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FLOW CONTROL

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Filed Nov. 16, 1967, Ser. No. 683,564

Int. Cl. E21f 17/16; B65g 5/00; F16k 21/18

U.S. Cl. 61—5

8 Claims

ABSTRACT OF THE DISCLOSURE

Flow control apparatus is provided for use with underground storage systems. Signals are established which represent changes in the rate of flow of fluids withdrawn from the cavern. When such changes exceed predetermined values, fluid flows are terminated. Control apparatus is also provided to terminate the fluid flows when the flow rates are outside predetermined ranges.

This invention relates to flow control systems for use in conjunction with the underground storage of fluids.

It is common practice to store certain fluids, such as liquefied petroleum gas, in underground storage caverns. When hydrocarbons are stored in caverns of this type, it is common practice to use brine for displacement of the hydrocarbon from the cavern. On the filling cycle, hydrocarbon is pumped down to displace the brine, which can be stored in a reservoir at the surface. In both of these operations it is important to know when the cavern is filled with either the hydrocarbon or the brine so that the delivery conduit can be closed to prevent withdrawal of mixtures of the two materials. This avoids the possibility of the removed hydrocarbon being contaminated with brine and the possibility of delivering flammable hydrocarbon to the brine reservoir.

In U.S. Patent No. 3,056,265 there is disclosed a control system for use in underground storage operations of this type. The flow rate of the withdrawn liquid is measured, such as by measuring the pressure differential across an orifice in the flow conduit, and the withdrawal of liquid is terminated when the indicated flow rate exceeds a predetermined value. In this manner, delivery of a mixture of two fluids is prevented. While the flow system described in this patent is quite effective in certain operations, a need exists for a more versatile control system. This is particularly true when it is desired to store and remove fluids at different rates of flow.

In accordance with the present invention, a control system is provided which is based on measurements of changes in the rates of flow of fluids withdrawn from an underground storage cavern. This control system can be employed on both the hydrocarbon and brine removal conduits. The control system serves to shut down flow of withdrawn fluid whenever a rate of change of flow in excess of the predetermined value is measured. This prevents mixing of the product streams, and permits operation of the system at various flow rates. In addition, control mechanism is provided in accordance with this invention for shutting down flows in the delivery conduits whenever the measured flow is greater or less than preselected limits. This provides automatic shutdown in the event of leakage or other malfunctions in the storage system.

Accordingly, it is an object of this invention to provide an improved method of controlling the operation of underground storage systems.

Another object is to provide novel control apparatus for use with underground storage systems.

Other objects, advantages and features of the invention should become apparent from the following detailed description in conjunction with the accompanying drawing in which:

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FIGURE 1 is a schematic representation of an underground storage system having the control apparatus of this invention associated therewith.

FIGURE 2 is a schematic circuit drawing of a first embodiment of the control apparatus which utilizes electrical elements.

FIGURE 3 is a schematic representation of a second embodiment of the control apparatus which utilizes pneumatic elements.

Referring now to the drawing in detail and to FIGURE 1 in particular, there is shown a subterranean storage cavern 10. Caverns of this type can be formed by conventional mining procedures or by solution mining when appropriate structures, such as salt domes, are available. As illustrated in the drawing, cavern 10 is partially filled with a volume of hydrocarbon 11 which floats on a volume of a more dense immiscible liquid 12, such as brine. Cavern 10 is connected to the surface of the earth by a suitable access hole into which a hollow casing 13 is cemented. The lower end of casing 13 terminates near the top of the storage cavern 10 to permit introduction and withdrawal of the hydrocarbon to be stored. A tubing 14 extends through casing 13 and terminates at its lower end adjacent the bottom of the storage cavern. Brine is introduced and withdrawn through tubing 14. Conduits 16 and 17 are connected to casing 13 and tube 14, respectively, at the surface to permit introduction and withdrawal of the hydrocarbon and brine. A conduit 18, which has a pump 19 and a check valve 20 therein, communicates with conduit 16 to introduce hydrocarbon to be stored. A conduit 21 which has a pump 22 and a check valve 23 therein, communicates with conduit 17 to permit introduction of brine. A conduit 24, which has a valve 25 therein, communicates with conduit 16 to permit withdrawal of hydrocarbon. A conduit 26, which has a valve 27 therein, communicates with conduit 17 to permit withdrawal of brine.

