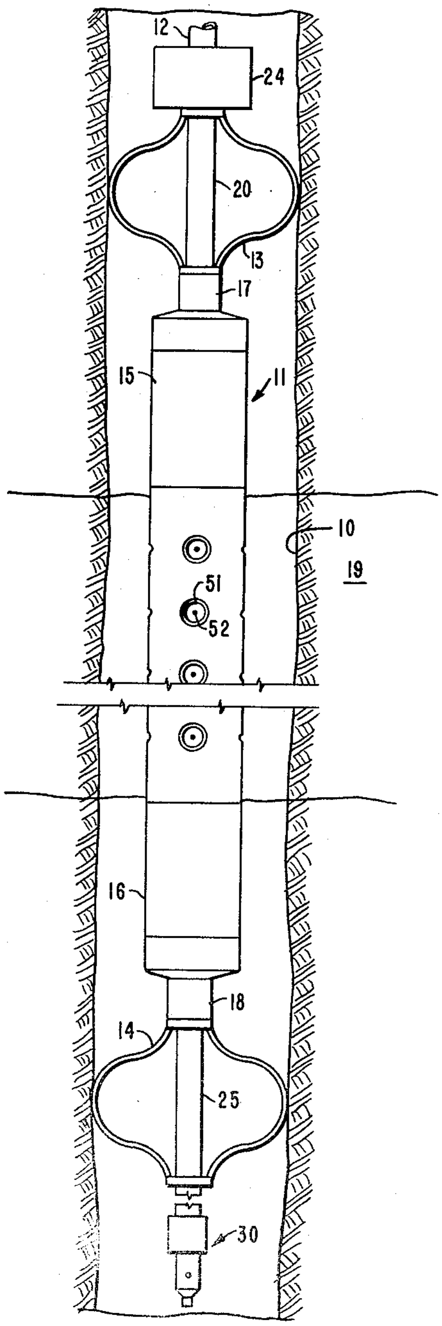

FIG. 1

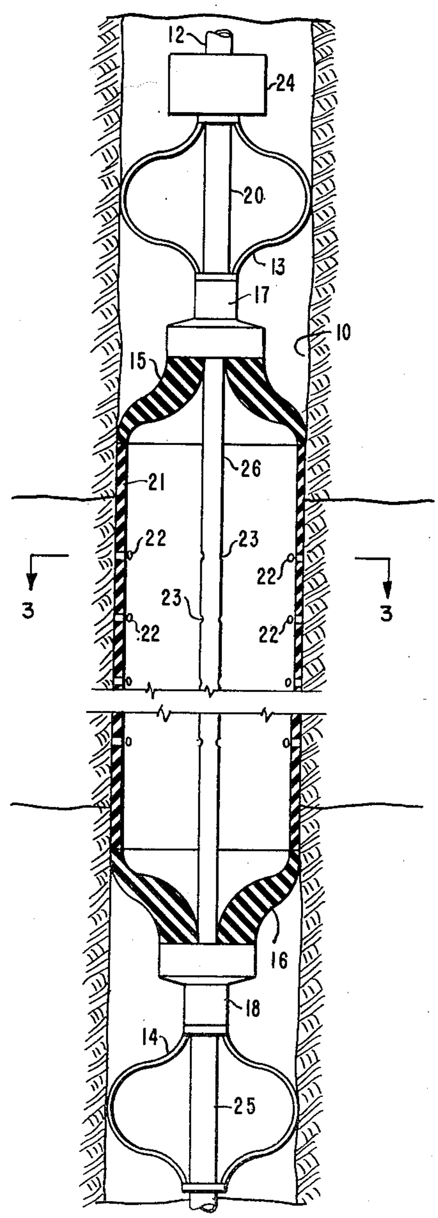

FIG. 2

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May 4, 1965 J. M. PALMER 3,181,608

