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CORE ANALYSIS AND APPARATUS THEREFOR

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2 Sheets-Sheet 1

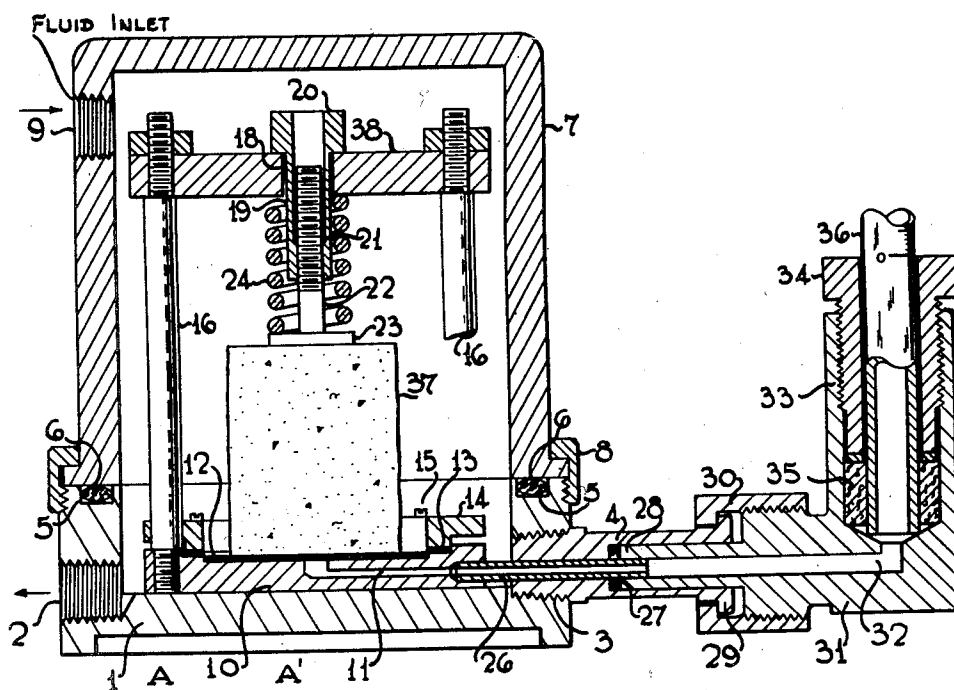


Fig. 1



Fig. 2

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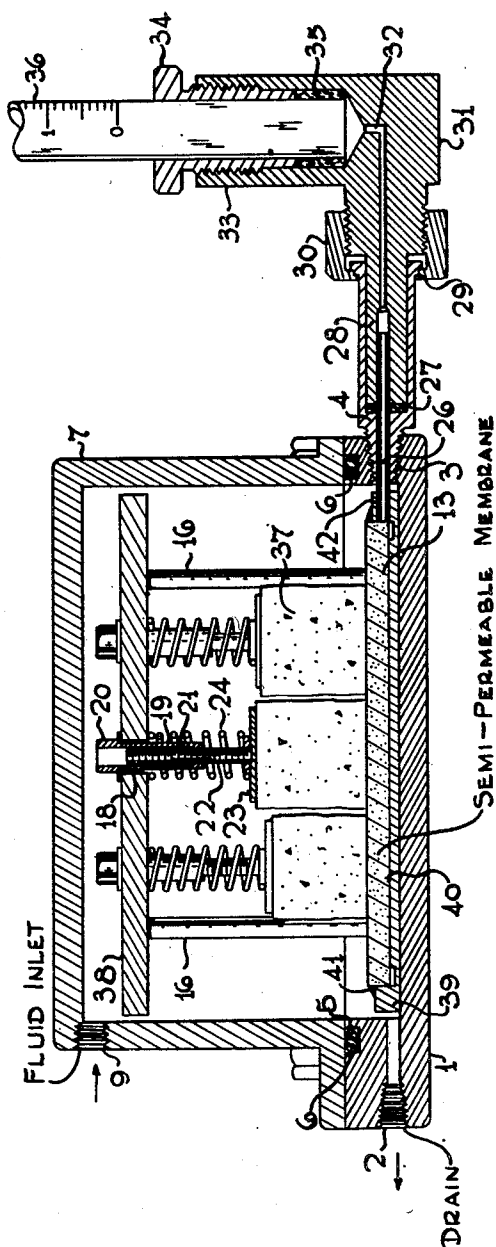


