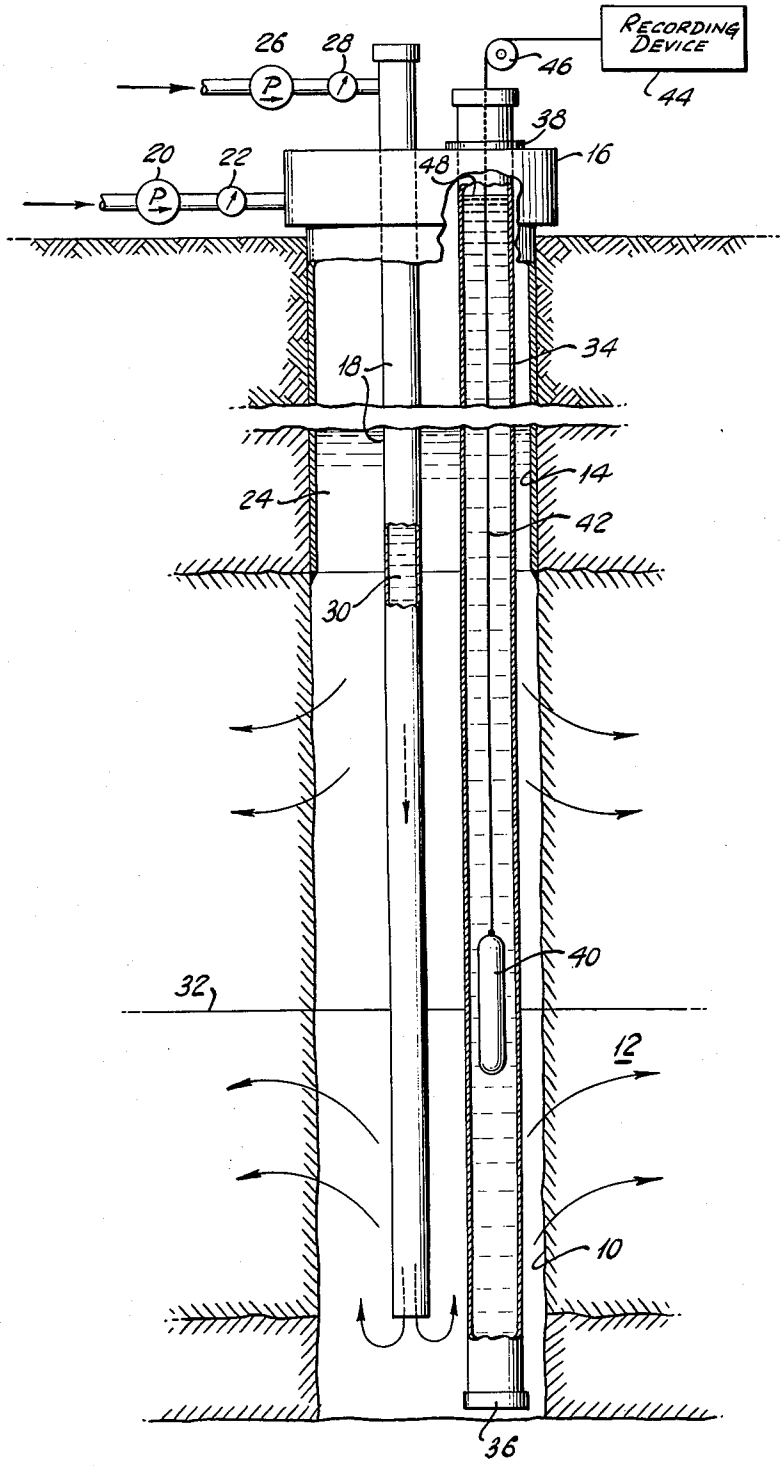
Aug. 6, 1963 J. C. ALLEN ETAL 3,100,259

RADIOACTIVE WELL LOGGING

Filed May 7, 1959



United States Patent Office 3,100,259 Patented Aug. 6, 1963

3,100,259

RADIOACTIVE WELL LOGGING

Joseph C. Allen, Bellaire, and Hugh E. Hall, Jr., Houston, Tex., assignors to Texaco Inc., a corporation of Delaware

Filed May 7, 1959, Ser. No. 811,727
12 Claims. (Cl. 250—43.5)

This invention relates to a method of studying subsurface earth formations and more particularly to a method of logging high pressure wells.