METHOD FOR DETERMINING PERMEABILITY ALIGNMENT IN A FORMATION

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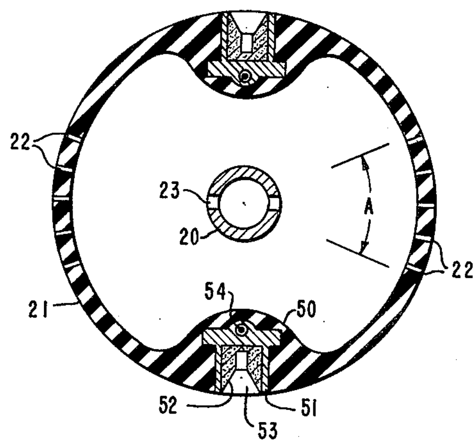

FIG. 3

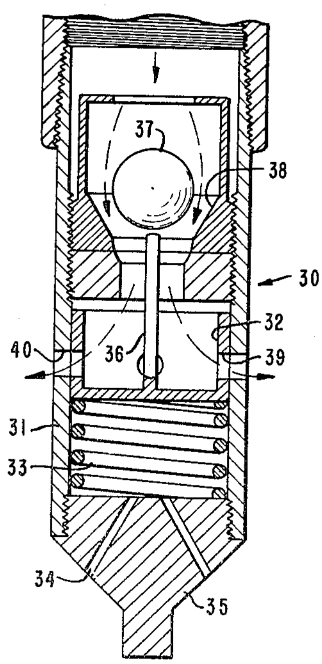

FIG. 5

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METHOD FOR DETERMINING PERMEABILITY ALIGNMENT IN A FORMATION

Filed Aug. 11, 1961 4 Sheets-Sheet 3

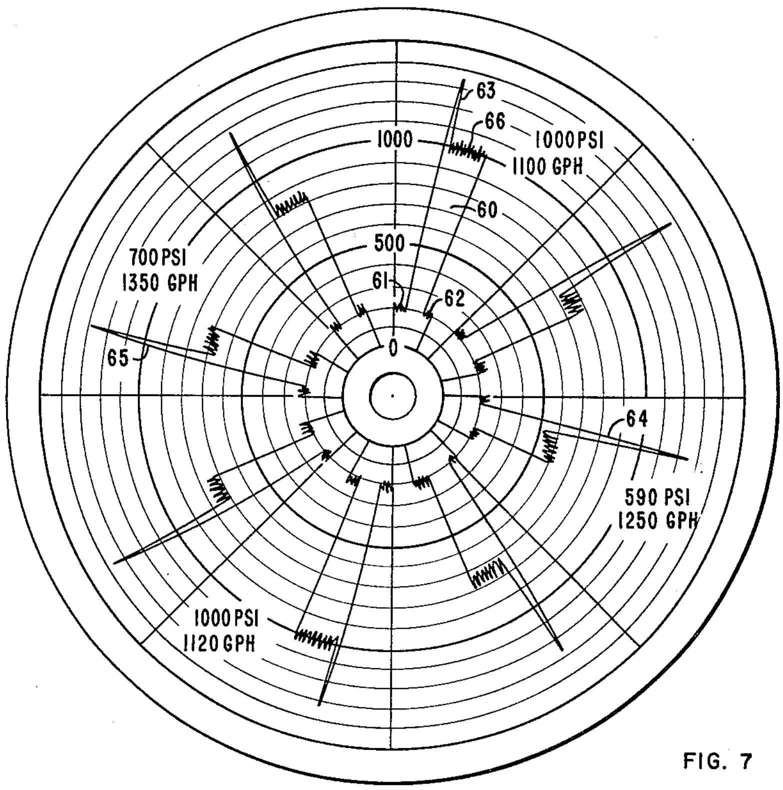

FIG. 7

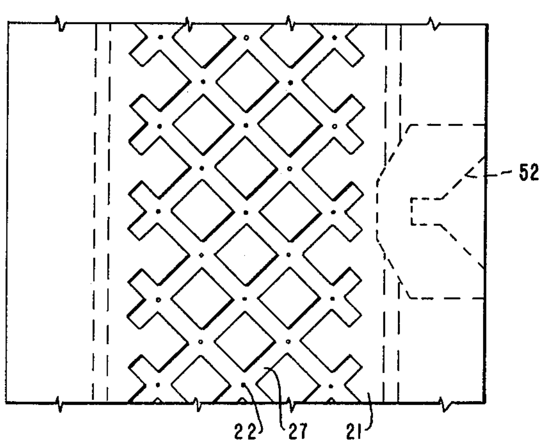

FIG. 4

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METHOD FOR DETERMINING PERMEABILITY ALIGNMENT IN A FORMATION

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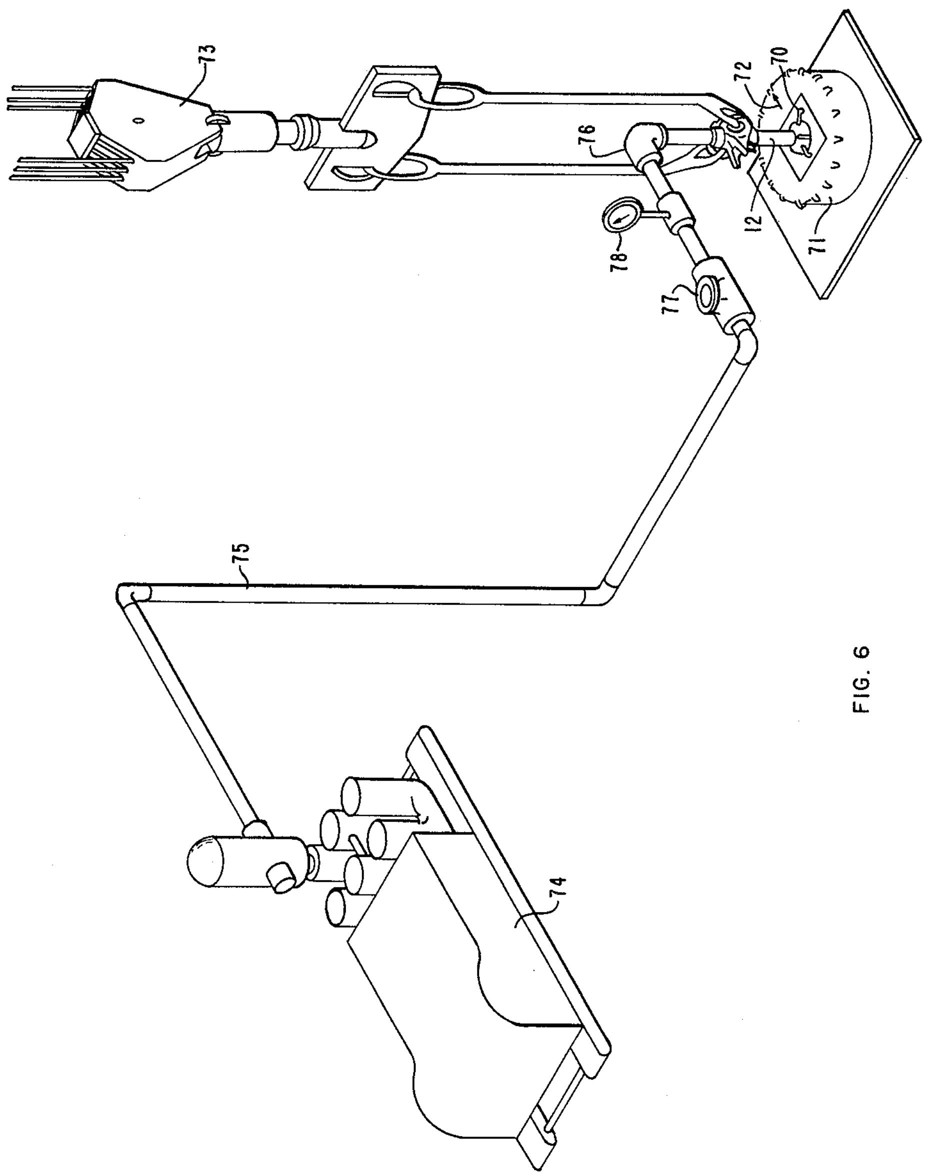

FIG. 6

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United States Patent Office 3,181,608
Patented May 4, 1965

3,181,608
METHOD FOR DETERMINING PERMEABILITY ALIGNMENT IN A FORMATION

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Filed Aug. 11, 1961, Ser. No. 130,802
3 Claims. (Cl. 166—4)

This invention pertains to drilling well equipment and more particularly to a method which determines the direction of permeability alignment in an earth formation penetrated by a borehole and provides a method for perforating the formation at any desired angle to the direction of permeability alignment, and for directionally treating the formation; all of these services to be accomplished with one run of the tool.

