

June 7, 1966

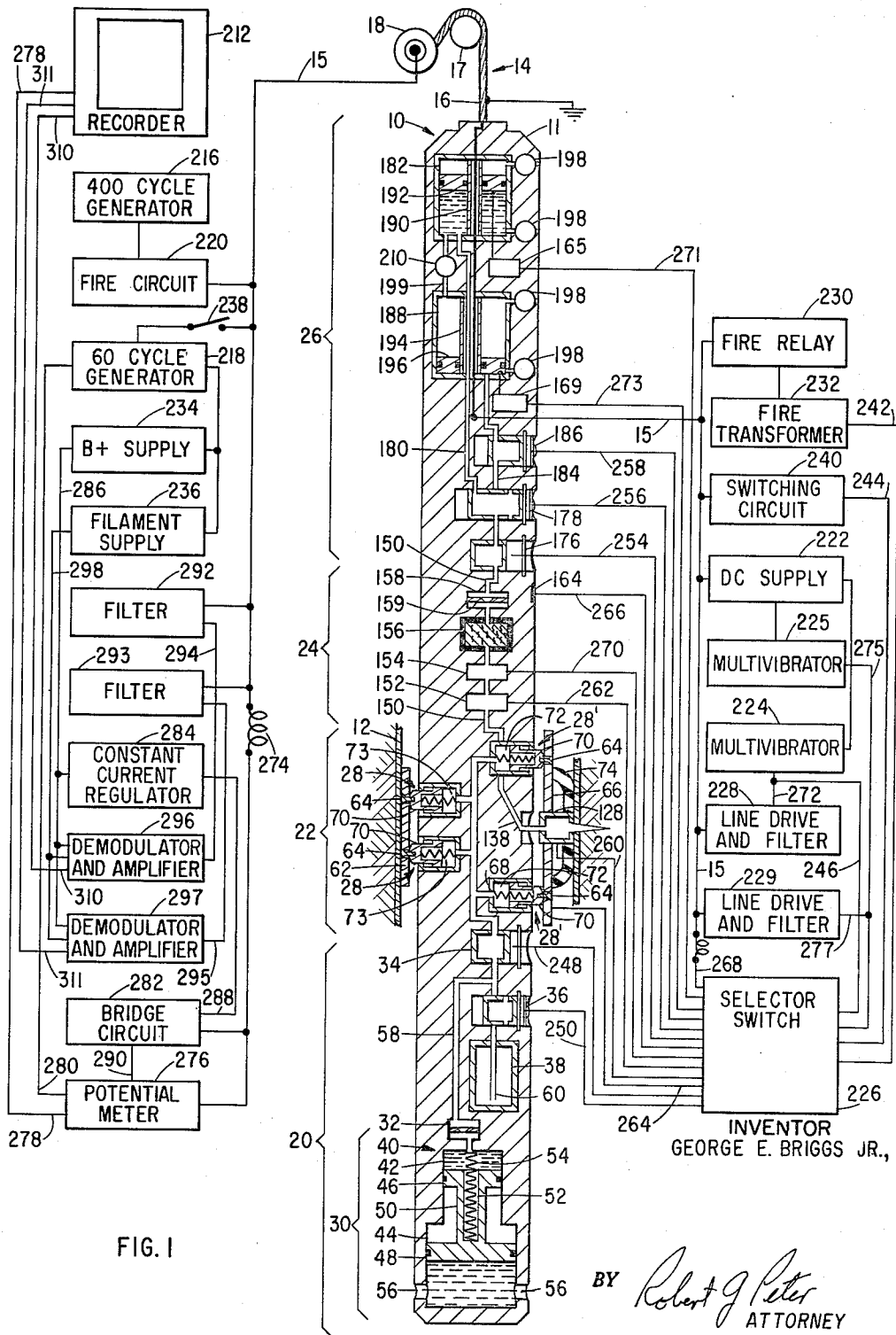
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3,254,531

FORMATION FLUID SAMPLING METHOD

Filed May 3, 1962

3 Sheets-Sheet 1



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FORMATION FLUID SAMPLING METHOD

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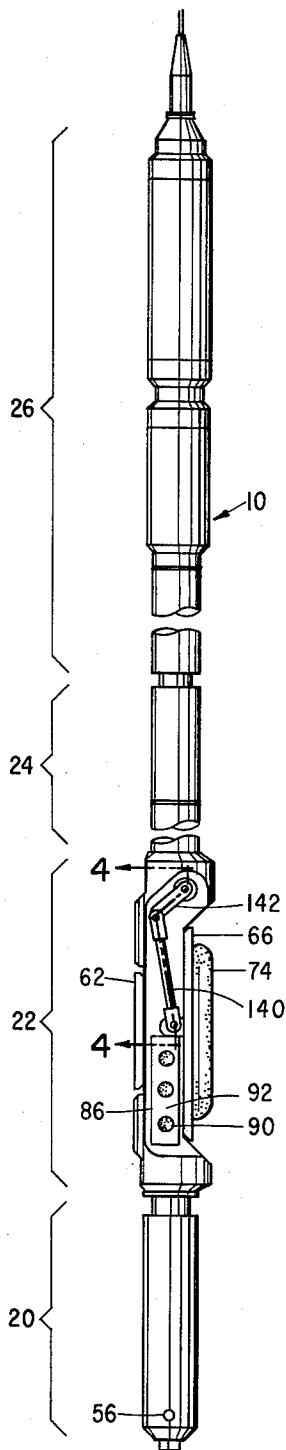


FIG. 2

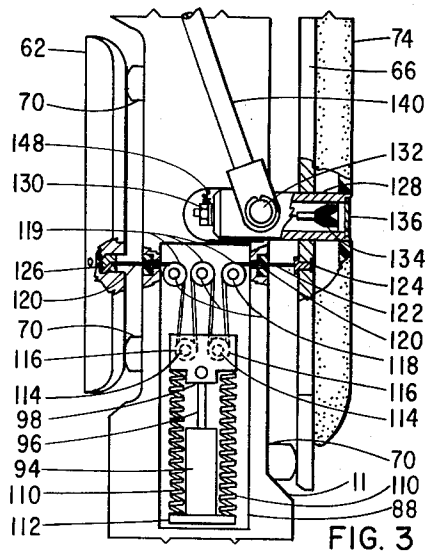


FIG. 3

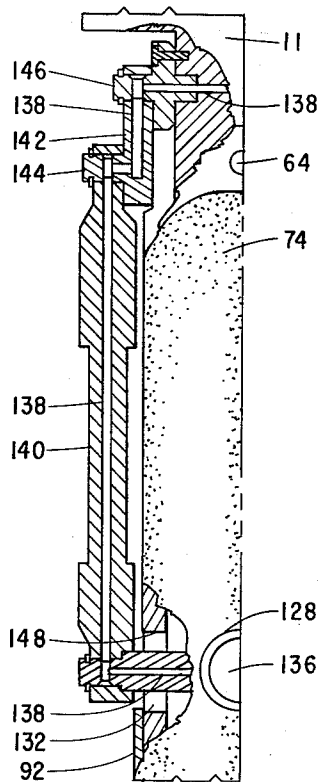


FIG. 4

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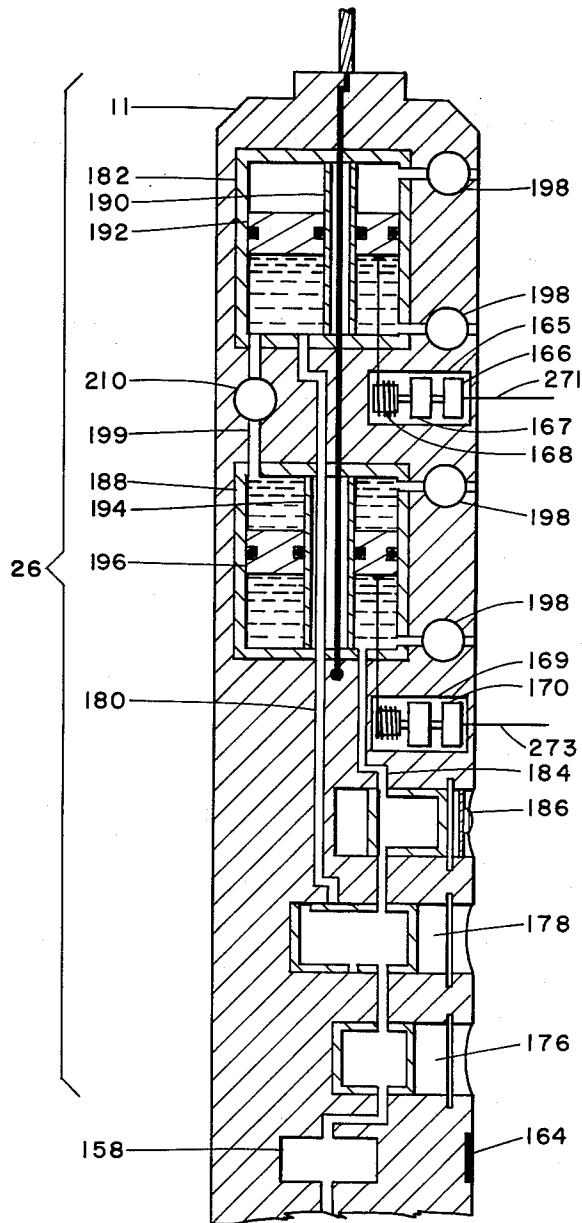
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FIG. 5

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3,254,531

FORMATION FLUID SAMPLING METHOD

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2 Claims. (Cl. 73—155)

The present invention relates to sampling of the fluid content of earth formations and, more particularly, to wireline system and apparatus for taking fluid samples laterally of a borehole piercing the earth formation of interest and to a method of sampling whereby additional data useful in reservoir evaluation is obtained.