Fig. -3

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CORE ANALYSIS AND APPARATUS
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4 Claims. (Cl. 73—38)

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The present invention is directed to a method and apparatus for the study of the static equilibrium fluid phase distribution conditions attained in subsurface formation rock when a fluid phase saturating the rock is displaced by another im-

miscible fluid phase. In the estimation of oil reserves in subsurface formations and in the prediction of the producing characteristics of petroleum reservoirs information regarding the distribution of liquids in the reservoir rock and the manner in which immiscible liquids displace each other in such rock under varying conditions of temperature and pressure is extremely important. Usually this information cannot be obtained directly by analysis of reservoir rock samples because of the virtual impossibility of recovering reservoir rock samples which have not been contaminated by extraneous fluids introduced into the borehole penetrating the reservoir.

Well known and adequately described in the literature is evidence to support the theoretical equivalence of displacement experiments to displacement occurring in the natural reservoir in yielding analogous displaced and displacing phase saturation distributions when displacement equilibrium has been attained. In the apparatus hitherto employed for these experiments and the procedure followed with this apparatus it has not been possible adequately to reproduce certain reservoir conditions, particularly reservoir pressure and temperature.

The principal object of the present invention is the provision of a method and apparatus for studies of the aforesaid character in which the reservoir rock samples are placed in an environment closely approximating their natural environment in the reservoir.

More specifically, it is an object of the present invention to provide a method and apparatus for studies of the aforesaid character in which the reservoir rock samples under examination are placed in contact with a continuous fluid phase, the displacement of which from the rock samples is to be studied, while being maintained under the pressure obtaining in the reservoir from which the samples were obtained and at reservoir temperature. Experimental evidence has been accumulated to indicate that laboratory displacement data give a measure of reservoir fluid phase distribution which is nearly perfect when all the significant reservoir conditions are simulated, and which is certainly less perfect and sometimes erroneous when certain conditions are not simulated.

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An additional object of the present invention is the provision of a method and apparatus for studies of the aforesaid character in which not only the reservoir conditions of pressure and temperature may be reproduced but in which also the capillary pressure (which is the pressure difference existing across a curved interface existing between the immiscible fluid phases) may be accurately adjusted throughout the ranges normally existing in the reservoir from which the rock samples are obtained.

A particular object of the present invention is the provision in an apparatus for studies of the aforesaid character of a semi-permeable barrier in the form of a membrane composed of cellophane or cellophane-like material which, when saturated with water, is capable of resisting breakthrough by oil at high pressures.

Another specific object of the present invention is the provision of a method and apparatus for studies of the aforesaid character in which a plurality of rock samples (in the form of plugged cores or rotary cuttings) can be processed simultaneously. This feature is of importance for many reasons. It is self-evident that the smaller the rock sample the less time will be required under otherwise similar conditions to displace a given fluid phase from the sample. However, the minimum size of an individual sample which may be studied is limited by the fact that enough fluid phase must be displaced for accurate measurement thereof. By providing an apparatus in which a large number of rock samples may be handled simultaneously the individual samples may be small enough to secure the aforesaid time advantage and at the same time the aggregate of the samples produce sufficient displaced phase for accurate measurement. Again, this feature makes it possible to reproduce more accurately actual reservoir fluid distribution by using rock samples from different points in a reservoir whereby an average value of phase displacement typical of the reservoir itself is obtained. The importance of this average value can be appreciated from the known fact that the reservoir formations are usually heterogeneous which means that at different points the reservoir rock has different permeability, porosity and other characteristics.