In oil wells drilled in carbonate formations it is often necessary to perforate the formations and treat them by acidizing or fracturing to produce the petroleum in place. In order to increase the effective drainage radius of the borehole to the maximum extent the perforations and subsequent treatment should be at right angles to any preferred direction of permeability alignment in the formation. It would be possible, under favorable circumstances, to obtain cores during the drilling operations and investigate the cores to determine the permeability alignment of the formation. However, the results of this procedure have not generally been satisfactory due to the expense and difficulty of obtaining cores and the problems associated with determining the azimuth of the core in relation to the formation.

In addition to the above described coring operation various logging methods are in use to determine the apparent porosity of the various formations penetrated by a borehole. While the use of various logging methods provides some information as to the apparent porosity of the formation they do not supply information as to the direction of lateral permeability variations in the formation.

The availability of information that indicates the apparent direction of permeability alignment in a formation would be useful in many fields of petroleum operations. For example, the information could be used to predict formation permeability trends, and also to indicate the most efficient disposition of input and withdrawal wells in a secondary recovery operation.

Accordingly, it is the principal object of this invention to provide a method capable of determining the preferred direction of permeability alignment that may exist in a formation penetrated by a wellbore.

A further object of the present invention is to provide a method which employs an apparatus that seals off from overlying and underlying layers a formation whose permeability alignment is to be determined and then forces fluid into the formation in a plurality of directions to determine the preferred direction of permeability alignment of the formation.

A still further object of the present invention is to provide a method for determining the directional permeability of a formation and then perforating and treating the formation in a direction normal to the preferred direction of permeability alignment, all being accomplished with a single run of the tool in the wellbore.

The above objects and advantages of this invention are achieved by providing an apparatus having two expandable packing members spaced along a tubular support member. The packing members are disposed to seal off the formation to be tested when pressurized fluid is supplied to the apparatus to expand the packing members. A flexible expandable tubular member is attached to the packing members by a fluid tight seal and provided with at least one row of longitudinal holes or openings. Preferably two or more rows of holes that are spaced on diametrically opposite sides of the tubular member are utilized. A series of perforating charges are mounted on the outer surface of the flexible tubular member, and aligned normal to a plane passing through the axis of the holes.

The method of this invention consists of lowering the apparatus into the borehole and disposing it opposite the formation to be tested. Next, fluid is pumped into the tubular support member to expand both the packing members and the flexible tubular member into contact with the formation. After the members have been expanded the pressurized fluid will flow through the holes formed in the flexible tubular member and into the formation. The rate of flow and the pumping pressure of the fluid will be related to the permeability of the formation interval opposite the perforations in the packer. Thus, by determining the direction for which the largest volume of fluid is injected per pound of pump pressure, the directional alignment of maximum permeability of the formation will be determined. Once this direction is determined the formation can be perforated normal thereto (or at any other angle) by utilizing the perforating charges disposed on the outer surface of the flexible tubular member.

The above objects and advantages will be more easily understood from the following detailed description of a preferred embodiment when taken in conjunction with the attached drawings, in which:

FIGURE 1 is an elevation view of an apparatus constructed in accordance with this invention and disposed in a borehole;

FIGURE 2 is the vertical section of the apparatus shown in FIGURE 1 with the packing members and the flexible tubular member expanded into contact with the formation;

FIGURE 3 is a horizontal section taken along the line 3—3 of FIGURE 2 and showing the wall construction of the flexible tubular member;

FIGURE 4 is an enlarged elevation view of a portion of the expandible sleeve shown in FIGURE 1.

