March 12, 1957 C. S. MATTHEWS ET AL 2,784,787

METHOD OF SUPPRESSING WATER AND GAS CONING IN OIL WELLS

Filed Aug. 11, 1953 3 Sheets-Sheet 1

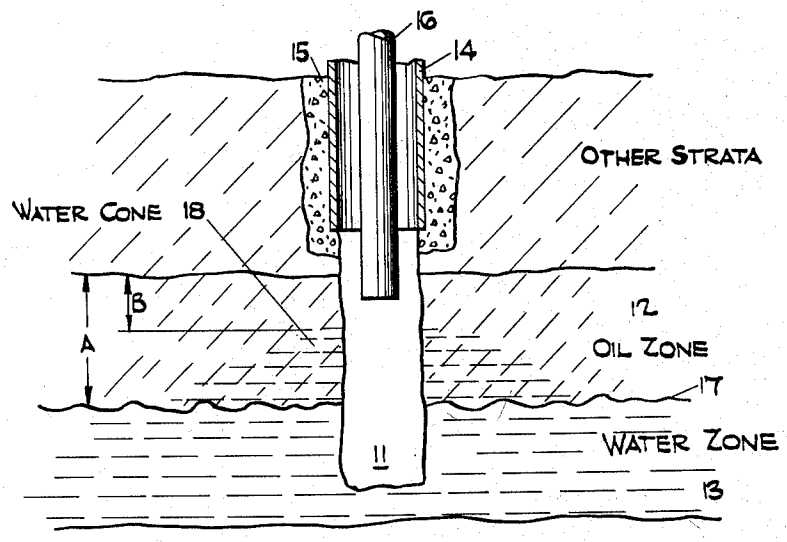


FIG. 1

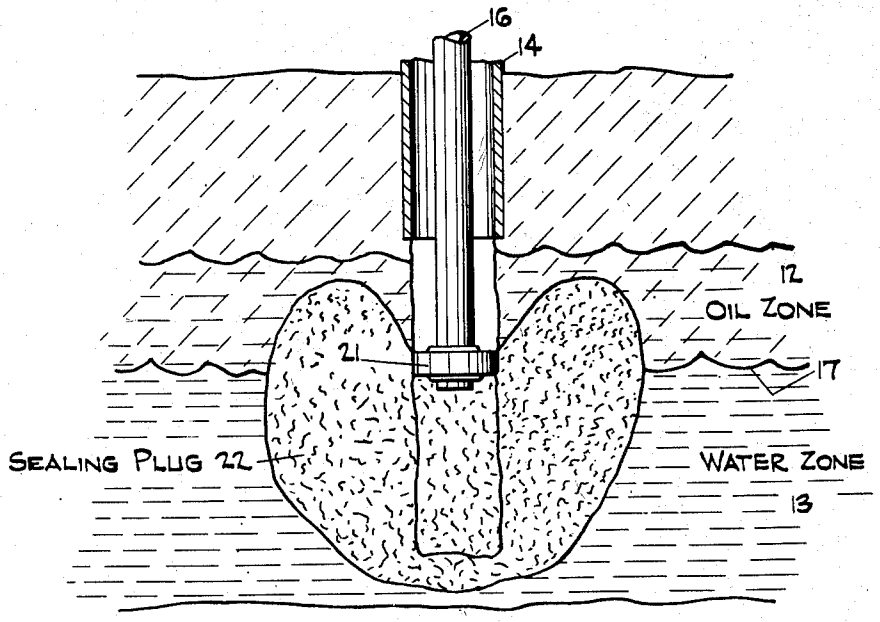


FIG. 2

