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Oct. 21, 1947. R. W. FRENCH, JR 2,429,577

METHOD FOR DETERMINING FLUID CONDUCTANCE OF EARTH LAYERS

Filed Nov. 22, 1944 2 Sheets-Sheet 1

Fig. 1

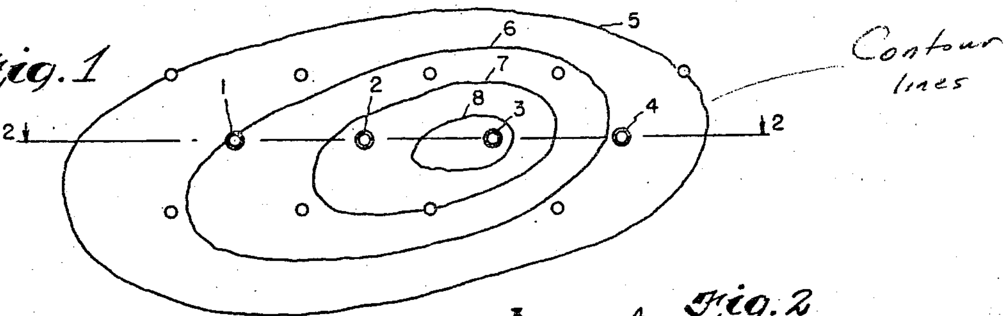
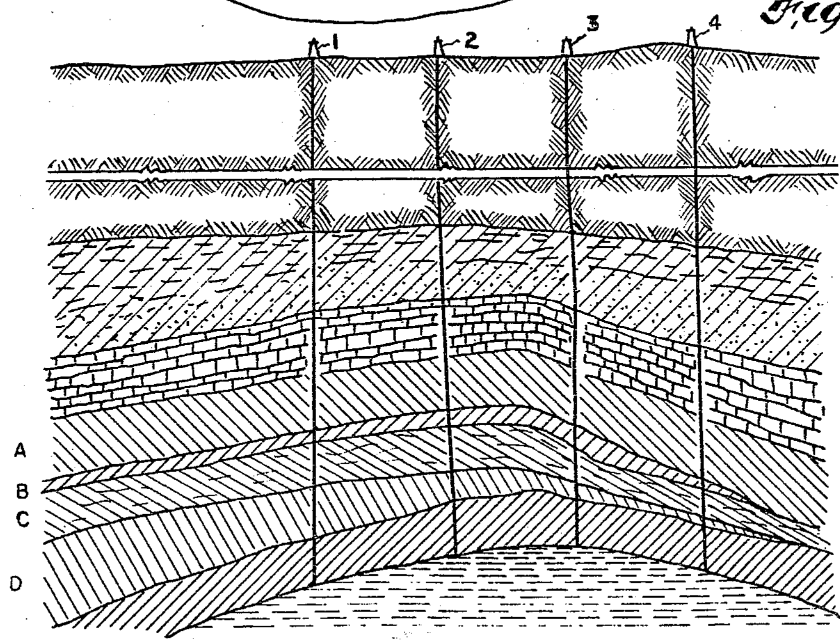