FIGURE 5 is a vertical section of the differential pressure valve disposed at the lower end of the apparatus shown in FIGURE 1;

FIGURE 6 is a perspective view of the surface equipment used to inflate the sleeve shown in FIGURE 1; and

FIGURE 7 is a representative chart of a recording obtained when operating this invention.

Referring now to FIGURE 1, there is shown an apparatus 11 constructed in accordance with this invention disposed in a borehole 10. The permeability testing apparatus 11 may be lowered into the borehole by various means, for example, a tubing string 12 may be used. The tubing string 12 in addition to providing a means for lowering the permeability testing apparatus into a borehole provides means for rotating the tool after it is lowered into the borehole. Of course, the use of a tubing string also provides a simple means by which fluid may be pumped into the interior of the packing members and the flexible tubing member to expand them into contact with the formation. The permeability testing apparatus is centered in the borehole by means of a plurality of circumferentially spaced upper centering springs 13 and lower centering springs 14 whose construction and use is well known in the art. An expandable packing member 15 is disposed at the upper end of the tool and has its collar 17 secured in a fluid tight manner to the tubular support 20 of the permeability testing apparatus. A semilar expandable packing member 16 is secured to the lower end of the tubular member 20 by means of a collar 18. The packing members may be attached to the collars by various means as by molding the flexible packing members directly to the collars. The collars may then be secured to the tubular supports 20 and 25 by means of threads or the like.

Referring now to FIGURE 2, there is shown a vertical section of the packing member shown in FIGURE 1. An elongated flexible elastic sleeve member 21 is coupled or sealed at opposite ends to the expanding packing members 15 and 16. The seal between the elastic sleeve 21 and the packing member may be effected by any means desired or the packing members and the sleeve may be molded from one piece of flexible elastic material, for example, rubber or the like. At least two vertical rows of holes or openings 22 are formed in the center portion of the elastic sleeve 21. As is seen in FIGURE 3 and FIGURE 4, several vertical rows of small size openings 22 are formed on each side of the sleeve 21 and disposed on diametrically opposite sides of the sleeve 21. The rows of holes are preferably circumferentially spaced over the surface of the sleeve 21 to include an angle A of approximately 45 degrees. The two collars 17 and 18 of the packing members are attached to a tubular member 26 by any desired means such as threaded connections or the like. The tubular member 26 maintains the proper alignment between the collars in addition to providing the necessary support for the packing members and sleeve 21. A series of openings 23 are formed in the tubular member 26 between the two packing members 15 and 16 to provide a means by which fluid may be pumped into the interior of the flexible sleeve 21 and the two packing members to expand them into contact with the formation.

As shown in FIGURE 4 the openings 22 in the sleeve 21 are preferably of small diameters and connected by a network of shallow channels 27 molded or otherwise formed in the outer surface of the sleeve 21. The channels 27 are on the order of 1/16 inch deep and insure maximum access of the fluid pumped into sleeve to the porous portions of the formations. The openings 22 must be maintained small to restrict the volume of fluid pumped into the formations to permit operation of the differential valve 30 as explained below.

Disposed at the lower end of the apparatus shown in FIGURE 1 is a differential pressure valve 30 designed to open whenever the pressure differential between the borehole 10 and the interior of the permeability testing tool exceeds certain limits. The construction of this valve is shown in greater detail in FIGURE 5.

Referring now to FIGURES 5, there is shown the valve 30 having a valve body 31 with a piston 32 disposed for movement therein. The piston is urged in an upward direction by means of a compression spring 33 held in position by an end cap 35 that threads into the lower end of the valve body 31. The end cap 35 is provided with a series of openings 34 in order that the bottom of the piston 32 will be subject to the pressure of the fluid present in the borehole 10. A vertical member or post 36 extends from the upper surface of the piston and is disposed to lift a ball member 37 from its seat 38 whenever the piston travels in an upward direction. The piston is provided with a series of ports or openings 39 which are aligned with ports 40 formed in the valve body 31 when the piston is in its upper position. From the above description it can be appreciated that normally the piston 32 will be urged to its upper position by the spring 33 thus aligning the ports 39 and 40 to permit free flow of fluid between the borehole 10 and the interior of the sleeve 21. Whenever the pressure on the top of the piston exceeds the combined force of the spring 33 and the pressure of borehole fluid acting on the bottom of the piston, the piston will be forced in a downwardly direction permitting the ball to seat on the surface 38. This will close off the communication between the interior of the sleeve member 21 and the borehole as a result of the ports 39 and 40 moving out of alignment.

