product, and the resulting current flow would be sufficient to light indicating light 41 even though the electrode is not in the water layer. Thus, the use of solenoid switch 33 prevents indicating light 41 from lighting until the current flow in the resistivity circuit reaches a certain minimum value and then solenoid switch 33 closes the indicating circuit and causes indicating light 41 to be lighted with a constant and regular degree of brilliance.

Sometimes, in the practice of this invention using a direct current source of electrical energy, deposits develop on the electrodes and the eductor pipe containing these elements with a material which offers a high resistance to the flow of electrons. This deposition of solid material is particularly prevalent on the electrodes and that part of the eductor pipe ordinarily located in the water layer. Another feature of this invention is the
provision of a simple method for removing such deposits without removing the eductor pipe and attached electrodes from the underground cavern. This removal of deposits is accomplished by periodically reversing the polarity of the direct current source of electrical energy for a short period of time when the fluid surrounding the electrode on which there are deposits has a low specific resistance. The duration of the period of reverse current flow depends upon the severity of the deposition problem and may be as short as 30 seconds and as long as 5 minutes or even longer where the deposition of solid material is very severe. The magnitude of the voltage is ordinarily used to test the resistivity of the fluids in the storage zone or it can be of a greater or lesser magnitude.

Another important feature of this invention is the method of placing electrodes at different elevations in an underground storage zone using the eductor pipe as a support for these electrodes as well as the conductors connected thereto. It is difficult to place and support electrical elements in chambers located deep in the earth, and it is particularly difficult when the only opening to the surface is a small drill hole, for example, of 12 inches or less in diameter. However, by employing the method of this invention, electrical elements can be readily placed and accurately located in such underground chambers. Thus, this feature of the invention is of considerable utility in the construction of underground storage caverns by the solution method by which an underground cavity is formed by drilling a hole into a strata in the earth which is readily soluble in water, pumping water into said strata to dissolve the soluble portion, and removing the solution formed to leave a cavity suitable for the storage of valuable products. However, the method of placing and locating electrical elements in an underground storage cavern is not limited to use in caverns formed by the solution method, but it can also be used in natural underground caverns or underground caverns constructed by mechanical mining methods.

In a specific embodiment of this invention, a storage cavern was constructed by first drilling a hole into the earth into a soluble salt-containing strata and then dissolving out the soluble material in the strata by pumping water into the well and removing the solution formed. The outer casing was set in the drill hole and the eductor tube was mounted concentrically within the outer casing with the lower end extending close to the floor of the cavity. The instrument outlet assembly was constructed as shown in Figure 2 of the drawings. Pressure plate 49 was welded to weld necks 46 and 47 and an ordinary gate valve was used to shut-in the fluid pressure whenever leakage should occur. The electrodes and their connecting insulated conductors were attached to the eductor pipe with insulating tape in the manner shown in Figure 3. An electric lamp was used for the indicating means and was connected with a solenoid switch in the manner shown in Figure 1. A 110 volt A.C. electrical potential was used as the source of electrical energy for application to the electrodes within the storage zone and to the indicating lamp. Liquefied petroleum gas was stored in the cavity over salt water and the location of the interface between these two layers was determined with accuracy and reliability.

Reasonable variation and modification are possible within the scope of the foregoing disclosure, drawings and the appended claims to the invention, the essence of which is that there have been provided a method and apparatus for ascertaining the elevation of the interface between two substantially immiscible fluids of different specific gravities and different specific electrical resistivities in an underground storage zone by attaching electrodes, and the conductors connected thereto, to the electrodes of the underground storage system at various distances from the lower end of said pipe, lowering the assembly of electrodes and conductors, attached to said eductor pipe, into said underground storage zone so that said eductor pipe serves as a support for said electrodes and conductors in said underground storage zone and said electrodes are located at different elevations in said underground storage zone, supplying said electrodes with electrical energy, and determining by an indicating means which electrodes are located in a fluid which provides a path of low electrical resistance through said fluid and the eductor pipe to ground; one feature of the invention providing an electrical connection between conductors located in a zone of high pressure in the underground storage system and in a zone of low pressure in an instrument outlet assembly which has a means to shut-in the pressure in said underground storage system whether there is leakage fluid from around said electrical connectors; another feature of the invention providing a means of maintaining the indicating means in an operative condition until the current flow in the resistivity testing circuit reaches a value which is greater than the maximum current flow permitted by either the resistance of the various electrical conductors of different length or the specific resistance of the fluid being stored; and still another feature of the invention providing for removing the accumulation of deposits from the electrodes, without removing said electrodes from the underground storage zone, by creating a direct current potential of a particular polarity to said electrodes; all substantially as set forth and described herein. Those skilled in the art in possession of this disclosure and its drawings will understand that they have been set forth for disclosure purposes only and that the underlying concepts can be embodied in form and manner different from those already shown.

I claim:
1. In an underground storage system having an outlet to the surface through a casing and wherein electric measurements are made on the surface from electric elements located in the storage zone, the apparatus comprising a branch pipe fixed to the casing in open communication therewith; a fluid pressure retaining member attached to the branch pipe; a plurality of insulated electrical connectors fixed in the pressure retaining member in a manner to prevent pressure loss, each connector extending through the pressure retaining member and protruding from each side thereof; a blanking means attached to the pressure retaining member to shut-in the pressure whenever there is leakage from around the electrical connectors; a conduit attached to said blanking means and having plural outlets; a junction box fixed to one of the outlets; insulated electrical connectors extending from the electric elements located in the storage zone to the terminals of the insulated electrical connectors located in the branch pipe; a plurality of insulated conductors extending from the opposite terminals of the insulated electrical connectors through the blanking means, the conduit and one outlet of the conduit to the terminals of the junction box; and a plurality of insulated conductors extending from the terminals of the junction box to the indicating means.
2. The apparatus of claim 1 wherein the blanking means is a valve.

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