Such a system and apparatus is useful in that the formations about a borehole at various depth zones may be selectively sampled to determine fluid content. Information derived from such samples is useful in evaluating the probable fluid productivity of such zones and, hence, is a valuable aid in selecting, from such zones, those having the best production potential for final completion.

Apparatus of this general type adapted for lowering in a borehole by means of a wireline and having provision for utilizing the hydrostatic pressure energy of its sampling environment for actuating power is well known and has long been recognized as potentially providing a more facile, efficient and economic means of formation sampling than similar apparatus lowered by means of a tubing string. However, the prior art has not enabled the attainment of a sampling success efficiency commensurate with this long recognized potential.

Among the many causes of failure experienced with prior art sampling apparatus and systems of this general type, the predominate ones have been found to be loss of control and data transmission for reason of electrical grounding due to abrasion of insulation from exposed electrical conductors, leakage past fluid seals in general and, particularly, leakage past defective pack-off seals, outright loss of the entire down-hole apparatus in the borehole because of lack of knowledge on the part of the operator of the actual disposition of the equipment in the borehole, and failure of flexible hydraulic lines, as by collapsing or fouling.

Aside from total failures as they bear on overall reliability, operation of the equipment of the prior art necessitates undesirably complicated and time consuming clean up and redressing operations which contribute to rig time loss and which further increase the chance of failure in the sampling operation because of operator errors of omission and commission in the unduly complicated redressing operation, particularly under conditions of darkness and/or inclement weather.

Further, prior art equipment has not provided a sample chamber system which is desirably effective to positively isolate, without chance for later comingling, successive sample portions to thus obtain in successive fluid sample portions representative of true connate fluids. In addition, prior art equipment, in providing only one mode of sample taking, lacks the versatility necessary to most efficiently take samples under different borehole conditions.

Accordingly, it is a principal object of this invention to provide a new wireline fluid sampler of improved general effectiveness, efficiency and reliability and having a new construction and mode of operation not provided in prior art devices.

Another object of this invention is the provision of a formation fluid sampler having a minimum number of electrical conductors exposed externally thereof and, hence, one of increased reliability in its control and data taking function.

Still another object of the invention is the provision of

a formation fluid sampler of extended flexibility and versatility due to its selective modes of sample taking.

Another object of the invention is the provision of a formation fluid sampler having a mode of actuation tending to assure a more effective sealing engagement with the wall of the borehole.

A further object of the invention is the provision of a formation fluid sampler of simple maintenance and service requirement to thereby promote economy and efficiency.

A still further object of the invention is the provision of a formation fluid sampler system and a method which provides new and valuable data for reservoir evaluation.

Another object of the invention is the provision of a formation fluid sampler having a pack-off actuation system characterized by an automatic recocking and priming ability which gives rise to improved efficiencies and economies associated with preparation of the fluid sampler for subsequent sample taking operations.

Still another object of the invention is the provision of a formation fluid sampler which positively measures and transmits to the surface a number of variables which relate the sampler to its environment whereby operators have added knowledge for proper operation of the apparatus and thus, are enabled to carry on an overall more effective and safer sample taking operation.

A still further object of the invention is the provision of a formation fluid sampler having sample chambers incorporating wall scrubbing means whereby chambers may be quickly and effectively cleaned between sample taking runs to thereby reduce the pollution of one sample by a previously taken sample.

Other and further objects of the invention will be obvious upon an understanding of the illustrative embodiment about to be described, or will be indicated in the appended claims and various advantages not referred to herein will occur to one skilled in the art upon the employment of the invention in practice.

A preferred embodiment of the invention has been chosen for purposes of illustration and description. The preferred embodiment is not intended to be exhaustive nor to limit the invention to the precise form disclosed. It is chosen and described in order to best explain the principles of the invention and their application in practical use to thereby enable others skilled in the art to best utilize the invention in various embodiments and modifications as are best adapted to the particular use contemplated.

In the accompanying drawings:

FIG. 1 is a schematic illustration of a wireline formation fluid sampling system embodying features of the present invention and showing the downhole device actuated and otherwise disposed for sampling;

FIG. 2 is a pictorial view of formation fluid sampling apparatus embodying the present invention and adapted for employment as the downhole unit in the system of FIG. 1, but shown in an unactuated disposition;

FIG. 3 is a partial sectional view of the hydraulic actuator section of the apparatus of FIG. 2, showing the wall engaging members thereof extended;

FIG. 4 is a partial sectional view taken along line 4—4 of FIG. 2; and,

FIG. 5 is a somewhat enlarged, more detailed, schematic showing of the fluid sampling section of the downhole device of FIG. 1 illustrating an alternate sampling disposition.

Described generally, the formation fluid sampler system embodying the present invention, as shown in FIG. 1, comprises a downhole sampling device generally indicated as 10 (and including a body 11) shown suspended from the earth's surface within a borehole 12 by means of a wireline 14 (including a central conduction path 15 and an outer sheath 16) from sheave 17 and winch 18, nec-

essary surface control and recording equipment (schematically shown to the left of the borehole 12 in FIG. 1) and electronic equipment normally incorporated in the downhole device 10 proper (which for purposes of clarity of illustration is shown schematically to the right of the borehole 12 in FIG. 1 of the drawing).

It is to be understood that the showing of borehole 12 as being cased is merely for purposes of illustration and that the device 10 is useful in either cased or uncased borehole penetrating the earth's surface . . . so long as such boreholes contain fluid (either a liquid or gas) under sufficient pressure for proper operation of the device which, in the main, derives its operating power from the pressure energy of a fluid environment under control from the earth's surface.

To provide a further frame of reference, a more specific showing of the downhole sampling device 10 is illustrated in FIG. 2. The device 10 is a rather long slender member comprised of a number of interconnected, generally cylindrical, sections of moderate weight and length. These sections, in being connected by screw threads, (not shown), are readily separable to enable the device to be transported from location to location with convenience.

These sections, in addition to providing structural division, generally divide the device 10 in a somewhat functional manner and for this reason will be useful in the present description of the construction and operation of the fluid sampling system of the invention. Referring to FIGS. 1 and 2, these sections, for purposes of the present description, are hydraulic power section 20, formation isolation section 22, measurement and control section 24 and fluid sampling section 26.

Hydraulic power section

Hydraulic power section 20 has as its function the provision of fluid power for the operation of actuators of formation isolation section 22. Hydraulic power section 20 is preferably located at the lower-most end of the formation fluid sampling device 10. This section is comprised of a number of elements (schematically shown together with their inter-relationships in FIG. 1) as follows: pressure intensifier 30, choke device 32, actuation valve 34, retraction valve 36 and dump chamber 38.

Pressure intensifier 30 includes a cylindrical chamber, generally denoted by reference numeral 40, which is stepped in diameter at a point near mid-length to define at its upper end a high pressure cylinder 42, and at its lower end a low pressure cylinder 44. A high pressure piston 46 is slidably mounted in high pressure cylinder 42, and a low pressure piston 48 is slidably mounted in low pressure cylinder 44. These two pistons are sealed with respect to their respective cylinders, e.g., by O rings, and are fixedly spaced and interconnected by a rod 50 to make up a unitary structure resembling a spool such that the two pistons are constrained to move together. Pistons 46 and rod 50 contain a coaxial recess 52 which receives an intensifier recocking spring 54. Recocking spring 54 is of the compression type and extends from recess 52 into contact with the upper end of high pressure cylinder 42. The recess 52 is desirably of sufficient depth to entirely receive recocking spring 54 in its compressed stacked condition. The spring 54 functions to bias interconnected pistons 46 and 48 toward the lower end of cylindrical chamber 40. Openings 56 are provided in low pressure cylinder 44 in order that borehole fluids may enter to exert an upward force on the low pressure piston 48. The high pressure cylinder is fluidly connected, by means of fluid channel 58, through choke device 32, with formation isolation section 22 and dump chamber 38 respectively by means of an actuation valve 34 and a retraction valve 36. Actuation valve 34 and retraction valve 36 in the unactuated condition of the device normally close channel 58 and block fluid flow to the formation isolation section 22 and to dump chamber 38.