Radioactive tracer techniques are being utilized to obtain points of entry of injected fluids into the subsurface formations traversed by injection wells and points of entry of produced fluids from the subsurface formations to the well bore in production wells. The need for a uniform mutual distribution of injection fluids in secondary recovery operations is well known. Production of undesirable fluids, namely, excess gas and water, results in costly operations and reduced recovery of oil.

Radioactive tracer techniques have been utilized for obtaining injectivity profiles using gas, oil, and water and for locating permeable zones for gas, oil and water in producing wells. Two major problems associated with the present techniques of obtaining injectivity and productivity profiles of wells have been encountered, namely, first, to successfully pack-off a conductor cable of a logging system at high well head pressures and, second, to lower an exploring unit of a logging system to a productive interval below the pump in a pumping well. Well head pressures in some wells may be considerably higher than 1,000 lbs. per square inch. In the case of high pressure gas wells, well head pressures can be as high as several thousand pounds per square inch. Successfully lubricating a conductor cable into the well head under such pressures presents a problem of considerable magnitude.

In some producing wells in which a high gas-oil ratio exists, very high pressures, for example, considerably above 4,000 lbs. per square inch, may be found. For example, in pumping wells in which a secondary recovery operation, specifically, gas injection, is being conducted and full or near full pressure is being maintained, a high gas pressure would exist in the well bore of the producing well. To determine the exact point or points of entry of the gas into the well bore, the two previously mentioned problems, that is, high well pressure and down hole pumping, are encountered.

In accordance with one aspect of the present invention a method of logging a well is provided which includes lowering into a borehole a string of tubing extending from the mouth thereof to the lowest point of interest therein and passing an exploring unit of a logging device through the string of tubing, and, more particularly, a method of logging a high pressure well is disclosed which includes providing in a borehole from the mouth thereof to the lowest point of interest a logging well or passageway containing a fluid having a pressure therein near the mouth of the borehole substantially less than the pressure in the borehole at the mouth thereof without the logging well or passageway, and then passing an exploring unit of a logging system through the logging well or passageway.

For a better understanding of the invention, reference may be had to the accompanying drawing in which the single FIGURE is a vertical sectional view through a well showing apparatus used in accordance with the present invention.

Referring to the figure more specifically, a well or borehole **10** is shown traversing several subsurface formations including a permeable formation **12** of which it is

desired to obtain an injectivity profile log. The upper portion of the well is shown as being provided with a casing **14** having a closed casing head **16**. A first string of tubing **18** passes through the casing head **16** downwardly through the well to a point near the bottom of the formation **12**. At the surface a pump **20** is connected to the casing head **16** through a meter **22** and is adapted to pump a stream of fluid **24** downwardly into the well through the annular space between the casing **14** and the tubing **18**. A second pump **26** it shown connected through meter **28** to the upper end of the tubing **18** and is adapted to pump a second stream of fluid **30** downwardly through the tubing **18**. The second stream of fluid **30** passes out the bottom end of the tubing **18** and upwardly around the tubing **18** until it meets the first stream of fluid **24** to form an interface **32** in the annulus between the tubing **18** and the wall of the borehole **10** and in the subsurface formation **12**. It can be seen that when the pumps **20** and **26** are adjusted to change their rates of pumping while the total amount of fluid pumped by both pumps remains constant, the interface **32** will generally be caused to move up or down in the hole depending upon the two pumping rates.

It should be understood that a single pump operating at a constant rate and an adjustable two-way valve may be used to change the relative rates of flow of the fluid flowing in the two streams **24** and **30**.