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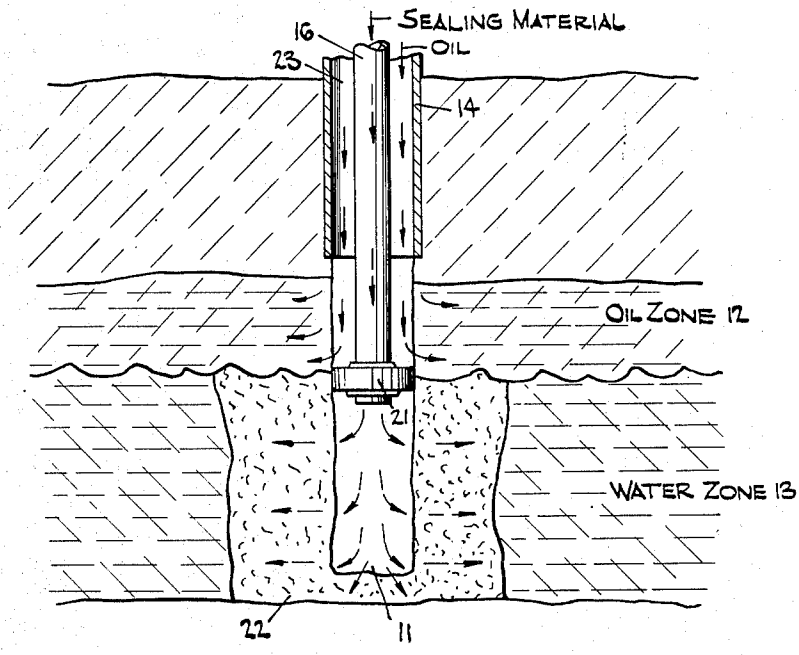


FIG. 3

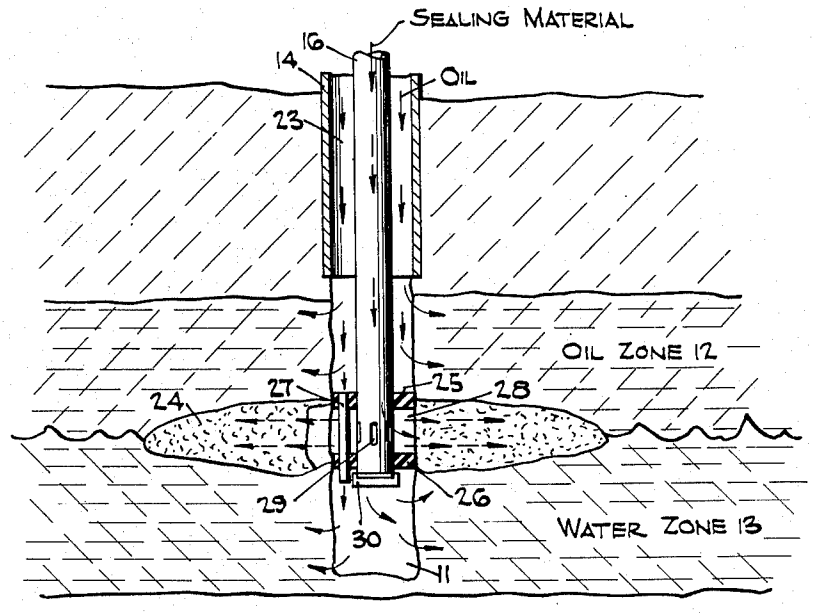


FIG. 4

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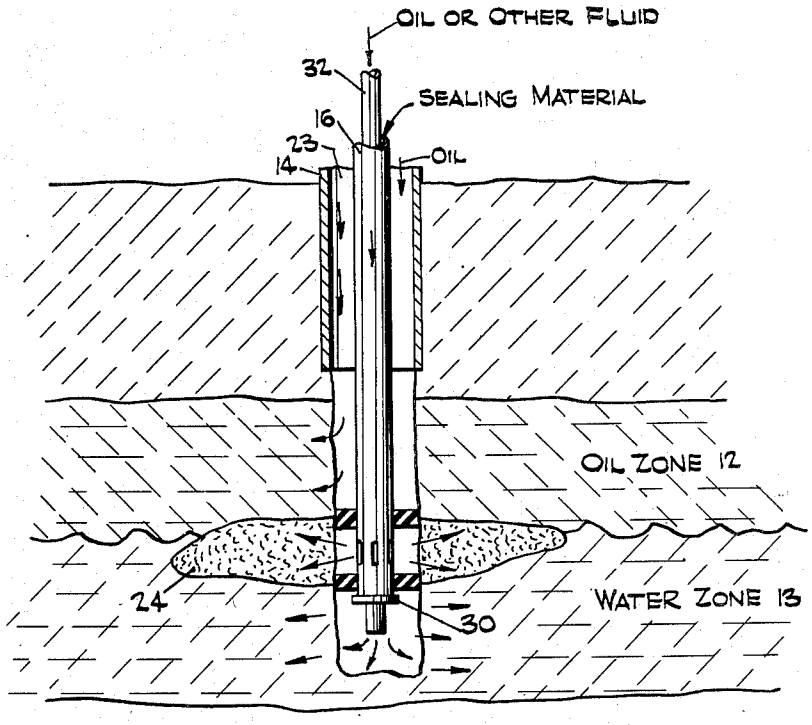