Further objects and advantages of the present invention will appear from the following detailed description of the accompanying drawing, in which

Fig. 1 is a vertical section of one embodiment of the present invention;

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Fig. 2 is an enlarged detail of Fig. 1 between the points A and A'; and,

Fig. 3 is a vertical section of an alternative embodiment of the present invention.

Referring to Fig. 1 in detail, numeral 1 designates a base member made of thermally conductive material of high strength, such as stainless steel, brass, or the like. It may be pointed out here that all of the metal parts of this apparatus are preferably composed of the same metal. Member 1 is a cup shaped member having on one side a drain opening 2, and at another point a threaded opening 3 to receive a nipple 4 hereinafter referred to. The upper edge of the cup-shaped member is provided with an annular recess 5 carrying packing material 6 which is more properly described as a self-sealing type gasket. A metal lid 7 rests on the upper edge of the cup member and is held securely thereto by clamping ring 8. At the upper end of the lid member is an opening 9 for the introduction of fluid.

Resting on the bottom of the cup member is a metal plate 10 having a radial passage 11, opening on the upper surface of the plate at its center and extending to the periphery of the plate. Resting on the upper surface of the plate 10 is a screen 12 covered by a membrane 13. This membrane may be termed a semi-permeable membrane and is characterized by being substantially impermeable to a displacing fluid phase when it is saturated with and wetted by a fluid immiscible with said displacing fluid. Thus if saturated with and wetted by water it is substantially impermeable to oil. An excellent material for use as this membrane is cellophane of the type commercially available. Other materials which may be used are graded collodion membranes of suitable permeability, animal membranes, porous metallic septa, and porous rubber. In practice the membrane is selected to suit the pressure at which the operation is conducted. The higher the capillary pressure which must be maintained in the operation the finer must be the capillary passages in the membrane. Thus, for higher pressure cellophane is best suited, whereas for lower pressures a more permeable material is preferred in order to cut down the time of operation.

The membrane is of somewhat larger diameter than the screen 12 and the overlapping portion of the membrane is clamped to the plate 10 by a ring 14 secured by screws 15.

Screwed into the plate 10 near its periphery are two vertical posts 16, which extend to the top of the chamber formed by the lid 7. At their upper ends these posts carry a bar 17 having a central opening 18 in which fits a sleeve 19 having at its upper end a flanged head 20 which rests on the bar and at its lower end an internally threaded portion 21. In engagement with this threaded portion is a threaded rod 22 carrying at its lower end a flat disk 23. A spring 24 is held in compression between the disk and the under side of the bar.

A small tube 26 extends laterally from the plate 10 in alignment with the radial passage 11 and through an opening in nipple 4. Near the outer end of this tube the central passage of nipple 4 is enlarged, and in the annular space between it and the end of the tube is arranged a gasket 27. Pressing against this gasket is a sleeve 28, the outer diameter of which forms a tight friction fit with the enlarged central passage in nipple 4. The outer end of nipple 4 has a flange 29 on which is seated the inwardly flanged end

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of a cap 30, which is internally threaded at its other end. In threaded engagement with this cap is a fitting 31 with which the sleeve 28 is integral. This fitting has a central passage 32 which terminates in an upwardly disposed cup member 33, which is part of the fitting 31. Screwed into the upper end of the cup member is a nut 34 which presses down against packing 35 in the bottom of the cup member and holds this packing in engagement with a glass tube 36 which rests on the bottom of the cup member and passes through the nut 34. The tube is graduated for volume measurement.

The provision of cap 30 in threaded engagement with fitting 31 and adapted to engage with flange 29 on nipple 4 permits that portion of the assembly to the left of the juncture of cap 30 and flange 29, which portion of the assembly may be referred to as the cell, to be inverted for certain tests described hereinafter, while permitting tube 36 and its associated parts to remain upright.

In the use of this device a suitably shaped rock fragment 37 is placed on the membrane so as to be in capillary contact therewith. Let it be assumed that the object is to determine the rate and extent of displacement of water from the rock fragment by oil. The system below the membrane is filled with water and the membrane itself is saturated with water. The rock fragment is also initially saturated with water.

