Sept. 2, 1958 D. F. BLOOM 2,850,097

METHOD OF SAMPLING WELL FLUIDS

Filed March 11, 1957 2 Sheets-Sheet 1

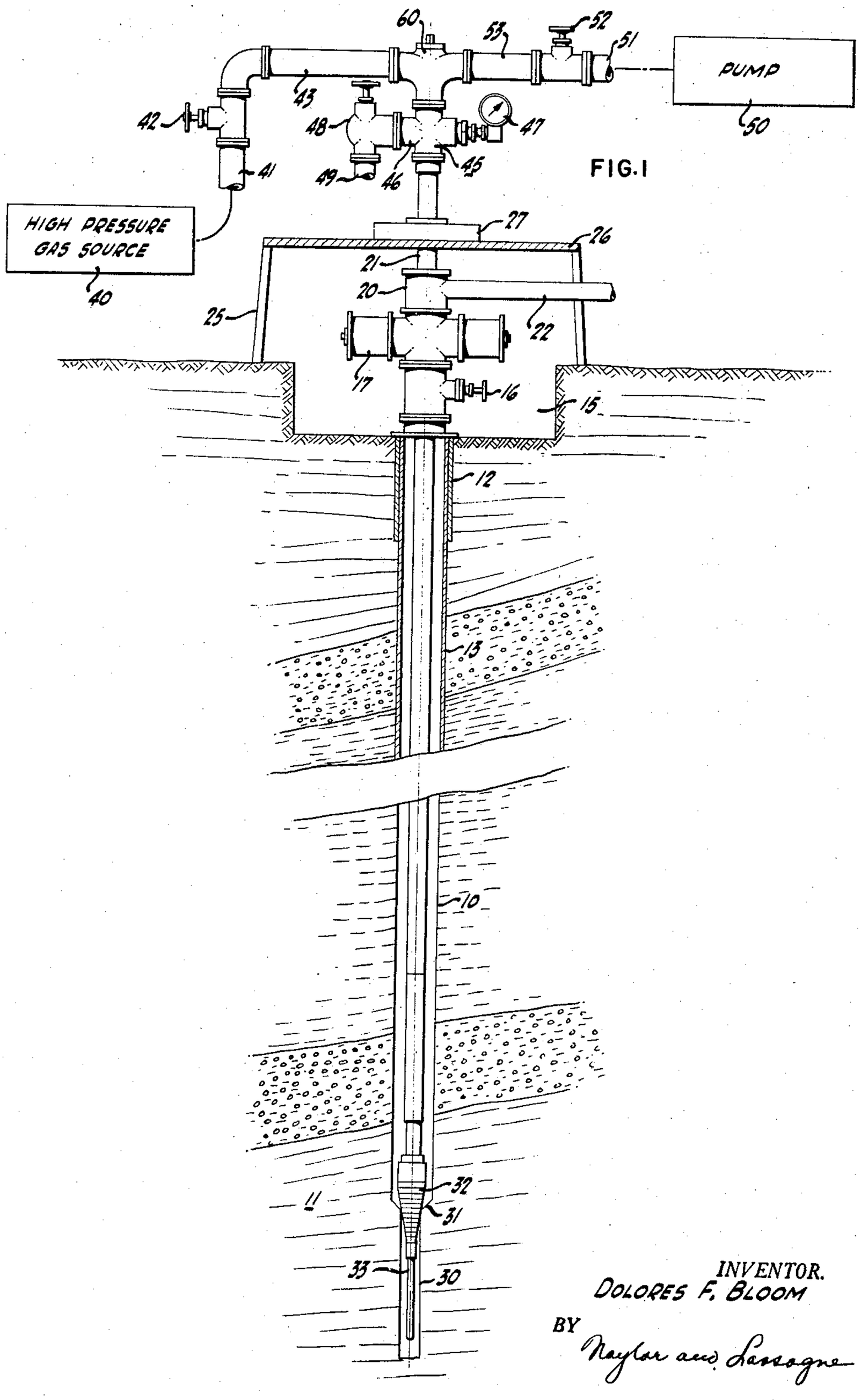