In accordance with this invention a second string of tubing **34** is lowered into the well **10** through the casing head **16**. A suitable plug **36** is attached to the lower end of the second string of tubing **34**. The second string of tubing **34** and the plug **36** are assembled so as to provide a complete pressure-tight seal between the interior and exterior of the string of tubing **34** within the well **10** to form a logging well through which a logging tool may be readily passed. A pressure-tight seal **38** is provided between the second string of tubing **34** and the casing head **16** to prevent the borehole fluids from discharging into the atmosphere.

Shown as suspended within the second string of tubing **34** is a logging instrument **40**, for example, a radioactivity logging system, the output of which is conducted upwardly through a cable **42** to a suitable recording device **44**. The logging cable **42** passes over a cable measuring device **46** which continuously indicates the depth of the radioactivity logging instrument **40** in the borehole. For extreme pressure cases, the second string of tubing **34** might collapse if it merely contained air. In order to prevent such a collapse the second string of tubing **34** may be filled with a fluid **48** heavier than gas, such as oil or water.

With the second string of tubing **34** and the plug **36** installed in the borehole, logs may be readily made during a time interval when fluids are being injected into a subsurface formation, when the well is being produced, or when the well is shut down.

During these intervals various types of logging tools may be run inside the second string of tubing to provide desired logs. For example, a gamma ray detector, a neutron gamma tool using a Geiger counter, a neutron gamma tool using a scintillation detector for gamma rays, a neutron-neutron log detecting thermal neutrons or other types of neutron-neutron logs or a density log using scattered gamma rays may be utilized.

A number of logs are desired during the time in which fluids are being injected into a predetermined formation, such as the permeable formation **12**.

To produce an injectivity profile log of, say, the permeable formation **12**, one of two streams introduced into the well **10** is tagged with a radioactive tracer and a log is produced to locate the interface between the two streams

by measuring the radioactivity emanating from the tagged stream, as described more fully in U.S. Patent No. 2,700,-734 granted to E. F. Egan and G. Herzog.

When fluids of different densities are injected into the well **10** scattered gamma or density logging may be employed to detect the interface between the two fluids of different densities. An advantage of using fluids of different densities is that neither of the injected streams need be tagged with a radioactive substance. Fluids of different densities such as gas and oil or oil and water may be used with a density contrasted by any two of the three fluids. As an example, the appropriate use of gas and oil would firmly establish an interface which would be detectable by the scattered gamma or density tool.

When the injection fluids are oil and salt water, a larger signal-to-noise ratio can be obtained by using radiation instruments producing a thermal neutron log since the chlorine in the salt water has a large cross section for thermal neutrons. A neutron gamma tool can also be passed through the second string of tubing **34** in this instance for determining the oil-salt water interface.

In general when the two stream injectivity method is being employed, if either of the two streams is anomalous with respect to the other as far as neutron cross sections or energy of gamma rays emitted after capture is concerned, then neutron logs may be used to differentiate between two streams. The injection of oil and salt water is an example of this in that one stream contains chlorine which has a high capture cross section for thermal neutrons and emits higher energy and more gamma rays per capture than does the hydrogen in the other stream. Accordingly, elements such as chlorine, boron or lithium may be added to one of the injected streams to differentiate between two streams. A very suitable substance which may be added to one of two streams of oil is carbon tetrachloride.

In regular water injection surveys, one stream could be more saline than the other. In order to obtain a clear indication of the interface using a thermal neutron log, a factor of two difference in salinity of water would be desirable. In general, it is desirable to provide thermal neutron logs when a high capture cross section gamma emitting element such as chlorine is used, because as the amount of chlorine is increased in hydrogenous fluid to 75,000 p.p.m., most of the neutrons are being captured by the chlorine and a further increase in the amount of chlorine will not change the number of high energy gamma rays. However, the diffusion length of a thermal neutron is still decreasing even at saturated salt water. Thus, a thermal neutron log can detect the difference between water of 100,000–200,000 p.p.m. of sodium chloride, whereas, a neutron gamma log cannot detect this difference. Accordingly, it can be seen that two streams of water can be used in the borehole with only a difference in the chlorine content. The use of chlorine has the added advantage that chlorine is easier to flush away from the borehole than sodium iodide which is often used as a radioactive tracer in formations since the sodium iodide tends to plate out.