When it is desired to store hydrocarbon in cavern 10, pump 19 is actuated to introduce the hydrocarbon from a source of supply, not shown. Valve 27 is opened to permit withdrawal of brine which is displaced upwardly through tubing 14 when the hydrocarbon is introduced into the cavern through casing 13. When it is desired to withdrawn hydrocarbon from the cavern, pump 22 is actuated and valve 25 is opened. Brine is then introduced into the cavern through tubing 14, and hydrocarbon is withdrawn through casing 13 and conduits 16 and 24. In accordance with this invention, a flow transducer 30 and a control valve 31 are disposed in conduit 16. Transducer 30 is connected to a flow transmitter 32 which provides an output signal that is representative of the rate of flow through conduit 16. This signal is transmitted to a recorder-controller 33. Recorder-controller 33 operates in the manner to be described hereinafter to shut valve 31 when certain conditions occur. Similarly, a flow transducer 34, a flow transmitter 35, a recorder-controller 36, and a valve 37 are associated with conduit 17.

A first embodiment of the control system, which utilizes electrical elements, is illustrated in greater detail in FIGURE 2. Flow transmitter 32a, which can be either flow transmitter 32 or 35 of FIGURE 1, provides an output electrical signal which is proportional to the rate of flow of fluid through conduit 24, for example. The first output terminal of transmitter 32a is connected to the junction between resistors 38 and 39 which form two adjacent arms of a current dividing bridge network 40. The same output terminal of transmitter 32a is connected by means of a variable resistor 42, which has a capacitor 43 connected in parallel therewith, to the junction between resistors 44 and 45 which form the remaining arm of bridge 40. A relay coil 46 is connected across the second

opposite terminals of bridge 40. Relay coil 46 serves to close a switch 47 when current of predetermined magnitude flows through the relay coil. Closure of switch 47 connects a current source 48 to a motor control circuit 49. Motor control circuit 49 connects a power source 51 to a motor 52 when the motor control circuit is energized. Motor 52 closes valve 31 of FIGURE 1 when motor control circuit 49 is energized.

The control elements of FIGURE 2 are employed when brine is being introduced into cavern 10 to displace hydrocarbon through conduits 16 and 24. In normal operation, the brine is introduced into the cavern by means of gravity plus whatever energy is required from pump 22 to transport the brine to tubing 14. The head of brine usually is sufficient to displace the hydrocarbon because cavern 10 is normally located a substantial distance below the surface. As the brine fills cavern 10 to displace hydrocarbon, there is a slow decrease in the rate of hydrocarbon withdrawal due to the changing differential pressure head exerted by the brine. When the interface between hydrocarbon 11 and brine 12 reaches the bottom of casing 13, brine enters the casing and flows upwardly toward outlet conduit 16. Since the brine introduced into the cavern has a much smaller volume of hydrocarbon to displace at this time, the differential pressure head and the flow detected by transducer 30 decreases at a substantially greater rate. The control system of FIGURE 2 senses this decrease in flow rate and actuates motor 52 to close valve 31, thereby preventing brine from being withdrawn through conduit 24.

Bridge 40 is balanced initially, under normal flow conditions, by adjustment of resistor 45 such that any current flow through relay coil 46 is less than that required to energize the relay. As long as a relatively uniform rate of flow is detected, the circuit remains in this condition. However, any rapid fluctuation in the rate of flow changes the potential applied across bridge 40 and energizes relay coil 46 to close switch 47. This results from the electrical delay action imposed by resistor 42 and capacitor 43. Under relatively steady state conditions of flow, the same potential is applied to both of the bridge input terminals. A change in the output from transmitter 32a appears instantly at the junction between resistors 38 and 39, but the change at the junction between resistors 44 and 45 is delayed because of resistor 42 and capacitor 43. Thus, a rapid change in flow through conduit 16 is detected by the circuit of FIGURE 2, and this serves to close valve 31. Motor control 49 is adapted to energize motor 52 to drive valve 31 to a fully closed position when an input pulse is received by switch 47 being closed momentarily. For example, a latching relay can be energized by such a pulse. This latching relay can energize motor 52 to move valve 31 to a closed position. A Limitorque motor can be used for this purpose, for example.