With the parts in the position shown, oil is admitted through the inlet port 9 through a suitable valve until reservoir conditions of capillary pressure are attained in the chamber formed by the lid 7 and the cup member 1. That is, a pressure difference is established between the oil and water phases such that the difference in pressure across the membrane 13 is equal to the desired capillary pressure. At this time the whole assembly is immersed in an oil bath heated to reservoir temperature. While maintaining the aforesaid temperature and pressure the increase in the water level in the glass tube 36 is observed. By this observation data are obtained indicating the rate of water displacement from the rock fragment and also the total amount of water displaced over a period of time.

The operation as described above may be modified to compensate for the effects of reservoir gross fluid pressure by initially establishing reservoir pressure conditions on both sides of the membrane 13 and then creating a pressure difference across the membrane equal to the capillary pressure.

The foregoing operations simulate what has occurred in nature by the intrusion of oil into a water bearing formation. The water displaced from the core fragment gives a measure of the amount of water which was displaced from the water bearing formation by the intrusion of oil. The water left in the fragment which can be determined by subtracting the displaced water from the known pore space of the fragment is a measure of what is known as connate water in the reservoir rock, or, in other words, that water which is retained by capillary forces in the rock after the reservoir has become filled with oil. It may be mentioned here that the rock sample may be removed from the unit shown after the water displacement is completed and subjected to a treatment for the measurement of the actual water contained in it.

The apparatus described is useful in many additional studies of reservoir behavior. For example, it can be used to determine the productivity

and rate of production of oil from such a reservoir by either water drive or gas drive. In this procedure the core is saturated with oil to an extent corresponding to that obtained in the reservoir itself; this saturation occurring when the core still contains its connate water. For this determination also the membrane is saturated with oil and the system below the membrane is also filled with oil.

When the object is to determine the productivity or the rate at which oil is produced from the reservoir under water drive the cell is turned upside down which involves turning the fitting 31 through 180° so that the glass tube 36 will still be upright. With the parts in this position water is introduced through inlet 9 and a water pressure equivalent to that available for the water drive in the reservoir is built up. Then again the rate and amount of increase in level in the glass tube 36 is observed.

If productivity under gas drive is to be studied the apparatus is used in the position shown with gas instead of water being admitted through the inlet port 9. For best results in a study of this type the gas employed is that which is available in a reservoir.

Referring to Fig. 3, parts corresponding to those shown in Fig. 1 bear the same numerals. In this embodiment the sample chamber is made larger to accommodate a larger number of samples. The number of posts 16 is suitably increased and the bar 17 is replaced by a plate 38. In this embodiment the bottom plate 10 is replaced by a tray 39 in which is a plate 40 of porous material, such as porous alumina, ceramic material, sintered glass, unglazed porcelain, porous metal produced by the powdered metal technique or the like. This plate extends slightly above the upper edge of the tray 39 and the junction between the two is sealed by a suitable cement 41. One side of the tray has a radial passage 42 in which is arranged the tube 26 as in Fig. 1.

It will be understood that the same type of membrane can be utilized in both embodiments of the invention shown, the choice depending upon the capillary pressure conditions to be imposed. In general, the ceramic type material is used when low pressure operations are contemplated.

In utilizing the embodiment shown in Fig. 3 various techniques are possible. The number of samples which may be handled at once is limited only by the design of the apparatus, it being possible to construct it for any desired number of samples. The samples may be all from the same location in the reservoir, they may be from different levels in the reservoir, or they may be from laterally spaced points in the reservoir at the same level or different levels. Where they are taken from different depths the capillary pressure to be used in their study as a group is the average of their individual capillary pressures. The selection of samples to be processed simultaneously is determined by the object of the study and is left to the discretion of the operator.