FIG. 5

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METHOD OF SUPPRESSING WATER AND GAS CONING IN OIL WELLS

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Application August 11, 1953, Serial No. 373,640

7 Claims. (Cl. 166—21)

This invention relates to the treatment of oil wells, and pertains more particularly to improved methods of treating formations of wells producing both oil and water, whereby a water-bearing portion or zone of the formation may be sealed or isolated from the oil-bearing portion or zone near the borehole to prevent the migration of water into the oil-bearing zone.

In many oilfields the oil-producing portion of the formation is underlain by a water-producing portion. The water may not have underlain the oil originally but may have entered later. Under either condition water from the lower zone usually flows into the well borehole mixing with the oil therein. In many wells producing both oil and water, the encroachment of the water progresses through various stages until finally the well may be producing large quantities of liquid of which but a small portion is oil. First, some of the water from the lower zone may finger up into the oil-producing zone before entering the borehole; then, as the flooding advances, the water rises higher and higher in the oil-producing sand adjacent to the borehole and reduces more and more the flow area by which the oil may enter the well borehole. This process may continue to such an extent that the production from the well is largely water even though a significant quantity of oil may remain in the formation. Production of this oil may not be economically feasible at the very reduced oil rate caused by the water influx into the well bore.

This migration of water from a lower portion or zone of the formation into the producing section of the formation adjacent the well borehole is known as coning of water. The formation of such a "cone" increases the flow area for the water at the expense of the flow area for the oil, the rate at which this takes place depending largely upon the character of the formation, the character of the fluids therein and the rate of production. This may result in the almost complete saturation with water of the sands adjacent the well, most of the oil gaining access to the well as globules that have to pass through the water. When this condition is attained, methods generally used in the petroleum industry for attempting to cope with the influx of water have met with little degree of success.

Several methods of suppressing water coning in wells producing both oil and water have been suggested. For example, the most obvious method consisted of depositing cement in the well borehole adjacent the water-producing formation up to the interface between the water-producing and oil-producing zones. This remedy proved ineffective as the water from the lower zone continued to intrude into the oil-bearing zone adjacent the borehole. In another attempt to prevent water coning, a packer was set in the borehole at the interface between the oil-bearing zone and the adjacent water-bearing zone, and a sealing material was forced down a tubing and through the packer into the space below which was adjacent the water-producing zone. Pressure was then applied to the column of plastic sealing material to force the impervious material into the water-bearing zone to seal it off effectively. While the

impervious material expanded radially from the borehole into the formation to seal off the water-bearing zone, some of the material was also forced both radially and upwardly into the oil producing zone thereby diminishing the effective production area of the well.

Other workers in the field have suggested introducing into the well borehole and positioning therein adjacent to the oil-producing zone either a stagnant fluid or a gel-like mass which would prevent the material used to seal the water zone from contaminating the oil producing formation. The use of a stagnant liquid in such a manner, however, did not prevent the intrusion of a mass of sealing material from the water-producing zone into the oil-producing zone. Further, it has been suggested to crack the producing formations at the interface of the oil-bearing zone and water-bearing zone and to inject into the cracked formation a thin layer of cement or other impervious material extending radially from the borehole. The difficulty with this method is that it is usually not possible to crack the formation in the desired direction for any appreciable distance.

It is therefore a primary object of this invention to provide a method for suppressing water coning into well boreholes.

A further object of this invention is to provide a method for suppressing water coning into well boreholes having both oil and water-producing zones without contaminating the oil-producing formation.

Another object of this invention is to provide a method for suppressing water coning in a well borehole having both oil and water-producing zones without appreciably reducing the effective producing area of the oil-producing formation.