FIG. 1

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FIG. 2

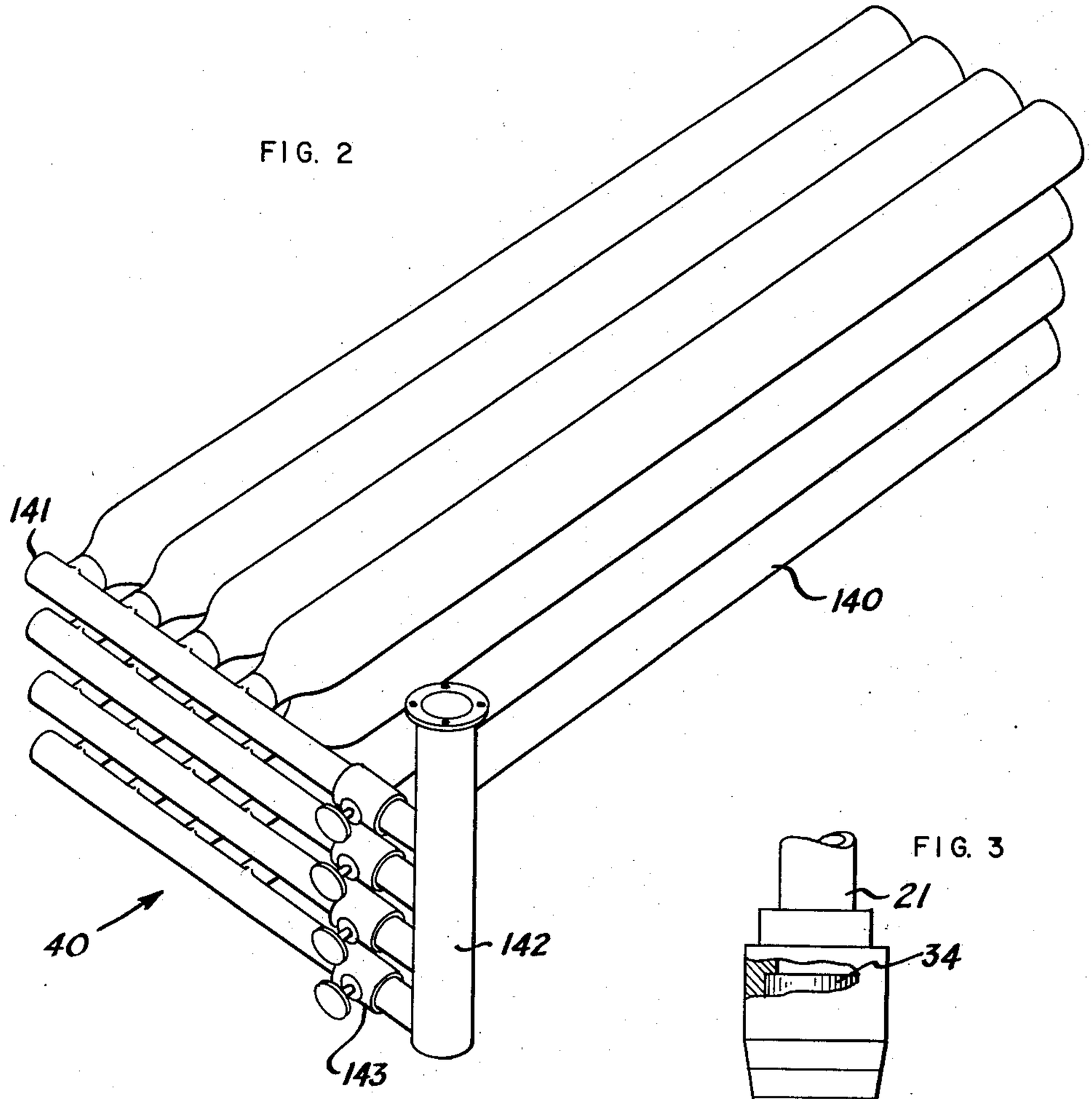
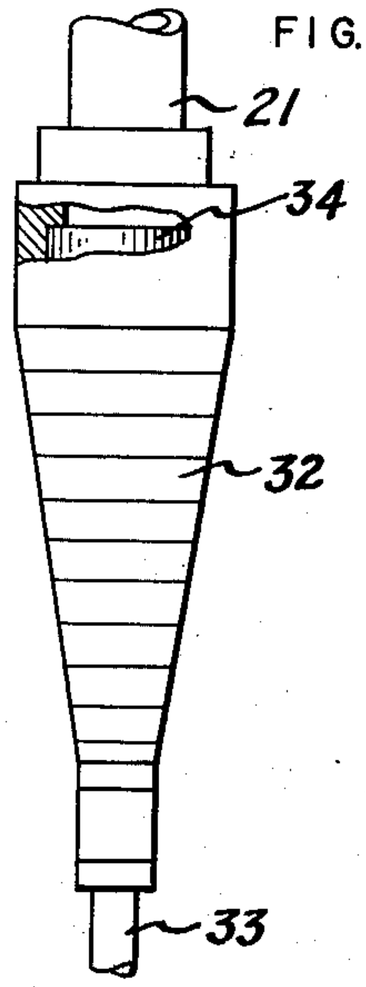