High pressure cylinder 42, choke 32 and channel 58

are filled with a working hydraulic fluid. As the downhole sampling device is lowered into the borehole, borehole fluids enter the low pressure cylinder 44 by means of the openings 56. In the normal case where the borehole is filled with a liquid, the hydrostatic pressure of such liquid is applied to the low pressure piston 48 to exert a force thereon which is equal to the product of such pressure times the area of the low pressure piston. At depths in boreholes where a fluid sample is usually desired, the hydrostatic pressure of the borehole is of considerable magnitude, thus exerting a considerable force on the low pressure piston 48. This force is transmitted by rod 50 to high pressure piston 46 which, in turn, generates a pressure in high pressure cylinder 42 which is equal to the force divided by the area of the high pressure piston 46. Inasmuch as the area of high pressure piston 46 is less than the area of low pressure piston 48, the pressure generated in the high pressure cylinder 42 is at all times greater than the hydrostatic pressure of borehole fluids in accordance with the ratio of the area of the low pressure piston 48 divided by the area of the high pressure piston 46. It will be appreciated that as the sampling device is lowered into the borehole, the high pressure cylinder 42 is pressurized in a gradual manner.

The wall engaging member actuators of the formation isolation section are displaced or extended by the power fluid at a velocity which is directly related to the flow rate of power fluid in the channel 58. It has been found that the borehole sidewall may be severely damaged by impact caving or cratering when the wall engaging members are displaced thereagainst at high velocities. This caving or cratering may render the borehole wall surface so irregular that sealing off of an area so damaged is difficult, if not impossible. To reduce the actuator velocity and consequent impact damage to the borehole sidewall, it is desirable that a choke means 32 be employed to moderate the power fluid flow rate. The choke 32 may be of any well known type, e.g., a sharp edged orifice, to suitably restrict the power fluid flow rate.

The operation of both actuation valve 34 and retraction valve 36, as well as all other remotely controlled valves in the sampler device, is initiated by means of an electrical signal which fires a blasting cap affixed to a frangible valve cover disc. The valve cover disc normally shields the valve from the influences of borehole pressure, which, when the valve cover disc is destroyed by the blasting cap, provides the actuation force to throw the valve. This type of valve is well known in the art, having been disclosed in commonly assigned Patent No. 2,982,130 to McMahan. Upon the firing of the blasting cap and the consequent destruction of the cover disc, the valve is exposed to and is moved by the pressure of borehole fluids from an initial or normal position into an associated air-filled void suitably provided in the body 11. This movement shifts the position of the valve porting and, in the case of a normally closed valve such as 34 or 36, permits the power fluid, which is normally blocked, to communicate through the spool into a communicating conduit. As illustrated in FIG. 1, the valve 34 is no longer closed since the device is illustrated as being in an actuated condition with operation of valve 34 having been initiated by a blasting cap, as mentioned above.

Normally closed retraction valve 36 communicates channel 58 with dump chamber via an eduction tube 60 which depends and opens within chamber 38 at a low point therein. Chamber 38 normally contains a gas at atmospheric pressure and is of sufficient size to receive all of any power fluid which may be displaced from high pressure cylinder 42. When the power fluid enters the dump chamber 38, the gas therein is displaced upwardly and compressed to a pressure higher than atmospheric in proportion to the amount of fluid which enters the chamber. This gas compression by the hydraulic power fluid, together with the fact that the eduction tube 60 opens below the surface of the fluid in the chamber 38

enables the hydraulic section of the device to prepare itself for subsequent runs as will appear in connection with a description of the operation of the apparatus of the invention.

Formation isolation section

As may be seen in FIG. 2, the formation isolation section 22 is located immediately above hydraulic power section 20. The primary function of the formation isolation section is to pack-off or isolate a selected section of borehole wall by pressing a sealing pad into engagement therewith to thereby exclude well bore fluids from comingling with a fluid sample being taken from the selected section. Another function of the formation isolation section is the anchoring of the entire downhole sampling device 10 at the desired point in the borehole where a sample is to be obtained. For purposes of carrying out these functions, formation isolation section 22 is provided with a pair of actuators 28 and a pair of actuators 28'.

As shown, each actuator 28 is disposed or extendable toward the left of device 10 and has the distal end of its piston interconnected with the other actuator 28 by a wall engaging member denominated as back-up plate 62. The attachment of the piston end to the back-up plate 62 may be by any suitable means such as screws 64 illustrated in FIG. 1. The pistons of actuators 28' extending to the right of the device 10 have the distal ends of their respective pistons interconnected by a pressure plate 66. When the pistons are retracted, the distal ends of the pistons extend from the cylinder openings an amount to accommodate the attachment screws 64 for mounting back-up plate 62 or pressure plate 66 thereon. The mode of attachment of the plates to the pistons is well known in the art, having been fully disclosed in U.S. Patent No. 2,612,346 to Nelson.

All of the actuators 28 or 28' are generally similar to the lower right hand actuator 28' of FIG. 1 which is shown to be comprised of a cylinder 68 disposed radially with respect to the body 11 of device 10. The cylinder 68 has an opening toward the borehole through which a piston 70 extends in slidable sealing engagement. The seal (not shown) is desirably disposed within the cylinder opening and may be of any suitable well known type such as O rings. As may be seen in FIGS. 1 and 3, the actuators 28 and 28' are vertically spaced in pairs along formation isolation section 22. It will be further noted that the actuators 28 are generally oppositely disposed with respect to the actuators 28'. The cylinder of each actuator 28 and 28' is in fluid communication with a portion of fluid channel 58 extending beyond the actuation valve 34. Pistons 70 are each provided with an enlargement at the proximal end thereof, i.e., the end which bottoms within the actuation cylinder. The enlargement, in addition to limiting piston stroke to prevent the pistons from being ejected from the cylinders, serves as a rear radial bearing surface for maintaining the pistons in coaxial relation with the bore of the actuator cylinders. The pistons are also each provided with a coaxial recess penetrating the enlarged proximal end thereof and extending a sufficient distance therealong to receive a retraction spring. The recesses of the pistons employed in association with each of actuators 28 receive a retraction spring 73 to normally retain these pistons in their retracted position. Likewise, a retraction spring 72 is employed in association with each of actuators 28'.

All of the actuators 28 and 28' are normally retracted and when hydraulic power fluid is supplied to their cylinders upon the opening of actuating valve 34, all of the pistons of all of the actuators will be extended by hydraulic power fluid pressure. The actuators 28', mechanically associated with pressure plate 66, operate in concert to move pressure plate 66 outwardly when the actuator pistons are displaced. The pair of actuators 28, having their piston ends interconnected by a back-up plate

62, likewise operate in concert to move the plate 62 outwardly of the body of the device 10 upon application of pressure fluid to their associated actuator cylinders.

All of the parts of power actuators 28 and 28' are preferably interchangeable with the exception that actuators 28' installed in association with pressure plate 66 are desirably provided with retraction springs 72 having lower spring rates than their counterparts, springs 73, associated with the actuators 28.

All of the retraction springs 72 and 73 are of the extension type and each is attached at one end to the bottom of its associated piston spring recess and at its other end at the bottom of the associated actuator cylinder. These springs are under sufficient tension preload to effectively and normally hold the pistons 70 in their retracted position, thus holding associated pressure plate 66 and back-up plate 62 in their normally retracted positions against the body 11 of the device 10.

The formation isolation section 22 is provided with a sealing pad member 74 mounted on that surface of pressure plate 66 which is disposed opposite the body 11. Sealing pad member 74 is molded of suitably resilient material, e.g., rubber or plastic, in a general shape somewhat resembling the scooped-out rind half of a longitudinally sliced watermelon. Sealing pad member 74 has a convex front surface adapted for engagement with the walls of the borehole and a rear surface which is generally concave, but with a flat surface, extending about the edges of the concavity, adapted for attachment to pressure plate 66. This attachment may be made by vulcanizing, gluing or any other suitable means. The convex or formation engaging front surface of pad 74 is suitably sized to approximate the curvature of the walls of boreholes from which samples are desired.

The scooped-out or concave portion of sealing pad member 74 is enclosed by pressure plate 66. This space thus enclosed imparts to the pad structure a quality of compressibility which it would not otherwise have if made of a solid piece of resilient material. This quality of compressibility enhances the sealing ability of the pad member 74 which, together with pressure plate 66, comprises a unitary wall engaging member having a resistance to longitudinal bending supplied by the dimensional stability of pressure plate 66 and having, at the same time, a formation engaging surface which is resiliently compliable for sealing with respect to the borehole wall when forced thereagainst. Of course, this unitary structure, including movable plate 66, moves toward and away from the borehole wall with the plate.

Although the wall engaging members of the device 10 are shown to be somewhat rigidly attached to their respective actuator pistons 70, there may be occasions, e.g., in tapered boreholes, where a somewhat loose attachment is desired. The reason for this is that loosely attached wall engaging members may better conform to a tapered borehole wall by assuming the angle of any such taper and thus is more likely to provide an effective seal. It will be readily appreciated that, but for a loose connection, sealing pad member 74 and back-up plate 62 could not assume an angular displacement with respect to the body 11 without imparting to the actuator pistons a tendency to cock or bind in their respective actuator cylinders. It will be apparent that some looseness, permitting some angular movement, may be obtained by merely loosening the plate attachment screws 64. This degree of looseness obtained by this means is sufficient in moderately tapered boreholes.