It is also a further object of this invention to provide a method for suppressing water coning into a well borehole having both oil and water-producing zones by sealing or isolating the water-producing zone from the oil-producing zone at a point adjacent the borehole.

Another object of this invention is to provide a method for suppressing water coning in a well borehole having both water and oil-producing zones by effectively sealing off the water-producing zone of the well while preventing the sealing material from entering the oil-producing zone.

Still another object of this invention is to provide a method for reducing the water/oil production ratio in a well having both oil and water-producing formations.

Another object of this invention is to provide a method for reducing gas coning.

A further object of this invention is to provide a method for reducing the gas-oil production ratio in wells with a gas cap.

These and other objects of this invention will be understood from the following description taken with reference to the attached drawing, wherein:

Figure 1 is a vertical section through a well borehole diagrammatically illustrating the formation of a water cone around an oil well.

Figure 2 is a vertical section through a well borehole diagrammatically showing equipment whereby a sealing material is being injected into the water zone of the well borehole, with a portion of the plugging material "ballooning" upwardly into the oil zone.

Figure 3 is a vertical section through a well borehole diagrammatically illustrating the injection of a plugging material into the water-producing zone while injecting a non-plugging fluid or material into the oil-producing zone.

Figures 4 and 5 are vertical sections through a well borehole diagrammatically illustrating two different methods for injecting a disk of plastic or other sealing material radially into the formation at a point substantially at the interface of the oil and water-bearing formations.

Referring to Figure 1 of the drawing, a well borehole 11

is shown which has been drilled through various strata including a formation or formations having an oil-producing zone **12** and a water-producing zone **13** which underlies the oil zone. The well casing **14** is shown as positioned in the borehole **11**, being sealed therein by cement **15**. Depending within the well casing **14** is the lower end of a production tubing **16**.

The actual contact or transition zone represented by line **17** which separates the oil-bearing formation **12** from the water-bearing formation **13** varies in degree of abruptness but is usually characterized by low water saturation in the lower part of zone **12** and in the upper part of zone **13** with progressive increase in water saturation with depth below the oil-water contact zone along the line **17**.

Area **18** is a diagrammatical representation of what is commonly designated as a "water cone" around the well borehole **11** in the oil-bearing formation producing both oil and water. Within such area **18**, the natural oil-water saturations have been greatly modified by water encroachment and the formation thus represented has become more permeable to water than to oil. Water from the water-bearing zone **13** has moved upwardly into the oil-bearing formation **12** adjacent the well borehole **11**, thus reducing the depth of the oil sands at the wall of the borehole **11** from its original depth A to its present depth B. Continued enlargement of the water cone **18** by further upward migration of the water into the oil-bearing zone **12** would ultimately cause the oil sands **12** adjacent the borehole to become flooded with water thus effectively shutting off the entrance of oil from zone **12** into the borehole **11**.

In an attempt to prevent water coning, the lower water-bearing formation **13** is often sealed off by depositing a volume of plastic at the bottom of the borehole and injecting it into the adjacent water-bearing zone **13**. As shown in Figure 2 of the drawing, a well packer **21** may be mounted on the lower end of a pipe string **16** and lowered into the well to the level of the interface between the oil and water-bearing zones where it is sealed against the walls of the well casing or borehole. A sealing material in then pumped down the pipe string **16** and forced under pressure into the water-bearing formation **13**. A sealing plug **22** is formed around the borehole by the sealing material which is forced into the formation. It is to be noted that the sealing material besides expanding radially into the formation is also forced upwardly into the oil-bearing formation **12** around the packer **21**. This movement of sealing material upwardly into the oil zone **12** around the packer **21** is known as "ballooning."

The present invention may be practiced to suppress water coning in a well producing both oil and water and to prevent the ballooning of a sealing material injected into the well to seal off the water-bearing zones. In accordance with the present invention a pipe string **16**, having a packer **21** attached to the lower end thereof, is lowered into a well borehole **11** as shown in Figure 3 and the packer **21** is set against the walls of the borehole at above or below the interface of the oil and water-bearing zones **12** and **13**, respectively. A fluid plastic or other impervious material is pumped down the pipe string **16** into the bottom of the borehole **11** where it is forced radially into the adjacent water-bearing formation under pressure to effectively seal the water-bearing formation adjacent the borehole by forming a sealing plug **22**.