FIG. 3



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METHOD OF SAMPLING WELL FLUIDS

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7 Claims. (Cl. 166—3)

My invention relates to a new and improved method of sampling well fluids, and more particularly to a new and improved method of sampling well fluids or, as it is commonly called, "formation testing," yielded by a particular geological strata or formation which has been penetrated by a drilled well.

This application is a continuation-in-part of my prior application for United States Letters Patent filed May 18, 1954, under Serial No. 430,475, now abandoned.

A variety of techniques and of special tools called "formation testers" have been developed in the petroleum industry for securing samples of the fluid contained in a given formation which has been penetrated by a well, without requiring the running and cementing of casing and without bailing or otherwise removing the drilling fluid from the well. Such techniques and tools are also utilized in testing the effectiveness of water shut-offs and may be used to determine whether casing perforations are freely admitting fluid from the formation.

As described by Uren in "Petroleum Production Engineering-Oil Field Development," 3rd edition, 1941, such formation testers are employed in conjunction with a packer which, when properly seated against the wall of the well or casing, relieves the test interval immediately below the packer of the hydrostatic pressure of the overlying column of drilling fluid in the well. In "straddle" testing, above the bottom of a well, a second packer is employed which is located below the tester. By means of a valve located in the formation tester, fluid is permitted to flow from the formation below the packer, through the tester into a pipe string such as, for instance, drill pipe. Fluid so entering the pipe string is trapped therein by means of a valve located in the tester, so that the entrapped fluid may be withdrawn from the well with the pipe string for subsequent examination; or if the formation pressure is sufficient to cause the flow of the fluid from the formation to the surface, a sustained flow test through the pipe string will provide, in addition to the sample, a quantitative measure of the productive capacity of the formation being tested. However, one objection to this method of testing a formation is that there is no control permitted of the rate of the escapement of the fluid and pressure from the formation into the pipe string because of the differential in pressure between the high rock pressure below the packer and the low pressure in the pipe string. Frequently this causes caving or collapsing of the hole immediately below the packer, thereby causing the packer and the pipe string to which it is attached to stick in the hole.

A specific example of one form of formation tester in which the valving means are actuated by a weight, or "go-devil," dropped from the surface through the drill pipe, is described by Uren at pages 562–3; but other types of formation testers, such as the Halliburton "Hydrospring" tester are also in general use, which provide for control of the valve by relative movement between the pipe string and the body of the tester. Either of these testers is typical of a formation tester which may be used in carrying out the method of the present invention.