As previously brought out, the actuators 28' which motivate the sealing pad member 74 are equipped with extension type retraction springs 72 of lower spring rate (of greater compliance) than the similar springs 73 of the actuators associated with back-up plate 62. This difference in spring rates provides for a very desirable sequencing during the period when the device 10 is being anchored and sealed with respect to the borehole

walls. Because of this sequence or difference in timing, the sealing pad member 74 is allowed sufficient time to position itself in the most advantageous attitude with respect to the borehole wall prior to any clamping compressive force being exerted through the body 11 thereon by the contact pressure of back-up plate 62 against the opposite borehole wall portion.

Contact time sequencing by means of the differential spring rates just described is a preferred way of accomplishing the sequencing of the wall contacting or setting of these members. It will be apparent, however, that similar results could be obtained by the provision of back-up plate actuators 28 and sealing pad actuators 28' of selected seal friction resistance to movement such that the sealing pad would move into contact with the borehole wall first.

A caliper device, generally indicated by reference numeral 86 in FIG. 2, is shown also generally in FIG. 3 to be housed within a rectangular pocket 88 in the side of the formation isolation section. The caliper mechanism is normally protected from well bore fluids by a diaphragm 90 (may be of rubber) which is, in turn, protected by a superposed cover plate 92. Cover plate 92 has suitable vent holes therethrough to provide for pressure balancing of pocket 88 with respect to external pressure in the borehole. The diaphragm 90 may be seen through these vent holes in the illustration of FIG. 2. The cover plate and diaphragm are attached by means of machine screws threadedly engaging the marginal edges of the pocket 88. These screws are not shown in the drawing, however.

A potentiometer type resistance 94 is attached to the bottom of the pocket 88 in a position generally centrally located in and toward the lower end thereof. The potentiometer 94 has a shaft 96 longitudinally slidable therein in the direction of the upper end of the pocket 88. A cross head member 98 is fixedly mounted by means of a set screw on and is movable with the potentiometer shaft 96. The shaft is normally maintained retracted within the body of the potentiometer by bias exerted thereon by extension springs 110 which interconnect cross head member 98 with a spring retainer member 112 which is also secured to the bottom of the pocket 88.

As viewed from the top of the pocket 88, the cross head member 98 has two downwardly extending, laterally spaced subshafts 114, on each of which is rotatably mounted a small peripherally grooved pulley 116. Fixed to the bottom of the pocket 88, near the upper end thereof, are three laterally spaced upwardly extending subshafts 118, on each of which is rotatably mounted a small pulley 119 similar to pulleys 116. The pitch circles of the grooves of all the pulleys mounted on all the subshafts 114 and 118 are disposed substantially within a plane parallel to the bottom of the pocket 88.

The left and right hand sidewalls of pocket 88 are provided with openings 120 located in substantial alignment with tangents extending from the uppermost point of the pitch diameters of the left and right hand pulleys 119. Openings 120 are provided with a rubber wiper member to exclude well bore fluids from the pocket 88 and at the same time enable the passage of a small cable 122 therethrough. The pocket is desirably packed with a fluid such that by virtue of pressure equalization communicated through the vent holes of the cover plate and the flexible diaphragm 90, there will be no pressure differential across openings 120. This equalization minimizes any tendency for well bore fluids to enter the pocket 88 through the openings 120.

As may be seen in FIG. 3, one end of cable 122 is socketed in a screw 124 which is threadedly engaged with pressure plate 66 in order that this end of the cable moves with the pressure plate and with the sealing pad 74 attached thereto. Cable 122, at its other end, is fixed to back-up plate 62 by means of a clamp screw 126

so that this cable end moves as one with the back-up plate. It will be noted that the screw 124 and the clamp screw 126 attach the cable ends respectively to pressure plate 66 and back-up plate 62 at a point generally toward the middle of the longitudinal span of each.

Intermediate its ends, cable 122 extends inwardly of the pocket 88 through openings 120 at either side thereof. The segment of cable 122 within the pocket is alternately reeved about the pulleys 119 and 116 to provide four falls or segments which extends between the two sets of pulleys. The arrangement of pulleys and cable within the pocket is similar to the arrangement known as a "double luff tackle," but without its usual standing part or element.

It will be apparent that since the ends of cable 122 move with the wall engaging members, back-up plate 62 and sealing pad member 74, and since there are four falls or segments which extend between the two sets of pulleys, 119 and the cross head mounted pulleys 116, any displacement of either or both the wall engaging members will be reflected by a total cross head displacement which is equal to one-fourth the sum of the displacements of the wall engaging members. Further, since the shaft 96 moves with cross head member 98, the electrical resistance value of the potentiometer 94 will vary with the sum of the displacements of the wall engaging members or, expressed differently, will vary with the absolute disposition of one wall engaging member with respect to the other. The variable electrical resistance of potentiometer 94 comprises a part of one leg of an electrical bridge circuit which will be described hereinafter.

In order that a sample may be taken from within the packed off area of the borehole wall, sealing pad member 74 (FIG. 3) is provided with a sample inlet member 128 of generally cylindrical shape which penetrates, but is flush with, the surface of the sealing pad at a point generally centrally thereof. Members 128 and 74 are attached, e.g., by vulcanizing, at their mutually contiguous surfaces to comprise a unitary assembly. The sample inlet member 128 extends rearwardly of sealing pad 74 and slidably through a suitably located opening in pressure plate 66. The rearwardly extended end of sample inlet member 128 is closed with respect to borehole fluids but is penetrated by an electrical connection 130 insulated with respect thereto.

As may be best seen in FIGS. 3 and 4, sample inlet member 128 has a lateral tubular extension 132 having a bore in fluid communication with the bore of sample inlet member 128 at a point rearwardly of pressure plate 66. A shaped charge and detonator assembly 134 is enclosed within sample inlet member 128 and is electrically connected to the electrical connection 130 extending within the inlet member 128. The end of sample inlet member 128 which is flush with the surface sealing pad member 74 is normally closed to exclude borehole fluids by means of a frangible disc 136 which is readily penetrable by the shape charge and detonator assembly 134 at such time as a sample is desired to be taken.

As is indicated in FIG. 1, sample inlet member 128 is in communication, by means of fluid sample channel 138 and an extension 150 thereof and through measurement and control section 24, with fluid sample section 26. The sample channel 138, in bridging between the body 11 and the relatively movable sample inlet member 128, must effectively vary in length to accommodate this movement.

This bridging portion of the sample channel 138 is desirably constructed of rigid heavy-walled tubular material to reduce the hazard of fluid channel wall collapse at the pressures normally experienced in boreholes. To impart to such rigid materials the ability to effectively vary in length with movement of the relatively movable parts of the apparatus, this bridging portion of channel 138 is comprised of two rigid tubular joints 140 and 142 (FIGS. 2 and 4). Each joint is pivotally joined at one end to the other joint and each joint is pivotally joined at its other end to one of the relatively movable parts.

Tubular joint 140 is, at one end, rotatably mounted on and in sealing engagement with the distal end of the lateral extension 132. As may be seen in FIG. 4, this joint connection is such that the bores of the sample inlet member 128 and first tubular joint 140 fluidly interconnect to constitute a segment of sample channel 138. At the other end of first tubular joint 140, there is provided a similar connection with second tubular joint 142.

Second tubular joint 142 has a laterally extending crank portion 144 which is similar in construction to the lateral extension 132. The sample channel 138 communicates through the joint 142 and its lateral extension. At the end of the tubular joint 142 opposite the lateral extension thereof, it is connected to a fitting 146 which is attached to the body 11 by screws or other suitable means. This fitting 146 has a coaxial extension which interengages with tubular joint 142 in much the same manner that lateral extension 132 interengages with the tubular joint 140. Thus, it is seen that the sample channel 138 fluidly communicates between the sample inlet member 128 and the body 11 through interconnection tubular joints 140 and 142.

The body 11 is provided with a recess 148 (FIG. 4) which provides a clearance for accommodating the rearward extension of sample inlet member 128 and the lateral extension 132 thereof in all positions that these elements are likely to assume in their movement with the sealing pad member 74.

It will be apparent that inasmuch as these tubular joints are rotationally interconnected and are disposed at an angle with respect to one another in their retracted position, the rigid tubular joints may accommodate the variation in distance occasioned by movement of the pad member 74 with respect to the body 11 by simple compensating angular movements.

The various rotating connections of the tubular joints are provided with fluid seals (not shown). These may be straddle mounted O rings, for example. As indicated in FIG. 4, the movable joints of the rotating connections are mechanically locked together by spring type locking rings.

Measurement and control section

As has been previously brought out, measurement and control section 24 is located immediately above formation isolation section 22 and includes an extension 150 of sample channel 138 which communicates with fluid sample section 26. Within section 24, the sample channel extension 150 communicates successively through a pressure sensing device 152 which measures sample flow line pressure, a resistivity cell 154 which measures the resistivity of fluids in the sample flow line, a filter device 156 which separates solids above a selected size from the sample fluid and passes the remainder, and a choke device 158 which serves to limit the rate of fluid flow in the sample line.

Section 24 also includes a spontaneous potential electrode 164 and such components of the telemetry and control system which are desirably housed in the downhole device 10. The telemetry and control equipment of the system will be described hereinafter.