In producing wells, when it is desired to determine the point of entry of gas, the desired information may be obtained simply by running a density log or neutron gamma log while the well is producing, shutting down the well and then running the log again. The difference in these two logs is indicative of where the gas is entering the well. For example, the response of a neutron gamma log will increase by a factor of three in going from a liquid filled to an air filled section of a borehole.

If gas is entering a well at one point there would be a constant rise in response above this point. For a linearly increasing response over the log when the well is shut down uniform gas entry would be indicated.

This technique could also be applied to obtain the point of oil entry into a producing well by making a thermal neutron log if the formation water were saline. In this instance the shut down fluid opposite the producing interval would normally be water. Then when producing the well oil enters into the well bore and the response of the thermal neutron logging instrument increases as the amount of chlorine decreases.

Although heretofore primarily radioactivity logging systems have been described in connection with this invention, it should also be understood that exploring units of electrical logging systems may be passed through the logging string of tubing **34**. Where the tubing **34** is made of conventional steel well tubing, a radioactivity logging system would, of course, be preferred, however, where the tubing **34** is made of a nonconductive and nonmagnetic material, such as an epoxy resin, an induction logging system could be utilized. Furthermore, an electrical resistivity logging system could be used by employing in the region of interest tubing having appropriately spaced insulated conductors electrically connecting known points exterior of the closed tubing **34** to known points within the tubing **34**, for example, as a composite pipe made of alternate conductor and insulator rings stacked in the direction of the longitudinal axis of the pipe.

Accordingly, it can be readily seen that an improved method of logging a well has been provided wherein there is little or no chance of the cable or exploring unit of the logging system becoming entangled or stuck in the borehole, and also, an improved method of logging a high pressure well has been provided which can be simply and safely performed. The present invention eliminates the need of well lubricators or stuffing boxes in well heads for packing off cables of logging systems, which lubricators or stuffing boxes have been found unsatisfactory at high well head pressures.

The present invention is particularly suitable for use in gas injectivity profile logging since the pressure in a gas column is nearly as great at the wall head as it is at the bottom of the well. At times the cable of the system logging these wells must be fed into the wells by hand when a lubricator or stuffing box is used at the well head since the weight of the exploring unit is not sufficiently heavy to pull the cable through the lubricator or stuffing box adjusted to prevent discharge of borehole fluids into the atmosphere.

Furthermore, it should be understood that the invention may be used for injectivity logging not only when two streams are employed but also when three streams, forming two interfaces, are being injected into a well, for example, as disclosed in U.S. Patent No. 2,869,642 granted to A. S. McKay and E. F. Egan.

Obviously, many modifications and variations of the invention as hereinabove set forth may be made without departing from the spirit and scope thereof and therefore only such limitations should be made as are indicated in the appended claims.

We claim:

1. Apparatus for logging a zone of interest in a high pressure well comprising means for providing a low pressure passageway from the mouth of the well through a high pressure seal at the well head to a point below the zone of interest, a logging unit, means for moving the logging unit through said passageway means and means for recording signals derived from said logging unit.

2. Apparatus as defined in claim 1 wherein said logging unit includes a source of penetrative radiation and a detector of radiation resulting in the borehole due to irradiation by said source.

3. Apparatus for logging a zone of interest in a high pressure well comprising a string of tubing disposed in the well, said string of tubing extending through a high pressure seal at the well head and having a closed lower end located at a point below the zone of interest, a logging unit, means for moving said logging unit through said string of tubing and means for recording signals derived from said logging unit.