Simultaneously, a second fluid, which is non-sealing in character, is forced down the annulus **23** between the well casing **14** and the pipe string **16**. The non-sealing liquid is forced radially into the oil-producing zone **12**. Any suitable non-sealing material which will not contaminate or block the oil sands **12** may be used to prevent the ballooning of the sealing material. The most common non-sealing fluid which could be used would, of course, be some of the oil which had already been produced by that well.

Chemicals or other materials which control the viscosity of the oil may be added to the oil to alter its viscosity. Radial velocities of the non-sealing oil into the oil zone and of the plastic sealing fluid into the water zone can be maintained equal and parallel to the interface **17** provided that a proper relationship is maintained between the permeabilities of the two zones **12** and **13** and the viscosities and injection pressures of both fluids. The permeability of the oil sand **12** to the non-sealing fluid and of the water sand **13** to the sealing fluid can be readily determined in a manner well known to the art after cores from each zone have been obtained as by a sidewall coring operation. After determining the permeabilities of the sands of the two zones, the viscosities of the sealing fluid and/or of the non-sealing fluid may be adjusted, as by the addition of chemicals, other oils, or other materials, so that the two fluids pass through the respective formations at equal radial velocities when they are injected into the well under pressure greater than formation pressure and so adjusted that the pressure in the non-sealing fluid just above the packer is equal to the pressure in the sealing fluid just below the packer. If the formation containing the oil and/or water-producing zone is not homogeneously permeable, the adjustment should be made to maintain equal radial velocity at the sealing/non-sealing fluid interface.

Alteration of the viscosity of the non-sealing fluid is not essential if some contamination of the oil zone is allowable. The basic steps in the present invention comprise the simultaneous injection of the two fluids, although alteration of non-sealing fluid viscosity may be desirable in many cases. When the well is put on production, the oil in the oil sand **12** forces the non-sealing liquid out of the sand and into the borehole where it is raised ahead of the normal well fluid.

The suppression of water coning may also be readily accomplished by carrying out the present method as diagrammatically illustrated in Figure 4 of the drawing. In this modification, the coning of water from a lower water-producing zone **13** to the upper oil-producing zone **12** may be suppressed by forming either in the oil zone **12** or between the two zones **12** and **13** at a point adjacent the borehole **11**, a disk **24** of plastic or other impervious material, which will solidify after being forced into place. To form the disk **24** a pipe string **16** is lowered into the well borehole **11**, there being carried on the lower end of said pipe string **16** is spaced relationship a pair of packers **25** and **26**. The packers **25** and **26** are adapted to be sealed against the wall of a borehole, while the space above the packers is in communication with the space therebelow through a suitable conduit means such as a short pipe **27** extending through both packers **25** and **26**. The space **28** between packers **25** and **26** is in communication with the bore of the pipe string **16** through one or more suitable ports **29** in the lower end of the pipe string. The bottom of the pipe string is closed in any suitable manner as by a cap or plug **30**.

The disk **24** shown in Figure 4 may be formed by placing the double packers **25** and **26** in the borehole **11** so as to straddle the desired level at which the plastic is to be placed. While the plastic disk **24** is preferably injected and formed at the interface between the oil and water-bearing zones, the plastic may, however, be injected above or below the interface. Thus, it may be desirable in many cases to inject the plastic entirely in the oil-bearing zone. This should postpone coning even longer than injection at the interface. As the water level rises and passes over this first plastic disk, coning may begin anew. If a sufficient thickness of oil-bearing formation is left it may then be feasible to set a second plastic disk above the water layer. Possibly a multi-disk device could be used to inject several disks at one time, then as water encroached, a borehole packer or plug could be used to seal each disk at the well bore. The plastic could be injected at the time the well was completed if thought desirable. Prior to the place-