In addition to the above objection, the existing formation testing techniques are, however, inadequate to meet conditions encountered in certain situations. Wells drilled in unconsolidated sand and caving formations, such as

heaving shales, and wells drilled into a stratum which is under high pressure are especially difficult to sample without damaging the stratum being sampled or causing a blowout which may be accompanied by an uncontrollable flow of gas or oil. The use of a flow bean in the tester to restrict the flow, and the use of water or drilling fluid in the pipe string to balance the formation pressure have been among the expedients used in testing such formations. A sufficiently restricted flow bean may be easily clogged. Counter pressure created by water or drilling fluid, either alone or accompanied by conventional swabbing, can never be sufficiently accurately controlled to avoid the risk of either a "dry run" if the weight of the column of fluid is excessive, or of formation damage and cavitation accompanied by a possible blowout if it is insufficient.

My invention provides a method of sampling well fluids which avoids dry runs while at the same time controls the flow of fluids into the tester and pipe string in such a manner as to prevent caving of the formation, and insures against blowouts. This is accomplished, in summary, by running a pipe string carrying a formation tester, associated valve means, and a packer into the hole with the valve closed, by introducing gas under pressure into the pipe string, prior to opening the valve, to a pressure approaching but preferably below the estimated pressure of the fluid present in the packed off formation to be tested, holding the pressure on the well until the formation pressure and the pipe pressure are in equilibrium, and subsequently gradually bleeding off the gas pressure at the surface of the ground at such a rate as to control the rate of ingress of fluids into the tester and pipe string within desired limits and sufficiently slowly so as to prevent caving or channeling of the formation below the packer. Gas pressure within the pipe string lower than the pressure in the formation will not result in a blowout because, as the fluid or gas from the formation rises in the pipe string and the fluid or gas flows into the pipe string, the cushion of gas above the valve will compress until the pressure in the pipe string becomes balanced against the formation pressure. Since this compression of the gas in the pipe string cushions the rising fluids originating in the formation, shock effects which might precipitate caving or channeling of the formation are simultaneously avoided.

The manner in which this is accomplished will be best understood from the following description of examples of my method, reference being had to the accompany drawings in which:

Figure 1 shows a diagrammatic illustration of a petroleum well and an example of apparatus useful in carrying out the steps of the method embodied in my invention;

Figure 2 shows a bank of high pressure cylinders, which is preferably used as a source of high pressure gas supply embodied within my invention; and

Figure 3 shows a view of the packer and valve which may be used in practicing this method.

In Figure 1 there is illustrated diagrammatically a well 10 which has penetrated the formation to be tested 11. As illustrated, the well is provided with a conventional surface casing 12 and a deep string of casing 13.

At the surface of the ground a well cellar 15 is provided, through which the casing 13 rises; a master control valve 16 being provided for the purpose of closing the space between the drill pipe and the casing 13, while a conventional blowout preventer 17 is provided for the same purpose above the master control valve. The casing 13 is closed at its top by a packing gland 20 through which the drill pipe 21 is passed, as shown, and connected to the casing 13 at the gland 20 is a conventional drilling

mud return 22. The derrick substructure 25 supports a derrick floor 26 upon which is mounted a conventional rotary table 27 through which the drill pipe 21 likewise extends. A conventional valve assembly, also known as a "Christmas tree," 45 having cross T 46, a pressure gauge 47, a bleed valve 48 and a connection 49 is provided, as shown. All of the foregoing apparatus is conventional in rotary drilling operations and forms no part of this invention. On the top of the "Christmas tree" 45 there is provided a two-way cock valve 60 connected on one side to valve 42 by means of a suitable length of pipe 43. A high pressure source of gas 40 is connected to the valve 42 by means of pipe 41. Compressor 50 is likewise connected to valve 60 by means of connections 51 and 53 separated by valve 52.