Pressure sensing device 152 is provided in extension 150 for the purpose of measuring sample flow channel fluid pressure at all desired times. This pressure measurement information is of great value in formation evaluation. The pressure sensing device 152, although only shown schematically, may be of any well known type having the ability to withstand pressures upward of 10,000 p.s.i. One type of transducer element which has proven satisfactory comprises a Bourdon type tube element adapted to move a potentiometer element responsive to pressure changes. These elements are immersed in a compatible fluid medium, such as oil, and are isolated from sample fluids by means of a pressure transmitting diaphragm (not shown). The potentiometer resistance element of the

pressure sensing device forms a portion of one leg of a bridge circuit to be described hereinafter.

Pressure sensing device 152 is adapted to detect and measure any pressures within the extension 150. Depending on the valving of the sample taking system and flow conditions therein, the pressure sensing device 152 is adapted to measure formation pressure, flow line pressure during the period of sample taking, formation shut-in pressure, and hydrostatic pressure of the borehole subsequent to sample taking.

A sample flowing in sample channel 138 and extension 150 next passes through resistivity cell 154 where a continuous determination may be made of sample resistivity. The resistivity cell, although only shown schematically in FIG. 1, is comprised of a pair of electrodes exposed within an insulated portion of sample channel extension 150, such that any current passing between these electrodes must pass through the flowing fluid sample. Variation in resistance of the sample causes a variation in voltage in accordance with the resistivity of the fluid. The voltage variation is transmitted to the surface for recording.

The electrical resistivity of sample fluids may vary from low values indicative of salt water and filtrate to relatively high values indicative of hydrocarbon fluids. When the sample flow is initiated in the flow line, the resistivity would be low and vary toward higher values as a formation productive of hydrocarbon fluids is purged of filtrate fluids which have invaded the formation from the borehole. This variation is indicative of fluid flow in the sample line. Fluid resistivity measurements give an operator insight as to the probable test result, i.e., the type of fluid being obtained as judged by its resistivity, before actual physical examination of the sample is possible. If from this indication it is the operator's judgment that no wanted fluids are being obtained from the zone being tested, he may elect to terminate the test with a view to sampling another zone.

Next in the sequence of flow along sample extension 150, the fluid sample passes through filter device 156 where, as has been indicated, large solid particles comparable in size to the sample flow line are removed from the sample. Removal of these particles contributes greatly to the reliability of the entire sampling apparatus in that, but for the removal of these large particles, the sample flow line would be prone to plug during the instant the sample channel 138 is opened to fluid flow and during the earlier moments of such flow. Such plugging would, of course, abort the entire function of the apparatus since no sample could be obtained.

Next after leaving filter device 156, sample channel extension 150 passes through choke device 158 which has the function of moderating flow rates within the sample channel and across the formation face in the sampling disposition illustrated in FIG. 1. As moderated, the flow rates are low enough to minimize fluid erosion of the sealed off portion of the formation face to, in turn, minimize entrainment of formation detritus in the flowing sample. There are many well known types of choke devices which may be employed to perform this function. One such device employs the simple sharp-edged orifice plate 159 as shown. Although the orifice plate 159 is normally employed, it is selectively removable since it is not employed in the sampling disposition of FIG. 5. After passing through the choke device 158, sample channel extension 150 continues into the fluid sampling section 26.

The sample flow channel 138, as well as extension 150 thereof, is preferably initially filled with a clean incompressible fluid so that the flow metering device employed to moderate sample flow velocity will be effective at the initiation of flow.

The S.P. or spontaneous potential electrode 164 is conveniently provided within measurement and control section 24 for the purpose of enabling spontaneous potential measurements to be taken as the device 10 is being lowered

within an open or uncased borehole. S.P. measurements greatly facilitate depth location for sample taking in that they enable the matching of S.P. values with spontaneous potential curves previously obtained by other logging equipment. This matching enables an operator to precisely locate the formation isolation section 22 opposite a formation zone of interest.

Fluid sampling section

Fluid sampling section 26 is located immediately above measurement and control section 24. It includes chambers for receiving and retaining fluid samples together with the necessary valves and flow lines for controlling sample fluid flow thereto.

Sample channel extension 150, after passing through choke devices 158, enters fluid sampling section 26 through a sample channel flow valve 176 which, although normally closed, communicates extension 150 to the inlet of a three-way valve 178. Three-way valve 178 has a normally open outlet which communicates with a sample flow channel 180, which, in turn, communicates with a first fluid sample chamber denominated as filtrate sample chamber 182. Three-way valve 178 is, in addition, provided with a normally closed outlet which communicates with a second flow channel 184 which further communicates, by way of normally open sample shut-in valve 186, with a second sample chamber denominated as connate sample fluid chamber 188.

Valves 176, 178, and 186 are of generally the same remotely controllable type as previously described valves 34 and 36. However, the sleeve or spool of valve 178 is somewhat different, as brought out above, in that it is provided with two outlet ports so that it may function as a three-way valve as intended.

Both filtrate sample chamber 182 and connate fluid sample chamber 188 are of generally cylindrical shape and are disposed in coaxial relation with respect to the body 11 of the downhole device 10. As may be seen in FIGS. 1 and 5, filtrate sample chamber 182 is provided with a tubular conduit member 190 which extends there-within parallel to the axis thereof and which is sealingly secured to either end of the chamber. The bore of the tubular conduit member 190 provides for the passage of an insulated portion of wireline 14 through the chamber 182. It is apparent that the external surface of tubular conduit member 190 constitutes, in effect, inner walls of chamber 182. Because of these inner walls, chamber 182 encloses a volume such that the cross section thereof is annular in shape. Filtrate chamber 182 is also provided with an annular piston 192 which is mounted in sealing slidable engagement with both the inner and outer walls thereof.

Connate fluid sample chamber 188 is similarly provided with a tubular conduit member 194 through which the insulated portion of wireline 14 further extends in communicating to the downhole electronic components housed in measurement and control section 24. Sample flow channel 180, in extending from three-way valve 178 to the filtrate sample chamber 182, also passes through the bore provided by tubular conduit member 194. Connate fluid sample chamber 188 is also provided with an annular piston 196 which is mounted in sealing slidable engagement with both the inner and outer walls thereof. As best shown in the somewhat larger scaled showing of the fluid sampling section in FIG. 5, piston location sensing device 165, including a rotary potentiometer 166, is provided adjacent sample chamber 182. The shaft of the rotary potentiometer 166 is resiliently biased toward a first or zero rotational position by torsion spring unit 167 which is mounted on the shaft. A pulley 168 is also mounted on the shaft and has wound thereon a number of wraps of an actuation cable which at one end is fixed to the pulley adjacent the rim thereof. At its other end, the actuation cable extends in sealed relation through the lower end of the sample chamber 182 and is connected

with the piston 192. With this arrangement, displacement of the piston 192 in the chamber, responsive to a fluid sample flowing into the chamber, exerts a pull on the cable which unwinds from and rotates the pulley 168. With this unwinding of the cable and rotation of the shaft of potentiometer 166 against the resistance of the torsion spring unit 167, the effective resistance of the potentiometer 166 is varied in a substantially linear manner with the disposition of piston 192.

Connate fluid sample chamber 188 is similarly provided with a piston location sensing device 169, including a torsion spring loaded potentiometer 170, in order that the disposition of the piston 196 within the chamber 188 may be detected.

Both the sample chamber 182 and 188 are provided with a pair of service valves or cocks 198 which communicate from the upper and lower end of each chamber to the exterior of the body 11. These cocks 198, which may be of any suitable manually operable type, provide means whereby hoses (not shown) may be connected to either end of either sample chamber. By injecting air or other fluid through one of the hoses into a selected chamber, the piston associated with that chamber may be actuated therein to expel any fluid from the other end of the chamber out through the opposite cock 198 into any suitable sample collection or analyzer means. These hoses may be reversed and the piston freely shuttled back and forth to accomplish a thorough cleansing of the sample chambers without need for disassembly thereof. These valves are normally closed during the sample taking operation.

An interchamber flow channel 199 is provided which fluidly interconnects the upper portion of the chamber 188 with the lower portion of chamber 182 and which incorporates a manually controlled valve 210. Valve 210 may be of any throttling type or otherwise suitable needle valve which may close off channel 199 or, selectively, throttle fluid therethrough. In its normal condition, valve 210 blocks fluid flow within the channel 199.

Valve 210 imparts to the sample chamber system of device 10 a degree of versatility which enables the device to operate either in a normal disposition wherein two samples consisting of a filtrate and a pure connate sample are taken, or in a water displacement disposition wherein a single sample is taken. The normal disposition is illustrated in FIG. 1 and the water displacement disposition is illustrated in FIG. 5.

In the water displacement disposition, the rate of sample taking is controlled by metering and throttling an incompressible fluid displaced from chamber 188 above piston 196 through flow channel 199 and throttling valve 210 into the chamber 182.

Although the normal disposition yields a desired pure sample of connate fluid under most conditions, the water displacement disposition is of some value in highly frangible formations having a fluid content consisting largely of gas. Thus, it is seen that either disposition may be more desirable than the other, depending on borehole conditions. It will be appreciated that the selective capability imparted to the device 10 by these two sampling dispositions enables the device 10 to more effectively take samples under diverse borehole conditions.