From the above description it can be readily appreciated that there has been provided an apparatus which may be readily lowered into a wellbore 10 by means of the tubing string 12. The differential pressure valve 30 will permit the pressure between the interior of the tool and the borehole to equalize as the apparatus is lowered until it is located at the elevation of the formation 10 to be tested. When located at the proper position fluid is pumped into the interior of the apparatus by means of the tubing string 12, the tubular support member 20 and 26. As the pressurized fluid is introduced into the interior of the testing member at a rate higher than the normal circulating rate it will close the differential pressure valve 30, and will expand the packing members 15 and 16 into contact with the wall of the borehole, thus sealing off the formation 19. Continued pumping at a pressure greater than that which will allow the differential valve to open again will then force the fluid out through the openings 22 of the sleeve 21 into the formation. The rate of the fluid pumped and the pump pressure required will be related to the permeability of the formation opposite the small openings in the expanded flexible member. After the pumping rate has stabilized and records are obtained the pressure is then reduced to permit the sleeve member to collapse, the differential valve to reopen, and free circulation through the tool is resumed. The apparatus may then be rotated to a new position and the operation repeated. These operations are repeated until the position is found that results in the maximum flow of fluid with the minimum pump pressure, which will be the direction of preferred permeability alignment within the formation interval tested. Once the direction of preferred permeability alignment is determined the azimuth may be recorded using an azimuth detecting means 24 located at the top of the apparatus. A suitable azimuth detecting and recording means is shown in Patent 2,659,160. The formation may be perforated normal to this direction (or in any other desired direction) as described below.

Again referring to FIGURE 3, there is shown thickened sections 50 formed in the wall of the sleeve member 21. The thickened sections are disposed on diametrically opposite sides of the sleeve member 21 in a plane at right angles to the openings 22. Disposed within the thickened section 50 are perforating charge supporting members 51. These supporting members are cup shaped chambers for supporting shaped charges as shown in FIGURE 1, and may be molded in the member 21 when it is formed or may be fastened therein by any well known means. The cup shaped members 51 are disposed to hold a shaped jet perforating charge 52. A suitable firing circuit 54 is also disposed in the thickened section 50 and couples all of the perforating charges together and to a firing device located just above the tool, and detonated by some method such as dropping a bar into the tubing from the surface. For example the firing circuit and actuating means shown in Patent No. 2,154,859 may be used. After the preferred direction of permeability alignment of the formation has been determined, the formation may be perforated at right angles to this direction (or in any other direction) by merely energizing the firing circuit 54 described above. This will cause the perforating charges to fire outward into the formation to perforate it. The apparatus may then be repositioned in the borehole and the formation treated by acidizing or fluid fracturing in the desired direction through the openings 22.

By disposing the perforating charges in the outer surface of the sleeve member 21 and then expanding the member firmly against the formation wall, more efficient perforating can be accomplished since the charges will not be required to travel through the borehole fluid before they reach the formation. The disposition of the perforating charges directly on the sleeve member permits the determination of the permeability alignment, and the perforating and treating of a formation interval with a single trip of the apparatus into the borehole. In some cases it may not be desired to perforate the formation but only determine its permeability alignment and treat in an appropriate manner. In these cases the same apparatus may be used and the perforating charges omitted or an apparatus may be constructed without provision for the perforating changes.

Referring now to FIGURE 6, there is shown a perspective view of the surface equipment for pumping fluid into the elongated member to expand it as well as the equipment required to measure the flow rate and pressure of the fluid being pumped. The tubing **12** that is used to support the instrument in the borehole is held in position by the use of ordinary slips **70** and the opening in the rotary table **71**. In addition, the rotary table may have a reference line **72** incribed thereon to permit the downhole tool to be positioned in a plurality of oriented directions around a periphery of the borehole. The pipe **12** is raised and lowered in the borehole by the derrick **73** of a customary drilling rig.