When fluid is to be sampled from the bottom of a well, a "rathole" 30, which is a portion of the well of reduced diameter, may be drilled at the bottom of the well to provide an annular shoulder 31 against which a suitable packer 32 can seat for the purpose of relieving the formation to be tested from the weight of the drilling and other fluid in the hole. For a detailed showing of the packer 32, attention is invited to Figure 3, which will be described in detail later. After the drilling of the rathole 30, the drill pipe is withdrawn from the hole and the packer 32 is attached to the end of the drill pipe or other pipe string. The tester 33 is provided with a positive seating valve 34. The valve 34 may be of any type desired as long as it provides a hydraulic-tight seat inside the packer. As has been pointed out above, the valve 34 can be either of a type in which a "go-devil" or ball is dropped through the casing to open the same or may be of the type which contains a J-tool which opens or closes the valve 34 by a partial rotation of the pipe string. Inasmuch as the particular type of valve 34 which is used forms no part of this invention, a further detailed description thereof is deemed unnecessary. A tester intake pipe, which extends below the packer 32 into the formation being tested, is provided as shown.

After the packer 32 and tester 33 with the valve 34 has been attached to the pipe string, and with the valve 34 closed so that no fluid remaining within the hole can enter into the pipe string, the pipe string is lowered into the well. The packer may be set on the shoulder 31 either at this time or at a later time, if the tester valve is controlled by downward pressure on the pipe string. At this time the method of the present invention contemplates a departure from the conventional practices which have thus far been referred to.

The pressure of the fluid present in the formation to be tested 11 being estimated or approximately computed by known methods, I now create within the pipe string 21 a gas pressure as nearly approximately equal to the formation or rock pressure as possible. The precise pressure of the gas in the drill pipe varies according to conditions from well to well. It has been found in actual practice that preferably this pressure should be less than the formation pressure, but under certain circumstances it may be desirable to go above this formation pressure, and the best results have been obtained when a pressure approximately equal to the formation pressure is used. On the other hand, pressures ranging from formation pressure down to approximately one fifth of the formation pressure could be used without departing from the spirit of my invention, and with varying degrees of satisfactory results. This is done by forcing air or inert gas, such as nitrogen, into the pipe string 21 at the surface of the ground until the desired pressure is built up. The use of an inert gas is preferred because it cuts to a minimum the fire hazard present at the well head and even within the well itself. Nitrogen, an inert gas, is particularly desired because of its chemical inertness in reference to gases present in earth formations, giving a much better formation gas sample at the casing head.

Since the tester 33 and pipe string 21 are lowered into the well 10 with the valve 34 is a closed position, it will be obvious that the inside of the pipe string 21, after it reaches the level of the formation to be tested, is free of drilling mud which might otherwise enter from the outside of said pipe 21.

As illustrated in Figure 1, the gas may be supplied either by the compressor 50 or by other high pressure source 40, such as a bank of storage tanks, which is shown in detail in Figure 2, or they may both be used. The storage tanks 40 preferably consist of a plurality of tanks 140 attached to a header 141 with a manifold 142 connected thereto. Provided in the header 141 is a plurality of valves 143. As can be seen from a study of Figure 2, the header 141 will permit the admission of gas from any bank of bottles 140 into the manifold 142 as desired. For example, a single bank of bottles can be opened at one time or any combination or all of the bottles can be opened at one time, depending upon the quantity and gas pressure desired to be introduced into the well. The purpose of this arrangement is to permit a more accurate control of the quantity and pressure of gas introduced into the pipe string.

An arrangement for opening the tester valve by dropping a weight while maintaining the pipe string 21 closed at its upper end may be provided as, for example, in Patent No. 2,137,296, dated November 22, 1938, to Macready; but where a tester such as the Halliburton "Hydrospring" tester previously referred to is employed, the valving means in the tester may be opened by relative movement between the pipe string 21 and the body of the tester 33, accomplished by permitting the weight of the pipe string to bear against the tester, thus seating it firmly on the shoulder 31 at the top of the rathole 30, and then backing off a half or quarter turn on the pipe string. In other types of testers mere downward pressure on the pipe string sets the packer and causes opening of the tester valve a few minutes later. It is immaterial so far as the present invention is concerned when the packer is set, so long as it is set before the tester valve is opened.