Fig. 2



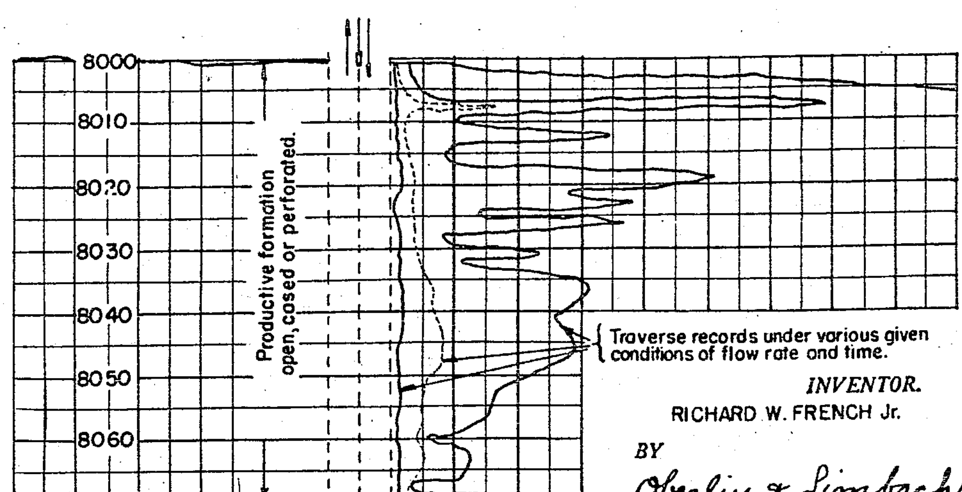


Fig. 5

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METHOD FOR DETERMINING FLUID CONDUCTANCE OF EARTH LAYERS

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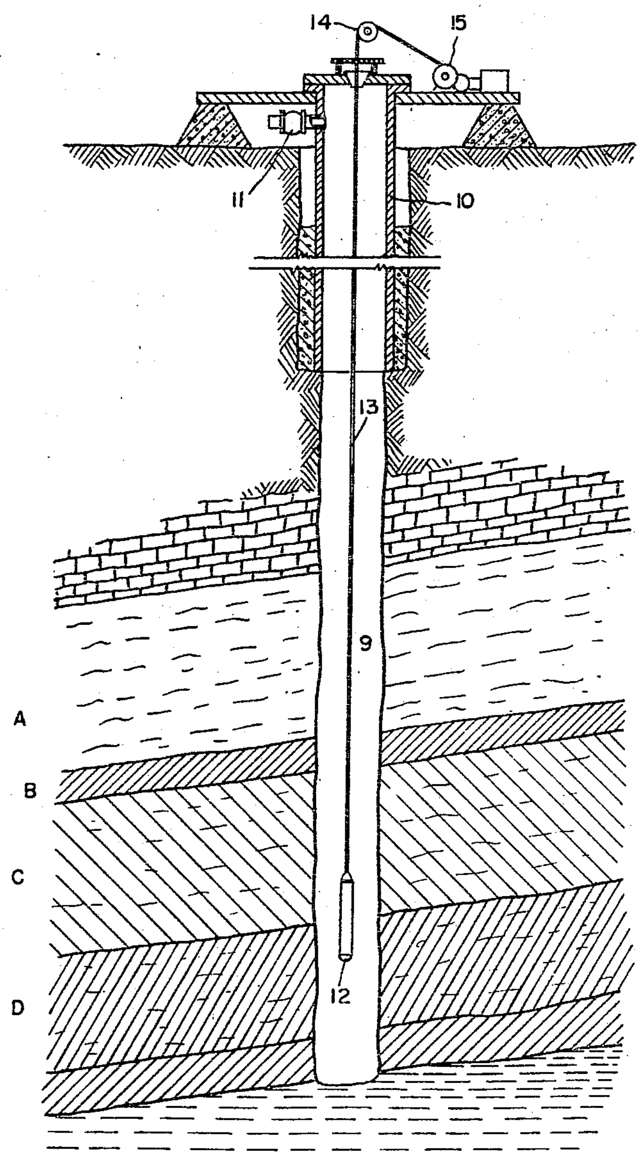

Fig. 3

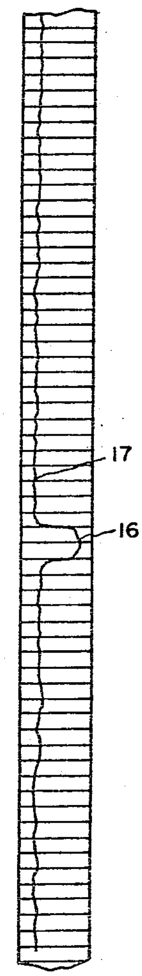

Fig. 4.