The fluid for expanding the downbore tool is applied by the mud pump **74** through a pipe **75** that is coupled to the end of the tubing string **12** by means of a swivel joint **76**. Disposed in the pipe **75** is a flowmeter **77** and recording pressure gage **78**. The flowmeter **77** should measure the rate of flow in units of time, for example, in gallons per hour. An alternative to the use of the flowmeter would be to count the strokes of the mud pump **75** and convert the strokes to volume. The recording pressure gage **78** is preferably of the type which utilizes a circular chart that is driven by a clockwork mechanism.

Referring now to FIGURE 7, there is shown the sample chart from the recording pressure gage **78** of FIGURE **6** with the flow rates noted thereon. From the chart of FIGURE 7 it is seen that the downhole tool was rotating in approximate 45 degree increments to survey the entire periphery of the borehole at the location of the formation being tested. Referring now to a particular signal **60** appearing on the chart of FIGURE 7, the low pressure recordings **61** and **62** reflect the pump pressures when the packers **15** and **16** of FIGURE 1 are deflated and circulation of the fluid is primarily through the differential pressure valve **30**, located at the bottom of the tool. The peak reading **63** reflects the pressures required to close the differential valve and inflate and packer against the borehole. The steady pressure readings **66** reflect the pressure required to pump fluid into the formation being tested after the differential valve closes.

The rate of pumping in gallons per hour is recorded on the chart record for each directional setting of the downhole tool. The rate of flow in combination with the steady pressure provide a ratio of gallons pumped per pound of pumping pressure. This ratio provides a relative measure of the permeability of the formation for each of the individual directional settings of the downhole tool. Thus, it is seen that for the signal **60** the ratio between the rate of flow and the pressure, i.e., 1100/1000 is equal to 1.10 while for the signal **64** the ratio is approximately 1250/590 or 2.12. Accordingly, for the particular formation tested the porosity in the direction indicated by the signals **64** and **65** is approximately twice the porosity of the formation in a direction normal to this.

If desired additional directional readings may be obtained although in most cases one reading for every 45° increment is sufficient. Furthermore, it is normally only necessary to take readings through 180° since the instrument is provided with two sets of openings in the flexible sleeve **21**.

While only a single embodiment of this invention has been described in detail, many modifications may be made within its broad spirit and scope. Accordingly this invention should not be limited to the details described for the purpose of illustration.

I claim as my invention:

1. A method for determining the alignment of lateral permeability variations in a formation penetrated by a borehole comprising: sealing off a section of the borehole including at least a portion of said formation; injecting a fluid into the sealed off portion of the formation in controlled directions; detecting the azimuth of the direction in which the fluid is injected; rotating the point at which the fluid is injected in increments of about 45° to attempt injection around the entire periphery of the borehole and recording the rate of injection and corresponding pressure as the fluid is injected in each direction increment.

2. A method of directionally perforating a formation penetrated by a borehole comprising: sealing off a section of the borehole including at least a portion of said formation; injecting a fluid into the formation in a controlled and measured direction, rotating the direction of the injection of said fluid in increments to include the entire periphery of the borehole; detecting the rate of injection and pressure of the fluid in each of said directional increments to determine the direction of maximum rate and minimum pressure; orienting a perforating device in a direction related to the direction of maximum flow and minimum pressure and perforating the formation in the oriented direction.

3. A method for determining directional permeability alignment and treating a formation, said method comprising: sealing off a section of a borehole including at least a portion of said formation; injecting a fluid into the formation in a controlled and measured direction; rotating the direction of injection of said fluid increments to include the entire periphery of the borehole; detecting the rate of injection and the pressure of the fluid in each of said directional increments to determine the direction of maximum rate and minimum pressure; orienting a perforating device in a direction related to the direction of maximum flow and minimum pressure, perforating the formation in the oriented direction and then injecting a treating fluid into the formation in said oriented direction.

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