When the valve 34 within the tester 33 is opened, the resulting changes of pressure within the pipe string 21 are noted on the gauge 47. If the pressure within the pipe string 21 should be indicated to be falling after the opening of valve 34, this indicates that the pressure introduced into the pipe string 21 was greater than the pressure in the formation to be tested, which in turn will indicate that pressure is backing up from the pipe string into the formation, a condition which, except in special situations, is undesired. When this condition is found to exist, the valve 48 is opened to bleed off the pressure in the well sufficiently to bring the pipe pressure above the packer into equilibrium with the formation pressure. Such a state of equilibrium will be indicated on the gauge 47 when it stabilizes or ceases to rise or fall.

The converse is true if it is found that the pressure in the pipe string 21 rises sharply and rapidly when the valve 34 is opened. This will be an indication that the pressure in the pipe is lower than that of the formation to be tested. When this condition is found to exist, the valve 48 is maintained closed until the formation pressure and the pipe pressure achieve equilibrium, which is indicated in the same way described above.

After the stabilization of the pressure within the pipe 21 has been attained, whichever condition has been found to exist, the valve 48 is opened gradually and the pressure in the pipe 21 is slowly reduced to permit the slow and gradual ingress of fluid from the test formation 11 into the tester 32 and then up into the pipe 21. This will gradually and slowly cause the formation fluid to flow out of the formation 11 into the pipe string, thereby preventing caving and channeling or other damage of the formation to be tested.

The gradual reduction of pressure within said pipe 21, achieved by employing the bleed valve 48 as a throttle,

as described, forms an important feature of the present invention, since by this practice the rate of flow of fluid from the formation **11** into the tester **33** and thence up into the pipe **21** can be held as low as desired, without the use of a flow bean which might clog; and, as pointed out above, possible caving or channeling of the formation is prevented by means of this gas cushion.

It is to be here noted that, if the formation pressure is sufficient, after the opening of the valve **48** and the bleeding off of the pipe **21**, the well can be flowed through the bleed-off valve **48** if desired or the test can be stopped before the well begins to flow and the specimen desired to be taken is entrapped within the pipe **21** by closing the valve **34** and then coming out of the hole with the pipe **21**.

In cases in which exceedingly high formational pressures are expected to be encountered during the making of a formation test, it is sometimes desirable to supplement the gas pressure cushion employed in the method embodied in the present invention with a liquid, preferably water, but occasionally by the use of drilling mud which is heavier in specific gravity and therefore can hold a much higher formation, or bottom hole, pressure. When it is desired to proceed in this manner, the water or specially prepared drilling mud having the specific gravity desired is gravitied into the open pipe **21** as it is run into the hole. In this way the exact height and weight of the liquid introduced can be measured. For example, if it is desired to include a column of liquid in the pipe 500 feet high, this liquid is introduced into the open pipe when 500 feet of pipe have been run and the remainder of the string is run into the hole dry. After the pipe is run, with the column of liquid therein, the gas line valve **42** is opened and gas is introduced through the pipe **43** into the pipe **21** in the same manner as described above. Gas from the reservoir **40** thus provides, above the liquid, a gas cushion such that the total pressure exerted at the tester valve by the combination liquid and gas equals the pressure desired to be exerted on the formation to be tested. At this point the process described above is repeated, the valve **42** is closed, and the valving means in the tester is opened with the packer set, as previously described, and the method of the present invention is then continued on from this point in the same manner as previously described.