Bridge 40 is employed in the circuit of FIGURE 2 to permit accurate adjustment of the current flow through relay coil 46 for different potential differences across the bridge. However, in some applications relay coil 46 can merely be connected across resistor 42 and capacitor 43. Adjustable resistor 42 permits the sensitivity of the control circuit to be varied.

The control circuit of FIGURE 2 also serves to close valve 31 in the event the flow through conduit 16 exceeds a first preselected value or falls below a second predetermined value. To this end, a variable resistor 53 and a relay coil 54 are connected between the first output terminal of transmitter 32 and ground. When relay coil 54 is energized, a switch 55 is closed. This switch is connected in parallel with switch 47 such that closure of switch 55 energizes motor 52 to close valve 31. Resistor 53 is adjusted such that relay coil 54 is not energized unless the current exceeds a predetermined value, which is indicative of an excess flow through conduit 16. A variable resistor 56 and a relay coil 57 are also connected between the first terminal of transmitter 32a and ground.

Resistor 56 is adjusted such that sufficient current normally flows through relay coil 57 to keep the relay energized. The relay is deenergized only when the indicated flow decreases below a preselected value. When this occurs, a switch 58, which also is connected in parallel with switch 47, is closed to energize motor 52.

The low flow shut-down provided by relay coil 57 and switch 58 serves as a back up system to relay coil 46 and switch 47. Once casing 13 is filled with brine, there is substantially no pressure differential so that the flow through conduit 16 decreases to a very low value. This closes valve 31 in the event that a failure has occurred in the primary control circuit. The high flow shut-down provided by relay coil 54 and switch 55 is activated in the event of a conduit rupture which permits rapid flow of volatile hydrocarbons from the cavern.

A normally closed switch 60 is connected in the circuit between current source 48 and motor control 49 to permit the motor control to be deactivated during normal start-up procedures or at any other time. An alarm 61 is connected in parallel with motor control 49 to alert an operator when valve 31 is closed. The output signal from flow transmitter 32a is also applied to a flow recorder 62 which can be of a type which provides a record of the cumulative flow through conduit 16. A flow meter 63 is provided with two individual flow indicating pointers 64 and 65. This meter is connected to the two end terminals of resistor 42 such that pointer 64 represents the output signal from flow transmitter 32a and pointer 65 represents the potential between resistor 42 and bridge 40. Under steady state conditions, these two pointers register the same flow. A difference occurs only when there is a change in flow, as previously described.

The apparatus of FIGURE 2 can also be employed as recorder-controller 36 on conduit 17. In this application, an increase in the rate of flow is detected when hydrocarbon enters tube 14 at the completion of the filling cycle. Bridge 40 is balanced initially such that this increase in flow results in current flow through relay coil 46. In a similar manner, the high flow shut-down feature serves to back up the action of relay coil 46.

In FIGURE 3 there is shown a second embodiment of the recorder-controller which utilizes pneumatic components. Transmitter 32b provides an output pneumatic pressure which is representative of the rate of flow through the conduit to which the recorder-controller is connected. This pressure is transmitted by a conduit 69 to first and second bellows 70 and 71. A conduit 72, which has an adjustable valve 73 therein, is connected to a third bellows 74 which opposes bellows 70. The first end of a lever arm 75 is connected to the junction between bellows 70 and 74. Lever arm 75 is adapted to rotate about an adjustable pivot point 76 in response to relative expansion and contraction of the two bellows. The second end of lever arm 75 is connected to a switch 47' which corresponds to switch 47 in FIGURE 2. Under steady state operating conditions, bellows 70 and 74 receive substantially the same pneumatic pressure and switch 47' remains open. A sudden increase in the rate of flow results in a momentary difference between the two pressures because of the presence of restrictor valve 73. This causes rotation of lever arm 75 such that switch 47' is closed. Pivot point 76 can be positioned on either side of the rotatable lever arm, depending on the particular application to which the recorder-controller is to be used. It is positioned below the lever arm, as illustrated, when an increase in flow is to actuate the control valve. It is positioned above the lever arm when the converse is true.