System telemetry and control

As previously indicated, a downhole portion of the electronic circuit (schematically illustrated to the right of the borehole 12 in FIG. 1) of the fluid sampling system of the invention is housed in the measurement and control section 24, and the remaining portion, the surface equipment (schematically illustrated in FIG. 1 to the left of the borehole 12), is located at the earth's surface.

These surface and downhole portions are electrically interconnected by means of the wireline 14 and respectively function to transmit surface generated electrical power and control signals for operation of the downhole device 10 and to transmit downhole measurement signals

from the borehole device 10 back to the surface to be indicated and recorded by a strip chart recorder 212.

The electrical circuit of the system is supplied with power by a 400 cycle generator 216 and by a 60 cycle generator 218. Both generators are located at the earth's surface. The 400 cycle generator 216 furnishes the principal electrical power for operation of the downhole portion of the electrical circuit. The output of the 400 cycle generator is electrically interconnected with a central conduction path 15 of wireline 14 by means of a firing circuit 220. Firing circuit 220 passes the 400 cycle voltage output of the generator 216 to the line for operation of D.C. supply 222 located in the downhole device 10. D.C. supply 222 provides power for operation of a first multivibrator 224 having a voltage output of approximately 8 kc. per second frequency and for operation of a second multivibrator 225 having a voltage output of approximately 10.5 kc. per second frequency. When the 8 kc. output of the first multivibrator 224 is suitably connected through selector switch 226 to resistivity cell 154, the 8 kc. voltage is amplitude modulated therein as a function of fluid resistivity to provide an amplitude modulated 8 kc. resistivity signal which is fed back to path 15 by interconnecting line drive and filter unit 228 for transmission to the earth's surface.

Similarly, when the 10.5 kc. output of the second multivibrator 225 is suitably connected through selector switch 226 via leads 271 and 272, respectively, to either the resistance element of rotary potentiometers 166 or 170 (FIG. 5), the constant 10.5 kc. voltage is amplitude modulated in the resistance element as a function of the displacement of pistons 192 and 196 respectively in chamber 182 and 188.

The 400 cycle output of generator 216 may have its voltage momentarily increased in firing circuit 220 to provide a momentarily stepped up 400 cycle voltage in the wireline. When the voltage is so momentarily stepped up, it actuates downhole firing relay 230 which further admits the same to a transformer 232 wherein the voltage is further increased sufficiently to actuate or fire certain explosive devices located in downhole device 10.

The principal function of 60 cycle generator 218 is to power surface located B+ supply 234, and a surface located filament supply 236 which provide power to other surface located equipment to be described hereinafter. The 60 cycle generator 218 has the additional function of providing momentary applications of 60 cycle voltage, by means of a switch 238, to the path 15. These momentary applications are supplied to the actuating solenoid (not shown) associated with the selector switch 226 through switching circuit 240 in order to actuate the selector switch and advance the same one position for each momentary application of 60 cycle voltage.

As will be noted in FIG. 1, firing relay 230, switching circuit 240, D.C. supply 222 and line drive and filter units 228 and 229 are all connected in parallel to the central conduction path 15 of wireline 14. These parallel connected circuit elements discriminate between the various voltages and frequencies supplied to the path 15 in the following manner. The steady or constant 400 cycle voltage normally produced by 400 cycle generator 216 is too low to actuate firing relay 230 and is of the wrong frequency to actuate switching circuit 240 which, as has been indicated, is responsive to the momentary application of 60 cycle power. The 400 cycle power is prevented from entering the downhole resistivity and piston disposition measuring circuits respectively by the filter portions of line drive and filter units 228 and 229 which block the same but which respectively permit the amplitude modulated 8 kc. and 10.5 kc. signals to pass in the other direction and be coupled to the path 15 of the wireline.

Power inputs to selector switch 226 come variously from fire transformer 232 over path 242, from switching circuit 240 over path 244 and from multivibrators 224

and 225 over paths 246 and 275 respectively. The selector switch 226, in response to the momentary applications of 60 cycle power at the earth's surface by means of switch 238, operates, depending on the number of 60 cycle applications, to complete downhole circuits as desired. In accordance with switching position of the selector switch 226, the output of fire transformer 232 is variously applied to specific blasting caps or explosive devices associated with the various valve cover discs in order to initiate operation of the specific valves and the sample inlet member 128.

As may be seen in FIG. 1 to the right of the borehole 12, a path 248 applies the firing voltage to the explosive initiator of valve 34. Further, it may be seen that conduction paths 250, 254, 256, and 258, when appropriately connected to the output of fire transformer 232, similarly apply firing voltages respectively to valves 36, 176, 178, and 186 to initiate the explosive devices associated with these various valves. Another path 260 similarly supplies an interconnection between fire transformer 232 and shaped charge and detonator assembly 134 which, as has been indicated, operates to perforate the frangible disc 136 to open the sample inlet member 128 to formation fluids.

Selector switch 226 is also interconnected with pressure sensing device 152 by a path 262 and with caliper device 86 (FIGS. 1, 2 and 3) by means of path 264. Selector switch 226 is, in addition, connected by means of a path 266 to the S.P. electrode 164. The outputs of pressure sensing device 152 and caliper device 86, as well as S.P. electrode 164, are D.C. signals which, depending on selector switch position, are applied to the path 15 of wireline 14 by means of a path 268 interconnecting the switch with the wireline.

A path 270 provides connection of the electrodes of the resistivity cell 154 with the selector switch 226. The 8 kc. output of multivibrator 224, as amplitude modulated in the cell, is taken from the path 246 over an interconnecting path 272 which communicates the resistivity signal to line drive and filter unit 228 for coupling to the path 15 of the wireline. Similarly, paths 271 and 273 respectively provide for connection of the resistance elements of potentiometers 166 and 170 (FIGS. 1 and 5) with the selector switch 226. The 10.5 kc. output of multivibrator 225, as amplitude modulated in these resistance elements, is taken from a path 275 over an interconnecting path 277 to communicate the piston disposition signals to the line drive and filter unit 229 for coupling to the path 15 of the wireline 14.

Thus, it is seen that the selector switch 226 interconnects the conduction path 15 of the wireline 14 with the various blasting caps of the various downhole units and that these blasting caps may be initiated by the output of fire transformer 232. In this manner, selector switch 226 exerts control over fluid flow in the various fluid flow paths of the sampler device. The selector switch further interconnects the path 15 with the various sensing or measuring devices incorporated in the downhole device.

Suitable contacts are provided in selector switch 226, in a first switching position thereof, to interconnect S.P. electrode 164 with path 268 and path 15 to the earth's surface and thence through a choke 274 to potential meter 276 which includes amplifying means, where the spontaneous potential voltage is amplified and is applied to a first writing element of recorder 212 over a conducting path 278 connecting the potential meter thereto. At such times as S.P. is being measured, no A.C. power is normally transmitted downhole over the wireline 14. However, 60 cycle generator 218 supplies power for operation of the amplifier of the potential meter 276 over conduction path 280.

At other switch positions, selector switch 226, which is provided with multiple sets of contacts, variously completes circuits therethrough to apply power for actuating specific valves that control flow functions in the down-

hole device and also, to suitably connect one or more sensing devices for communicating intelligence therefrom to the earth's surface. For example, when selector switch 226 is in position to fire actuation valve 34, other contacts of the switch connect the resistance elements of caliper device 86 into the measurement circuit. In order that the various connections made by selector switch 226 in the foregoing and other switch positions may be clearly and conveniently correlated with switch position numbers, the various positions and connections are charted as follows:

either flow line pressure or the relative disposition of the wall engaging members of the downhole device 10. The choke 274 in conduction path 15 blocks the 8 kc. and 10.5 kc. signals as well as the 400 cycle power on the wireline from entering the bridge circuit 282 and the potential meter 276. The amplitude modulated 8 kc. resistivity signal, as well as the amplitude modulated 10.5 kc. piston position signal, is taken from path 15 at the earth's surface respectively through high pass filter elements 292 and 293 which block the 400 cycle and direct currents present in

Connections of selector switch 226 with various sampler control and sensing devices

Selector Switch Position	Control Connections		Sensing Connections	
	Connection Path, Switch to Valve	Control Device Connected	Connection Path, Switch to Sensor	Sensing Device Connected
1		None	266	SP electrode 164.
2	248	Actuation valve 34	264	Caliper device 86.
3	260	Shaped charge and detonator assembly 134.	270	Resistivity cell 154.
			262	Pressure sensing device 152.
4	254	Sample flow valve 176.	270	Resistivity cell 154.
			262	Pressure sensing device 152.
5	256	Three-way valve 178.	271	Piston position sensing potentiometer 166.
			270	Resistivity cell 154.
6	258	Sample shut-in valve 186.	262	Pressure sensing device 152.
			273	Piston position sensing potentiometer 170.
7	250	Retraction valve 36.	270	Resistivity cell 154.
			262	Pressure sensing device 152.
			264	Caliper device 86.