ment of these packers 25 and 26, the formations at this level may be fractured as by shooting with explosives, or may be cut as by reaming, undercutting, or in any other manner well known to the art. After placement of the packers in position, a sealing material is forced down pipe string 16 out ports 29 into the space 28 between the packers 25 and 26 and thence into the formation between the oil zone 12 and the water zone 13 to form a disk-shaped deposit of material 24 which readily hardens or solidifies to become impervious to water. Simultaneously, oil or any other non-sealing material is forced down the annulus 23, a portion of the non-sealing material being forced into the oil-producing zone 12, while the other portion of the non-sealing material is forced through conduit 27 by-passing the packers and thence into the water-producing formation 13. By maintaining a flow of non-sealing fluid into the formation in a direction essentially parallel to the interface and at a radial velocity equal to that at which the sealing material flows into the formation, a disk 24 of suitable lenticular shape may be formed without any of the material ballooning upwardly into the oil formation or downwardly into the water formation. Such a flow may be maintained by suitable adjustment of fluid viscosity as discussed above and by maintaining pressures above and below the packers nearly equal. The thickness of the disk 24 may vary from several inches to several feet, depending on the character of the formations and the pressures and viscosities used.

As a substitute for the oil or other non-sealing fluid to be used in the region below the plastic disk 24, i. e., adjacent the water-bearing formation 13, water treated with viscosity-increasing chemicals, such as glycerol or sugar may be used. The apparatus needed to inject three different fluids into a well borehole would be modified slightly as shown in Figure 5 of the drawing to include a small diameter pipe string 32 positioned within the pipe string 16 and extending through the plug 30 closing the lower end of said pipe string.

Thus, by using the equipment shown in Figure 5 of the drawing, oil or any other non-sealing fluid is pumped down the annulus 23 between the well casing 14 and the pipe string 16 to be injected into the oil-producing formation 12 while at the same time the sealing material is pumped down the pipe string 16 and forced into the formation to form a disk 24 and a third fluid, preferably an inexpensive fluid, is forced down the inner pipe string 32 and into the water-producing formation 13. The pump pressures and the viscosities of the fluids may be adjusted (dependent upon the permeabilities of the formation(s) to the injected fluids) so that the radial velocity of all three fluids into the formations is substantially equal and in a direction parallel to the interface 17.

While best results are obtained when the velocities of all the fluids being injected are equal it is not essential to the prevention of coning that the radial velocities of all three fluids be equal. A curved or otherwise distorted disk will also suppress coning though, possibly, at some sacrifice in efficiency.

Any suitable sealing material may be employed according to the present invention which may be injected into a formation and form therein a water-impermeable mass. Among the various materials which may be used are many resins, synthetic resins, plastics, synthetic plastics, such as phenol formaldehyde and urea formaldehyde resins, various gels such as silica gel, various gums such as Yacca gum, mixtures of asphalt and pyridine, and the like. The materials used should be both water and oil insoluble.

After a sealing material has been forced into the formation, the remainder of the sealing material and/or non-sealing material may be removed from the casing 14 or the pipe strings 16 and 32 in any manner well known to the art, as by circulation. If the packers 21, 25, and 26 are removed from the borehole together with the pipe strings, they are preferably replaced by other packers in a manner well known to the art to prevent water from a water-bearing formation from mixing with oil in the well borehole.

We claim as our invention:

1. In a well borehole traversing an oil-bearing formation and other formations adjacent thereto containing undesirable fluids, the method of suppressing the migration of a fluid from said other formations into the oil-bearing formation adjacent the borehole, said method comprising packing off the section of borehole adjacent the formation to be sealed, injecting a fluid water and oil insoluble sealing material under pressure radially into the formation adjacent the packed-off section of borehole, simultaneously injecting a non-sealing liquid under pressure radially into at least said oil-bearing formation traversed by said borehole, both of said injections being carried out at pressures sufficient to maintain the radial flows of the fluid sealing material and non-sealing fluid into the formations at substantially equal velocities, and subsequently reopening the oil-bearing formation to production.

2. In a well borehole traversing an oil-bearing formation and a water-bearing formation, the method of preventing the migration of water from the water-bearing formation into the oil-bearing formation adjacent the borehole, said method comprising packing off a portion of the borehole at a level between the two formations, injecting a water and oil insoluble sealing fluid into said packed-off portion of said borehole and radially into the water-bearing formation, simultaneously injecting radially into said oil-bearing formation a non-sealing liquid, both of said injections being carried out at pressures sufficient to maintain the radial flows of the sealing fluid and non-sealing liquids into the formations at substantially equal velocities, and subsequently reopening the oil-bearing formation to production.