A reference pneumatic pressure is supplied to a fourth bellows 77 by a conduit 78 which has an adjustable pressure regulator 79 therein. Bellows 71 and 74 oppose one another such that the relative movement therebetween rotates lever arms 80 and 81 about respective pivot points 82 and 83. Lever arms 80 and 81 actuate respective switches 55' and 58' which correspond to switches 55 and

58 of FIGURE 2. By adjusting the reference pressure supplied to bellows 77, these two switches can be actuated when high and low flow rates are detected. Switches 47', 55' and 58' of FIGURE 3 actuate a control circuit of the type illustrated in FIGURE 2. An indicator 63' is connected to conduit 72 on the two sides of valve 73.

In the specific embodiment of this invention described herein where brine is used to displace hydrocarbon, flow detector 30 can advantageously be a turbine meter and flow detector 34 can be a magnetic flow meter. However, other detectors can be employed. The choice of detector depends to a large extent on the nature of the fluid being metered.

An important feature of this invention resides in the control system which responds to the rate of change of flow rather than the actual flow. This use of the derivative of flow permits the shut-down system to be operated at different rates of flow without any adjustment being required, as long as changes in flow rates are gradual. Another important feature of this invention resides in the safety back up controls.

While the invention has been described in conjunction with presently preferred embodiments, it obviously is not limited thereto.

What is claimed is:

1. In a system for storing liquids, which system includes an underground storage cavern, first conduit means extending from the surface of the earth to a region inside and near the top of the cavern for introducing and withdrawing a first liquid, and second conduit means extending from the surface of the earth to a region inside and near the bottom of the cavern for introducing and withdrawing a second liquid which is immiscible with and of greater density than the first liquid; control apparatus comprising first means associated with one of said conduit means to establish a first signal which is representative of the rate of flow of liquid through said first conduit means, a valve in one of said conduit means, second means responsive to said first signal to establish a second signal when said first signal changes and means responsive to said second signal when said second signal reaches a predetermined maximum value to close said valve.

2. The apparatus of claim 1 wherein said first means establishes a first electrical signal between first and second terminals, the magnitude of said first electrical signal being representative of the rate of flow of fluid through said one conduit means; said second means comprises a resistor and a capacitor connected in parallel with one another between said first and second terminals; and wherein said means to control said valve comprises means responsive to a predetermined potential difference between said first and second terminals to close said valve.

3. The apparatus of claim 1 wherein said first means establishes a first pneumatic signal, the magnitude of which is representative of the rate of flow through said one conduit means; and wherein said second means comprises first and second bellows connected in opposition to one another, means to apply said pneumatic signal directly to one of said bellows, conduit means having a restrictor therein to apply said pneumatic signal to the second of

said bellows, and means responsive to the relative positions of said bellows to establish said second signal.

4. The apparatus of claim 1, further comprising means responsive to said first means to close said valve when said first signal exceeds a first predetermined value, and means responsive to said first means to close said valve when said first signal is less than a second predetermined value.

5. The apparatus of claim 4 wherein said means to close said valve when said first signal exceeds a predetermined value comprises a first relay which is energized when said first signal exceeds said first predetermined value, and means responsive to said first relay being energized to close said valve; and wherein said means to close said valve when said first signal is less than said second predetermined value comprises a second relay which is deenergized when said second signal is less than said second predetermined value, and means responsive to said second relay being deenergized to close said valve.

6. The apparatus of claim 4 wherein said means to close said valve when said first signal exceeds said first predetermined value and said means to close said valve when said first value is less than said second predetermined value comprise a first bellows, means to apply said pneumatic signal to said first bellows, a second bellows in opposition to said first bellows, means to apply a reference pneumatic signal to said second bellows, and means responsive to relative movements of said bellows to close said valve when said bellows are displaced by predetermined amounts.

7. The apparatus of claim 1 wherein said first means is associated with said first conduit means, and further comprising third means associated with said second conduit means to establish a third signal which is representative of the rate of flow of liquid through said second conduit means, a second valve in said second conduit means, fourth means responsive to said third signal to establish a fourth signal when said third signal changes at a predetermined rate, and means responsive to said fourth signal to close said second valve.

8. The apparatus of claim 7, further comprising means responsive to said first means to close the first mentioned valve when said first signal exceeds a first predetermined value, means responsive to said first means to close said first mentioned valve when said first signal is less than a second predetermined value, means responsive to said third means to close said second valve when said third signal exceeds a third predetermined value, and means responsive to said third means to close said second valve when said third signal is less than a fourth predetermined value.

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U.S. Cl. X.R.

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