With these various interconnections by selector switch 226, the formation sampler system is enabled to sense and record S.P. during the lowering of device 10 into the borehole, to detect and record the output of caliper device 86 at all times that the wall engaging members of the device are being extended or retracted and to monitor and record the resistivity and pressure of fluids present in sample flow line extension 150 at all times of interest during a sampling sequence. Further, the positions of the sample chamber pistons may be sensed and recorded at the surface during entry of fluids into the chambers.

The pressure measurements made by sensing device 152, depending on sample flow line valve actuation, are representative of formation pressure (position 3), filtrate and pure sample flow pressures (positions 4 and 5, respectively), formation shut-in pressures (position 6), and the hydrostatic pressure of the borehole (position 7), once the sealing pad member 74 has been retracted.

When either caliper device 86 or pressure sensing device 152 are connected into the path 15 by selector switch 226, the variable resistance elements thereof, together with the conductors of wireline 14, comprise one leg of a bridge circuit 282. To supply the bridge circuit with energizing current, a constant current regulator 284 is provided to electrically interconnect B+ supply 234 to bridge circuit 282. In FIG. 1 of the drawing, the B+ supply is connected to constant current regulator 284 by means of a conduction path 286. A path for regulated current to the bridge circuit is provided by conduction path 288.

In operation of the bridge circuit thus provided with a constant current supply, variations of the resistance of the resistance elements of either caliper device 86 or pressure sensing device 152 operate to vary the voltage of the bridge output. The bridge output is supplied to potential meter 276 over conduction path 290. The bridge circuit output is amplified in potential meter 276 for transmission to the first writing element of recorder 212 via conduction path 278. The first writing element of the recorder, depending on selector switch position, records

the wireline. From filter elements 292, and 293, these signals are passed over paths 294 and 295 respectively to demodulator and amplifier units 296 and 297 which respectively amplify the 8 kc. and the 10.5 kc. waves and detect the amplitude modulation of each. The output of the demodulator and amplifier unit 296 is a varying D.C. signal which is proportional to the resistivity of the flowing fluid sample. The output of demodulator and amplifier unit 297 is a varying D.C. signal which is proportional to sample chamber piston position. Power requirements of demodulator and amplifier units 296 and 297 are supplied from B+ supply 234 over conduction path 286 and from filament supply 236 over conduction path 298. The varying D.C. outputs of demodulator and amplifier units 296 and 297 are respectively fed to second and third writing elements in the recorder 212 respectively over conduction paths 310 and 311.

Thus, it is seen that the recorder 212 is selectively adapted to record, by means of a first writing element, any one of caliper or sample flow line pressure, or S.P. signals fed to it over conduction path 278. It is also seen that the recorder is adapted to record, by means of a second writing element, fluid resistivity signals transmitted to it over conduction path 310. It is further seen that the recorder is adapted to record sample chamber piston position transmitted to it over a conduction path 311. The recorder 212 is provided with a time drive in order that all the various recordings are made with respect to time.

Operation

Prior to lowering the sampler device into the borehole for a test (the approximate depth of which is known), a hydraulic power section incorporating an intensifier 30 having an appropriate pressure multiplication factor must be selected and installed in connection with the sampler in order that the setting forces acting on the wall engaging members of the formation isolation section will be of a magnitude necessary to seal off the formation zone and to anchor the entire device in the borehole. The hydraulic power section would be selected from a

number of interchangeable sections having a variety of low-pressure-high-pressure piston ratios, such that a desired pressure will be produced in the hydraulic system at the depth of the test.

Also, prior to lowering the sampler into the borehole, a selection must be made between the two sampling dispositions illustrated in FIGS. 1 and 5 of the drawings. This selection is based on the best available knowledge as to the mechanical character of the wall of the borehole in the vicinity of the test, as well as the type of fluid (either oil or gas) likely to be produced by the test. As has been previously brought out, if the formation is highly frangible and is thought to be productive of large amounts of gas, the water displacement sampling disposition of FIG. 5 would normally be employed. If, on the other hand, the best available information indicated the formation to be firmly consolidated, the sampling disposition of FIG. 1 would be employed in order to desirably obtain two separate samples. For the purposes of the first part of the present description of the operation of the tool, it will be assumed that the sampling disposition of FIG. 1 has been selected.

As the tool is lowered into the borehole, the pressure of borehole fluid is exerted on the lower side of low pressure piston 48. This pressure exerts a force on the piston 48 which is transferred to the high pressure piston 46 which, in turn, generates, within the high pressure cylinder 42 and the power fluid flow channel 58, an intensified hydraulic fluid pressure sufficient to actuate the wall engaging members of the formation isolation section at the depth of the test. It will be understood that the pressure of the high pressure cylinder gradually builds up as the tool is lowered in direct proportion to depth within the borehole.

As the tool approaches the approximate depth from which a sample is desired, the selector switch 226 is positioned at its number one position whereby the S.P. of borehole formation may be monitored. The exact depth of setting and sample taking is found by matching or correlating the S.P. signal of the tool with an S.P. curve of a previously taken log of the particular borehole section. It will be appreciated that the original determination to obtain a sample has been based on previously taken S.P. and other logs correlated therewith.

When the S.P. showing of the sampler is matched with the prior log showing and the sealing pad member of the formation isolation section has been positioned precisely opposite the particular prior log S.P. showing, the selector switch is stepped to position number 2 which, as indicated in the foregoing switch position chart, connects the actuation valve 34 with the firing transformer circuit 232 and the caliper potentiometer 94 (FIG. 3) with the bridge circuit 282. When the 400 cycle power voltage is raised in the firing circuit 220, the blasting cap associated with the valve 34 is fired and the valve is actuated responsive to the hydrostatic fluid pressure of the borehole. Upon the actuation of the valve 34, the pressure generated in the high pressure cylinder 42 is communicated to the actuators 28 and 28' of the formation isolation section which responsively extend to set the sealing pad member 74 and the back-up plate member 62 against generally opposite portions of the borehole wall. The force of the actuators in pressing the wall engaging members against the opposite borehole wall portions is sufficient to anchor the entire sampling device within the borehole.

During the time the selector switch 226 is in position number 2 and the actuators are extending, the movement of the wall engaging members with respect to one another may be monitored and recorded at the surface. This information is helpful to an operator in ascertaining the fact of actuation and the probability of an effective seal having been obtained.

After the setting of the formation isolation section, the selector switch 226 is then stepped to position number 3.

In this switch position, the shaped charge and detonator assembly 134 (FIG. 3) within the pad inlet member 128 is connected with the firing circuit 220 (FIG. 1). Also, in this switch position, the outputs of resistivity cell 154 and pressure sensing device 152 are transmitted and recorded at the earth's surface.

As indicated in the switch position chart, the next operating sequence step is set up by stepping the selector switch 226 to switch position number 4. In this position, the blasting cap of sample flow valve 176 is connected into the firing circuit 220 at the earth's surface. Also, in this position, the outputs of the resistivity cell 154, the pressure sensing device 152 and the piston position sensing device 165 are connected for transmission to the earth's surface. When the blasting cap of the flow valve 176 is fired, the pressure of the borehole fluid displaces the spool element of the valve and opens the sample flow path 150 therethrough to communicate the same through the normally open outlet of three-way valve 178 and channel 180 into sample chamber 182.

With the opening of the valve 176, a flow of fluid is established from within the formation adjacent the packed-off area, responsive to the pressure difference between the relatively high pressure within the formation and the somewhat lower effective pressure in flow line channel 150, into the chamber 182. The effective pressure in the flow line is, of course, determined by the pressure drop across the orifice plate 159 of choke device 158 as the flow passes therethrough into the chamber 182 beneath piston 192 therein. Chamber 182, in the space above piston 192, is normally filled with a gas which is initially at atmospheric pressure in the instant sampling disposition of FIG. 1.

The first flow portion, i.e., the portion produced into sample chamber 182, contains any filtrate fluids which may have invaded the formation through the walls of the borehole. Because of the presence of these filtrate fluids, this first flow portion is not truly representative of fluids naturally occurring in formation being sampled. During the time of flow of this first or filtrate flow portion, the output of the resistivity cell will vary in accord with the variation of the relative amounts of mixed filtrate and connate fluids with flow time. As this flow portion enters the chamber 182, the piston 192 therein is displaced upwardly with cumulative flow. As the piston is displaced, the successive dispositions thereof are detected by the rotary potentiometer 166 (FIG. 5) and transmitted to the surface where they are recorded on the strip chart recorder 212. Although the record produced is of piston displacement, it is also a record or curve of cumulative sample flow with time. The slope of the curve is an accurate measurement of flow rate at any point of time.

When the output of the resistivity cell becomes constant, it indicates that the sample, then flowing, is a true one and that sufficient purging of the formation within the boundary of established flow has been accomplished. When purging is complete as indicated by the resistivity curve, the selector switch 226 is stepped to position number 5 which connects three-way valve 178 into the surface control firing circuit 220. When the electrical signal the surface has ignited the blasting cap of the three-way valve to thus disintegrate the frangible disc associated therewith, the pressure of the borehole fluid shifts the valve spool element thereof to close-in the normally-open port and to open the normally-closed port thereof. With the shifting of the three-way valve 178, the sample flow is diverted from the chamber 182 to the chamber 188 beneath the piston 196 therein. As was the case of chamber 182, chamber 188, in the space above the piston is filled with a gas, initially at atmospheric pressure. As has been indicated, the sample flow portion entering chamber 188 is representative of the connate fluid of the formation being tested.