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METHOD FOR DETERMINING FLUID CONDUCTANCE OF EARTH LAYERS

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4 Claims. (Cl. 250—83)

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This invention relates as indicated to a method for determining fluid conductance of earth layers, and more specifically to a method of locating gas and tracing its path through earth formations by the use of penetrating boreholes and the injection of treated gas into one or more of said boreholes.

In the production of oil and gas from substrata, knowledge of the content and fluid-transmitting properties of the various layers of the generally nonhomogeneous productive horizons is essential to successful operation. The deleterious effects of gas bypassing, coning, premature water fingering or encroachment, and lack of selective control over fluid extraction from layers of widely different effective permeabilities are well known. Particularly in operations where gas is injected or cycled or where other fluids are forced into the reservoir rocks to maintain pressure for maximum recovery, direct knowledge of the relative permeability and its effects upon fluid distribution and flow is a vital necessity.

At present this information is not directly obtainable but must be deduced through expensive and tedious coring operations during drilling of the well followed by laboratory analysis of the cores and interpretation based upon experience and estimates of the saturation effects upon fluid conductance. Even if this laborious approach yields usable approximations for the relative distribution of fluid conductance in depth, future values change as production progresses because of the resulting alteration of fluid saturation with its well-known attendant effects upon relative permeabilities.

It is among the objects of my invention to provide a method having all of the above named advantages with none of the disadvantages inherent in the described prior art procedure.

Other objects of my invention will appear as the description proceeds.

To the accomplishment of the foregoing and related ends, said invention then comprises the features hereinafter fully described and particularly pointed out in the claims, the following description and the annexed drawings setting forth in detail certain illustrative embodiments of the invention, these being indicative, however, of but a few of the various ways in which the principle of the invention may be employed.

In said annexed drawings:

Fig. 1 represents a plan or areal view of a common type of oil field;

Fig. 2 is a section showing structural relation of the wells illustrated in Fig. 1;

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Fig. 3 is a diagrammatic representation of apparatus which may be used in carrying out the method of my invention;

Fig. 4 shows a typical trace in simplified form of the detector record made in carrying out the method of my invention; and

Fig. 5 is a more elaborate and detailed showing of the type of record made during the logging operation performed as one step in the method of my invention.

Broadly stated, this invention comprises a method for determining the fluid conductance of a sub-surface stratum which comprises impressing such stratum with a radioactive gas and then measuring the radioactive characteristic of such stratum.

From the foregoing broad statement of my invention, it will be observed that this method may be used for various specific purposes. This method may be used for the purpose of determining the relative porosity or fluid conductance of the different subsurface stratum intersected by a borehole. This result may generally be achieved by impressing the exposed face of the strata in the borehole with a radioactive gas and then logging the borehole with a detector sensitive to radioactive materials.

The method of my invention may also be used to determine the lateral or areal distribution or extent of a porous stratum. In achieving this result, the face of such layer as intersected by a borehole will be impressed with a radioactive fluid and then other boreholes intersecting the same stratum logged with a detector sensitive to radioactive materials.

In either of the specific cases above identified, refinements, as for example degree of fluid conductance, may be determined by varying factors such as conditions of flow rate and time.

Before proceeding with a more detailed description of the invention, it may be well to refer to the accompanying drawings for an explanation of the mode of carrying out a representative mode of procedure in accordance with my improved method.

Referring now, therefore, more specifically to the drawings and more especially to Fig. 1, there is here illustrated a plan or areal view of a common type of oil field having three rows of wells illustrated, with one row of wells respectively designated by the ordinals 1, 2, 3, and 4, penetrating the substrata indicated by contour lines 5, 6, 7, and 8.

In Fig. 2 is shown the structural relation of the wells depicted in Fig. 1, as well as the various earth strata such as those designated by the reference characters A, B, C, and D intersected by the boreholes of the wells.

In Fig. 3 will be found a diagrammatic representation of a common arrangement used for the practice of this invention. Thus, Fig. 3 may be termed an enlarged view of a portion of one of the wells shown in Fig. 2. While the well illustrated in Fig. 3 is shown as uncased, it should be noted, however, that my invention may be practiced with wells which are cased or uncased, provided the casing in the well through which the radioactive gas is introduced is perforated opposite the face of the stratum to be impressed with the radioactive gas.