3. In a well borehole traversing an oil-bearing formation and a water-bearing formation, the method of preventing the migration of water from the water-bearing formation into the oil-bearing formation adjacent the borehole, said method comprising packing off a portion of the borehole between two levels vertically spaced from each other substantially at the interface between the two formations, injecting to a radial depth equal to at least the diameter of the borehole a water and oil insoluble sealing liquid into said packed-off portion of said borehole and into the formation substantially at the interface of said oil-bearing and water-bearing formations, simultaneously injecting a non-sealing liquid into said oil-bearing formation and through said packed-off portion of said borehole into said water-bearing formation, both of said injections being carried out at pressures sufficient to maintain the radial flows of the sealing and non-sealing liquids into the formations at substantially equal velocities, and subsequently reopening the oil-bearing formation to production.

4. In a well borehole traversing an oil-bearing formation and a water-bearing formation, the method of preventing the migration of water from the water-bearing formation into the oil-bearing formation adjacent the borehole, said method comprising fracturing the borehole wall at substantially the interface of said oil-bearing and water-bearing formations, packing off the fractured portion of the borehole, injecting under high pressure a water and oil insoluble sealing liquid into said packed-off portion of said borehole and into the formation fracture, simultaneously injecting into said oil-bearing formation a non-sealing liquid, both of said injections being carried out at pressures sufficient to maintain the radial flows of the sealing and non-sealing liquids into the formations at substantially equal velocities, and subsequently reopening the oil-bearing formation to production.

5. In a well borehole traversing an oil-bearing formation and a water-bearing formation, the method of preventing the migration of water from the water-bearing formation into the oil-bearing formation adjacent the borehole, said method comprising packing off a portion of the

borehole between two levels vertically spaced from each other substantially at the interface between the two formations, injecting a water and oil insoluble sealing liquid into said packed-off portion of said borehole and into the formation substantially at the interface of said oil-bearing and water-bearing formations, simultaneously injecting a first non-sealing liquid into said oil-bearing formation, simultaneously injecting a second non-sealing liquid through said packed-off portion of said borehole into said water-bearing formation, said injections being carried out at pressures sufficient to maintain the radial flows of the sealing and non-sealing liquids into the formations at substantially equal velocities, and subsequently reopening the oil-bearing formation to production.

6. In a well borehole traversing an oil-bearing formation and a water-bearing formation, the method of preventing the migration of water from the water-bearing formation into the oil-bearing formation adjacent the borehole, said method comprising packing off a portion of the borehole between two levels vertically spaced from each other substantially at the interface between the two formations, injecting a water and oil insoluble sealing liquid into said packed-off portion of said borehole and into the formation substantially at the interface of said oil-bearing and water-bearing formations, simultaneously injecting a non-sealing hydrocarbon base liquid into said oil-bearing formation, simultaneously injecting a non-sealing water-base liquid through said packed-off portion of said borehole into said water-bearing formation, said injections being carried out at pressures sufficient to maintain the radial flows of the sealing and non-sealing liquids into the formations at substantially equal velocities, and subsequently reopening the oil-bearing formation to production.

7. In a well borehole traversing an oil-bearing formation and a water-bearing formation, the method of preventing the migration of water from the water-bearing formation into the oil-bearing formation adjacent the borehole, said method comprising fracturing the borehole wall substantially at the interface of said oil-bearing and water-bearing formations, packing off above and below the fractured portion of the borehole, injecting under high pressure a water and oil insoluble sealing liquid into said packed-off portion of said borehole and into the formation fracture, simultaneously injecting a non-sealing liquid into said oil-bearing formation and through said packed-off portion of said borehole into said water-bearing formation, both of said injections being carried out at pressures sufficient to maintain the radial flows of the sealing and non-sealing liquids into the formations at substantially equal velocities, and subsequently reopening the oil-bearing formation to production.

References Cited in the file of this patent

UNITED STATES PATENTS

2,258,616	Kendrick	Oct. 14, 1941
2,368,424	Reistle	Jan. 30, 1945