As the sample flow is produced into chamber 188, the resistivity of the flow is being recorded from the output of

the resistivity cell 154. Also, the pressure of the flow is detected by pressure sensing device 152 and recorded at the surface. In addition, the increasing displacement of the piston 196, as displaced by the sample flow, is being detected by the rotary potentiometer 170 (FIG. 5) and recorded at the surface with respect to time.

The danger of sticking and losing the sampler device in the borehole increases with the length of time the device is sealed and anchored with respects to the wall thereof. To reduce this danger, test time usually is prudently held within some arbitrary time limit, say ten minutes. At all times during a test, from the recording of piston displacement, an operator has knowledge of sample flow rate and total sample flow. By this, the operator is assured that a sample is, in fact, being collected. If for some reason, such as flow line plugging, the flow is stopped, the operator is immediately put on notice that he may as well stop the present test and prepare for another.

Further, from this information as to total sample flow and flow rate, the operator may predict the sample volume which will likely be obtained at the expiration of the arbitrary time. If the prediction indicates that the chamber will be moderately short of being completely filled at this time, the operator may elect to continue sample taking a short additional time in order to recover a full sample. If, on the other hand, the flow rate and total flow information indicates that it would require a long additional time to fill the chamber, prudence would dictate stopping the test promptly at the end of the arbitrary time.

Thus, it is seen that the piston displacement recordings enable an operator to maximize sample production and, at the same time, perform an overall safer operation. The flow rate information, in addition to its value during the conduct of a test as just now pointed out, as a measure of formation permeability helpful in formation evaluation.

Also, because of the accurate segregation of filtrate and connate sample flow portions, new information is provided whereby the depth of filtrate invasion within the boundary of sample flow within the formation under test may be estimated, to thus provide additional data for use in formation evaluation.

When the sample chamber 188 has been filled, the selector switch 226 is stepped to position number 6 which places the sample shut-in valve 186 in connection with the firing circuit 220. When the valve is fired, it is displaced by borehole fluids to shut in the sample chamber 188.

The sample chambers, thus having been shut in, are now ready for retrieval from the borehole, but first, it is necessary that the wall engaging members of the formation isolation section be retracted. In order to accomplish the retraction, the selector switch is stepped to position number 7 which connects the retraction valve 36 into the firing circuit 220 at the earth's surface. When the retraction valve 36 is fired, the pressurized hydraulic power fluid in the channel 58 is communicated through the valve into the dump chamber 38 by means of education tube 60. As has been brought out, dump chamber 38 contains a gas at atmospheric pressure. When this communication is made, the intensifier piston assembly is driven full stroke by the force of hydrostatic pressure and bottoms out in the upper end of high pressure cylinder 42. Any power fluid remaining in the high pressure cylinder is displaced over the communicating path through the education tube into the dump chamber 38. Also, simultaneously with this latter action, the pressure of the hydraulic power fluid on the actuators 28 and 28' drops to atmospheric pressure. The pressure of borehole fluids acting on the extended ends of the actuator pistons, together with the force of the retraction springs 72 and 73, then forces the actuator pistons into their retracted or bottomed-out positions in their respective

actuator cylinders. The retraction of the pistons causes the hydraulic power fluid, which originally displaced the actuator pistons outwardly on actuation, to be displaced from the actuator cylinders back through the retraction valve 36, through the education tube 60 and into the dump chamber 38. When the actuator pistons retract in this manner, the wall engaging members, of course, retract therewith into their normal positions adjacent the body of the formation isolation section and the sampler is ready for withdrawal from the borehole.

As the sampler is raised within the borehole, the hydrostatic pressure of the borehole fluid thereon becomes less and less as the surface is approached. When the hydrostatic pressure has, in effect, been reduced to a point where the force of the recocking spring 54 exceeds the force of hydrostatic pressure on the low pressure piston 48, the spring 54 returns the pistons 46 and 48, together with rod 50, to their original positions. This action tends to create a vacuum in the high pressure cylinder 42. Power fluid in the dump chamber 38, under the influence of the pressure of gas compressed therein above the fluid level thereof, flows via education tube 60 through retraction valve 36, power fluid channel 58 and back into the high pressure cylinder 42. Thus, during the withdrawal of the sampler from the borehole, the intensifier 30 is recocked into its initial position and the high pressure cylinder 42 is reprimed or refilled with power fluid.

After the sampler is brought to the surface, the samples therein are taken from the respective chambers by means of the drain cocks 198, associated with each chamber, in the manner previously indicated.

If, because of indications of the nature of the formation within the zone to be tested, the sampling disposition of FIG. 5 instead of FIG. 1 had been selected, the previous sequence of operation would have been modified in the following manner. Prior to lowering the sampler within the borehole, the sample chamber 188 above piston 196 would be filled with an incompressible fluid instead of the normal fill of gas at atmospheric pressure employed in the normal sampling disposition in FIG. 1. In addition, the throttling valve 210, normally closed in the sampling disposition of FIG. 1, would be cracked slightly to provide for a proper degree of metering as the incompressible fluid within the chamber 188 is displaced therethrough into the chamber 182 responsive to sample flow entering chamber 188. One further other alteration from the normal sampling disposition of FIG. 1 is that three-way valve 178 is manually operated to shut off the normally-open sample flow channel 180 and to open the normally-closed channel through the shut-in valve 186 into the chamber 188 beneath the piston 196. Finally, the orifice plate 159 is removed from the choke device 158.

Having been thus changed over from the normal sampling disposition of FIG. 1 to the disposition of FIG. 5 in the manner just described, the sampler is lowered into the borehole as previously described and the sequence of sampling is the same as that previously described up to and including the steps provided for in selector switch position No. 4. Because of the change in sampling disposition, the flow of sample is directed into the chamber 188 beneath the piston 196 upon the opening of the sample flow valve 176. As the sample flow enters chamber 188, the piston 196 is displaced upwardly. As the piston 196 is displaced, it must in turn, displace the incompressible fluid from chamber 188 through the throttling valve 210 into chamber 182 below piston 192. The pressure drop across the valve 210 determines the rate of sample flow in this disposition. Since the incompressible fluid displaces the piston 192 upwardly as it enters the chamber 182 at the same rate at which the sample flow is displacing the piston 196, it will be apparent that the cumulative sample flow is indicated by the record of the displacement of either piston 196 in switch

position number 4 or piston 192 in switch position number 5.

When the chamber is filled to a desired extent, as indicated by the disposition of piston 196, the selector switch is then stepped to position 6 to enable the shutting-in of the sample by means of valve 186. From this point, the sequence of the operation of the device in its water displacement disposition illustrated in FIG. 5 is precisely the same as has been described with respect to the sampling disposition of FIG. 1.

Thus, it has been seen that the present invention provides a new and improved formation fluid sampler system and method which provides improved performance and safety as compared to prior art systems and methods and that the inherent versatility provided by the system promotes the general effectiveness of formation sampling by the versatile matching of sampler capability with the borehole conditions encountered. Further, it has been seen that the device employed in connection with the system, as compared with prior art devices, promotes the general effectiveness of sampling operations by enabling more effective pad seals, as well as providing a device requiring reduced maintenance because of certain automatic features thereof. It is further seen that a more reliable sampler device, as compared to prior art devices, has been provided by reducing the number of exposed electrical connectors and by providing an articulated sample line comprised of rigid tubular members which reduce the likelihood of line collapse at the high pressures experienced within boreholes. It has been seen further that the sampler device and system of the present invention provides new data useful in both sampling and formation evaluation. Further, as has been brought out, the sampling device and system of the present invention promotes a safer sample taking operation in that it yields to an operator more knowledge as to sampler disposition, both internally and with respect to the sampling environment to consequently enable the employment of the device in a safer surer manner.

As various changes may be made in the form, construction and arrangement of the elements herein disclosed without departing from the spirit and scope of the invention and without sacrificing any of its advantages, it is to be understood that all matters herein are to be interpreted as illustrative and not in any limited sense.

What is claimed is:

1. A method of obtaining samples of connate fluid content of an earth formation about a borehole traversing the same comprising the steps of: establishing a flow of fluids within and from said formation; measuring the electrical resistivity of said flow; purging the formation of filtrate fluids within the boundary of said flow until the resistivity measurement becomes substantially constant; diverting said flow into a collection means for obtaining a sample quantity of fluid; measuring said flow in said collection means; and, recording the variation of said flow measurement with respect to time.

2. A method of obtaining samples of connate fluid content of a filtrate invaded earth formation about a borehole traversing the same comprising the steps of: establishing fluid flow from said formation into a first collection means; measuring the electrical resistivity of said fluid flow and the amount of said fluid flow in said first collection means; diverting said fluid flow into a second collection means when said resistivity measurement becomes substantially constant; measuring said fluid flow in said second collection means; and, recording the variation of said flow measurements with respect to time.

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