In the upper end of the borehole 9, a casing 10 is provided with a connection 11 through which the radioactive gas may be introduced to the wellbore by any conventional means. A detecting instrument 12 is suspended in the wellbore 9 by means of a line 13 which passes over a measuring sheave 14 and winds on a hoist drum 15.

The instrument 12 may be any one of several types of radioactive well loggers which usually consist of a container filled with high pressure inert gas containing two electrodes connected to a surface micro-ammeter through suitable amplifying and recording equipment. In the presence of radioactive material, emanation of gamma rays at a given level in the well ionizes the inert gas, thus permitting flow of a small amount of current through the electrodes.

The construction and operation of the measuring sheave 14 and the related apparatus is so well-known to those familiar with the art that a further description thereof is unnecessary. Suffice it to say that there will be employed in conjunction with the instrument 12, and the measuring sheave 14, recorded apparatus on which will be traced a record of the degree of energization of the instrument 12 by the radioactive materials influencing the same as the instrument is moved vertically through the borehole.

Fig. 4 is a diagrammatic representation in simplified form of such a record made under such conditions that a longitudinally extending interval of given magnitude on the record corresponds to a vertical interval of given magnitude in the borehole itself. The lateral bulge at 16 in the trace 17 denotes an area within which the instrument 12 has been influenced by the presence of a radioactive material.

In this connection, it should be observed that no logging record as usually made will have the simplified form illustrated in Fig. 4. This is due to the fact that even when no radioactive material is introduced to the strata being explored, the logging of such strata by a radioactivity sensitive instrument will show that the natural earth formations have varying influences on the instrument. In making any final determination in accordance with the method of my invention, therefore, it will generally be necessary to first log the well with a radioactivity sensitive instrument, and before any radioactive material is introduced to the borehole. With this original data carefully prepared and recorded, the subsequent loggings may then be made to determine the distribution in the strata intersected by the borehole of the introduced radioactive material, which latter material was introduced through either the borehole being logged or another borehole intersecting the same stratum or layer. The comparison of the trace record of the initial logging with the trace record of the logging performed after the introduction of the radioactive material will provide the desired data from which the characteristics of the stratum may be determined in accordance with the method of my invention.

Fig. 5 is a representation of an actual record made by logging a single well under various given conditions of flow rate and time. For complete data on the characteristics of a given formation, it will generally be necessary to log the well several times under different conditions of injection rate and pressure since only in this way is it possible to separate those zones which do not take gas at a given injection rate and pressure from those that do. The permeability value of the various sections will vary widely and erratically throughout ordinary producing zones. This is a condition which requires the use of the present invention for a full understanding of the producing zone.

The radioactive gas is introduced to either completed wells or the method of my invention may be used during the drilling stages of a well and prior to the final completion in the permanent producing horizon. In other words, it is possible to introduce the radioactive gas by use of a tubing and packer prior to the installation of the oil string in the well for the purpose of delineating gas carrying zones. Likewise, similar tests may be made prior to completion of the well to determine whether activated gas injected in surrounding wells is being produced in sections of the subject well.

Any gas which is not itself radioactive, including air, may be used as a carrier for the radioactive emanation in oil field use. The radioactive material thus introduced may be either a material which is supercharged or energized by primary radiations or may be a natural substance having sufficient radioactivity so that its presence can be determined by instruments of the character described.

One type of such natural substance having radioactivity is commonly known as radon which is an exceedingly radioactive gas formed when radium bromide or a current of air is bubbled through a solution of a radium salt. Examples of commercial materials available at reasonable prices which may be used in the preparation of radon are ores containing radioactive material in various compositions and from purified salts such as radium sulphate, zinc sulphide activated by radium, and other prepared radium salts. Other materials are radioactive cobalt and other isotopes found or prepared in conjunction with radium-bearing ores such as carnotite and others carrying uranium, thorium, bactinium, etc. as found in pitchblende, monazite, tyuyamunite, thorianite, thorite, uranimite, etc. Either air or the natural gas customarily used for repressuring may be used as the vehicle for carrying the radioactive material.