Where such a combined "liquid-gas" cushion is employed, it is important that the pressure exerted at the tester valve **34** by the liquid be substantially less than the pressure of the formation to be tested and that a substantial part of the cushion be compressed gas. Under all circumstances a sufficient amount of compressed gas must be used above the water or mud to insure against the liquid cushion being forced against the top of the "Christmas tree" as a water hammer regardless of the formation pressure encountered.

It is to be understood that variations in packers, valves and the like can be resorted to; that the hole can be cased or open and other modifications and changes made without departing from the spirit of my invention, which is set forth in the appended claims.

I claim:

1. The method of testing a formation penetrated by a well comprising the steps of providing a conduit having a valved tester and a packer at the lower end thereof, maintaining said conduit and tester sealed from fluids present in said well until said packer is set, pressurizing said conduit and tester by introducing gas under pressure therein, maintaining the pressure within said conduit above said tester in the range of from approximately one-fifth of the pressure in the formation to be tested to approximate equality with the pressure in the formation to be tested, setting said packer while said conduit and tester are sealed to remove the hydrostatic pressure of overlying fluid in said well from the formation to be tested, providing an opening in said tester, when said packer is set, to permit the flow of a fluid therethrough from the formation being tested into said tester and conduit, and gradually releasing the gas pressure within said conduit and tester to permit a gradual rise, through the opening provided in said tester, into said conduit of the fluid from the formation being tested entrapped below said packer, in an uncontaminated condition.

2. A method according to claim 1 in which the pressure in said conduit above said tester is maintained at approximately one-fifth the pressure in the formation to be tested.

3. A method according to claim 1 in which the pressure in said conduit above said tester is maintained at approximate equality with the pressure in the formation to be tested.

4. A method according to claim 1 in which the gas under pressure introduced into said conduit above said tester is an inert gas.

5. The method of testing a formation penetrated by a well comprising the steps of providing a conduit having a valved tester and a packer at the lower end thereof, maintaining said conduit and tester sealed from fluids present in said well until said packer is set, pressurizing said conduit and tester by introducing gas under pressure therein, maintaining the pressure within said conduit above said tester in the range of from approximately one-fifth of the pressure in the formation to be tested to approximate equality with the pressure in the formation to be tested, setting said packer while said conduit and tester are sealed to remove the hydrostatic pressure of overlying fluid in said well from the formation to be tested, providing an opening in said tester, when said packer is set, to permit the flow of a fiuid therethrough from the formation being tested into said tester and conduit, bringing to equilibrium the gas pressure in said conduit and the pressure in the formation being tested and gradually releasing the gas pressure within said conduit and tester to permit a gradual rise, through the opening provided in said tester, into said conduit of the fluid from the formation being tested entrapped below said packer, in an uncontaminated condition.

6. The method of testing a formation penetrated by a well comprising the steps of providing a conduit having a valved tester and a packer at the lower end thereof, maintaining said conduit and tester sealed from fluids present in said well until said packer is set, pressurizing said conduit and tester by introducing a liquid into said conduit in a quantity sufficient only to provide a pressure at said tester valve substantially less than the pressure of the formation to be tested and by introducing gas under pressure into said conduit, maintaining the total pressure within said conduit above said tester provided by said liquid and gas in the range of from approximately one-fifth of the pressure of the formation to be tested to approximate equality with the pressure in the formation to be tested, setting said packer while said conduit and tester are sealed to remove the hydrostatic pressure of overlying fluid in said well from the formation to be tested, providing an opening in said tester, when said packer is set, to permit the flow of a fluid therethrough from the formation being tested into said tester and conduit, and gradually releasing the gas pressure within said conduit and tester to permit a gradual rise, through the opening provided in said tester, into said conduit of the fluid from the formation being tested entrapped below said packer, in an uncontaminated condition.

7. A method according to claim 6 in which the total pressure in said conduit and tester provided by said liquid and gas is brought into equilibrium with the pressure in the formation being tested immediately prior to gradually releasing the gas pressure within said conduit above said tester.

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