The procedure to be followed in the use of this embodiment is the same in all respects as the procedure described with reference to the embodiment shown in Fig. 1. The data obtained by observing the displacement of fluid into glass tube 36 as various pressure conditions are imposed reflects on the average character of the group of cores taken as a whole. Proper interpretation of these data is entirely apparent to those

skilled in experimental work of this type; for example, it is possible by employment of this technique to determine in a rapid manner the correlation between connate water and other measurable properties of the rock. Once this trend is established, and assuming these other properties are more easily measured, it then becomes possible to approximate values for connate water by these simpler measurements of associated rock properties rather than being required to employ the complete procedure originally required to establish the trend. For instance, simple methods for determining permeability are available. By using the procedure outlined above for securing average values of connate water for a plurality of samples and by plotting these average values against measured permeability of the samples, it is usually possible to establish a trend or relationship between the two values. Where a clear relationship is shown to exist, connate water in other similar samples may be approximated by resorting to the simple permeability measurements and determining connate water by reference to the aforesaid trend.

In the foregoing, reference has been made at various points to capillary pressure. Capillary pressure may be defined as the difference in pressure which exists at the curved interface between immiscible fluid phases. This capillary pressure is related both to the interfacial tension between the phases and is also related to the geometry of the porous system in which the phases exist. In experiments where it is desired to obtain values for connate water the relationship employed is $P_c = HDg$ where P_c is capillary pressure, H is the distance between the curved interface and the level of complete water saturation in the reservoir, D is the density difference between immiscible phases and g the gravitational constant. This relationship may be employed to establish the proper conditions of capillary pressure to be imposed. For example, where the rock fragment is obtained from the reservoir at a point 20' above the level at which water exists as the continuous phase, the value for capillary pressure in the equation given above may be shown to be about 2 p. s. i., assuming a density difference of 0.2 gm./cm.³ between the reservoir oil and water phases. Thus, it is evident from this equation that in the reservoir the forces of gravity (HDg) are balanced by opposing capillary forces (P_c) and it is the attainment of this condition of equilibrium in laboratory experiments which is one of the principal objects of this invention.

The apparatus heretofore described also lends itself readily to study of the fluid distribution in a reservoir under a gradually increasing capillary pressure caused by gradual recession of the water table. The technique to be followed in this study is to bring the apparatus to equilibrium with pressures on both sides of the membrane equal and then gradually to increase the pressure of the displacing fluid, meanwhile observing the amount of rock fluid displaced. This gradual increase in pressure of displacing fluid can be made equivalent to that obtained over a period of several years until a maximum capillary pressure is attained.

Various changes may be made in the design and arrangement of parts of the apparatus illustrated and described without departing from the scope of the present invention. Moreover, several studies for which the apparatus is adapted

in addition to those specifically described will be evident to those skilled in the art.

The nature and objects of the present invention having thus been set forth and a specific embodiment of the same given, what is claimed and desired to be secured by Letters Patent is:

1. An apparatus for the study of the distribution of immiscible fluids in a subterranean reservoir which comprises a metal cell capable of withstanding the pressure in said reservoir, a semi-permeable membrane arranged in said cell, means for sealing off the under side of said membrane from direct fluid contact with the interior of said cell while exposing the upper surface of said membrane to direct fluid contact with the interior of said cell, means for maintaining a fluid pressure head against the under side of said membrane, means for securing at least one rock sample from said reservoir against the upper side of said membrane in capillary contact therewith, means for introducing a displacing fluid into the interior of said cell and means for measuring the fluid head against the under side of said membrane.

2. An apparatus according to claim 1 in which the membrane is a thin cellophane sheet supported by a metal screen.

3. An apparatus according to claim 1 in which the membrane is a porous ceramic plate.

4. An apparatus for studying the distribution

of immiscible fluids in a subterranean reservoir comprising a metal cup member, a metal lid of substantial depth for said cup member, means for clamping said lid to said cup member to form a cell of the assembly, fluid sealing means between said cup member of said lid, a semi-permeable membrane arranged in said cup member, means for sealing the under surface of said membrane from direct fluid contact with the interior of said cell, a passage connecting the under surface of said membrane to the exterior of said cell, means for maintaining a head of fluid connected with said passage, means for securing at least one rock sample from said reservoir against the upper surface of said membrane in capillary contact therewith and means for introducing a displacing fluid into the interior of said cell.

WALTER DEAN ROSE.

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