The preferred concentration range of the radioactive gas in the carrier substance is of the order of 3×10^{-4} curies per thousand cubic feet of gas injected up to 7.5×10^{-3}. Concentrations above and below the values given will be found useful in some cases depending upon the desired life period, total volume of activated gas injected, and the nature of the formations under investigation.

Due to the fact that the porosity or conductance characteristics of a stratum many times change during the life of a well, it is preferred, in carrying out my method, to use a radioactive substance which has a relatively rapid rate of deterioration so that a particular injection of the radioactive material will not be contaminated by previous injections in the same or adjacent wells.

Within the range of concentrations of the radioactive material as previously given, changes in the density of the activated gas does not have any material influence on the accuracy of the results since the proportions of the active material mixed with the injection medium are quite small. The pressure at which the radioactive gas enters the well is immaterial so long as the gas stream itself has sufficient pressure to overcome the receiving formation pressure plus the friction accompanying that certain rate of flow. Ordinarily it will not be necessary to pump gas into the well during the entire logging operation, although such practice may be resorted to in the case of logging certain types of formations. It will generally be sufficient to introduce merely enough of the radioactive gas into the formation to provide a temporary concentration which will reveal through traverses of the detector the particular segment of the horizon which takes the gas or, conversely, produces it in the case of a well receiving the radioactive gas from injection in a neighboring well.

A study of one well by the method of my invention discloses that portion of the section which takes or produces gas and permits computation of the relative permeability of such portion. After locating the particular section which does conduct the gas, as differentiated from the unaffected portion of the pay horizon in any one well, the operator may then learn, by logging surrounding wells, not only that the producing formation is at least unobstructed between the two wells, but also how much of the oil saturated pay lies unaffected by the path of the injected gas.

Remedial work can then be done in the subject well to cement off the section taking the gas, if desirable, so that the effects of pressure injection may be applied to the well's less permeable volumes in depth and in areas which have hitherto been unaffected by the injection operations. Other producing wells may be recompleted selectively in the lower permeability sections, thus producing predominantly oil instead of gas which had been contributed by the section taking the gas. The main object of the injection is to learn which portion of the pay zone should be shut off to control the unrestricted flow of gas and obtain maximum production of oil. The main advantage of the rapid decay of the radioactivity resulting from radon is the fact that subsequent

tracing may be done at a later date when reservoir conditions have changed; this would not be possible if a relatively permanent source of radioactivity were used, because the original injection would continue to mask the effects of later changes and conditions.

Other modes of applying the principle of the invention may be employed, change being made as regards the details described, provided the features stated in any of the following claims or the equivalent of such be employed.

I, therefore, particularly point out and distinctly claim as my invention:

1. A method for determining the fluid conductance of a sub-surface stratum which comprises impressing such stratum, in a local area, with a radioactive fluid and measuring the increase in the radioactive characteristics of such stratum at a point laterally remote from said local area.

2. A method for determining the fluid conductance, areally, of a sub-surface stratum which comprises impressing such stratum with a radioactive fluid in a local area and measuring the increase in the radioactive characteristics of such stratum over the entire laterally extending area.

3. A method for determining the location of gas flow in formations exposed to a borehole which comprises injecting gas, previously rendered radioactive, into at least one input well, then traversing the boreholes of the input and neighboring wells with a detector which records relative concentration of radioactive material.

4. In the production of hydrocarbons from a subsurface formation, a method for determining the path of both injected and produced gas in depth and areally, comprising use of at least two wells in a common pool respectively for gas injection and production, said input gas having been previously rendered radioactive by the addition of a radioactive component, followed by exploration in various boreholes in said common radioactive pool by a well logger to determine the formation level showing maximum radioactivity.

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