4. Apparatus as defined in claim 3 wherein said logging unit comprises a source of penetrative radiation adapted to pass from said logging unit through said tubing string to conduct a log of said well and a detector sensitive to radiation resulting in the well due to radiation from said source and passing from said well through said tubing string to the logging unit for detection.

5. Apparatus for logging a zone of interest in a high pressure well having a seal at the mouth thereof, a string of tubing disposed in said well and extending from a point below the zone of interest through the seal of the well, means for plugging the lower end of said string of tubing, a logging unit disposed in said string of tubing, means for moving said logging unit through said string of tubing and means for recording the signals derived from said logging unit.

6. Borehole apparatus comprising a casing disposed at the upper end of a borehole, a casing head mounted on said casing, a string of tubing inserted in said casing head and extending to a given depth in the borehole and means for plugging the lower end of said string of tubing, said casing, casing head, string of tubing and plugging means being interconnected to form a pressure-tight seal between the interior of the borehole and the atmosphere.

7. In the method of logging a borehole traversing subsurface earth formations wherein a first fluid material is pumped downwardly through a tubing string inserted in the borehole to a depth below a zone of interest and a second fluid material having a different characteristic than said first fluid is simultaneously pumped downwardly through the annulus between the said tubing and the walls of the borehole and the pumping rates of said two fluids are adjusted and arranged to provide an interface between said two fluids in said annulus and a detecting means sensitive to the difference in said characteristic between said two fluids is passed through the borehole to locate said interface between the fluids, the improvements wherein a second tubing string having its lower end sealed from the pressure of the borehole is inserted into the borehole and said detecting means is passed through said borehole within said second tubing string to locate said interface between said two fluids whereby the detecting means is isolated from the high pressure environment of the borehole.

8. The method of claim 7 further characterized in that a liquid material is introduced into said second tubing string in order to increase the weight of said second tubing string.

9. In the method of logging a borehole traversing subsurface earth formations wherein a first fluid material is pumped downwardly through a tubing string inserted in the borehole to a depth below a zone of interest and a

second fluid material is simultaneously pumped downwardly through the annulus between the said tubing and the walls of the borehole and the pumping rates of said two fluids are adjusted and arranged to provide an interface between said two fluids in said annulus, one of said two fluids including a radiation emitting tracer material, and a detecting means sensitive to the radiation emitted by the tracer material in one of said two fluids is passed through the borehole to locate said interface between the fluids, the improvements wherein a second tubing string having its lower end sealed from the pressure of the borehole is inserted into the borehole and said detecting means is passed through said borehole within said second tubing string to locate said interface between said two fluids whereby the detecting means is isolated from the high pressure environment of the borehole.

10. The method of claim 9 further characterized in that a liquid material is introduced into said second tubing string in order to increase the weight of said second tubing string.

11. A method of logging a zone of interest in a high pressure well which comprises the steps of providing a high pressure closure system at the well head, providing a low pressure passageway from the mouth of the well through said high pressure closure system to a point below the zone of interest in the well, introducing a liquid material into said low pressure passageway in order to increase the weight of the material in said passageway, passing an exploring unit of a logging system through said low pressure passageway and recording the signals from said exploring unit.

12. A method of logging a zone of interest in a high pressure well having a seal at the mouth thereof which comprises the steps of passing through the seal of the well a string of tubing closed at the lower end thereof, lowering the tubing into the well so as to extend from the seal of the well to a point below the zone of interest, introducing a liquid material into said string of tubing in order to increase the weight thereof, while maintaining the integrity of said seal passing an exploring unit of a logging system through the string of tubing and recording the signals derived from said exploring unit.

References Cited in the file of this patent

UNITED STATES PATENTS

2,335,409	Hare	Nov. 30, 1943
2,540,049	Hinson	Jan. 30, 1951
2,662,985	Good	Dec. 15, 1953
2,700,734	Egan et al.	Jan. 25, 1955
2,805,346	Piety	Sept. 3, 1957
2,869,642	McKay et al.	Jan. 20, 1959