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SELECTIVE PLUGGING OF PERMEABLE EARTH FORMATIONS

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This invention relates to the plugging of permeable earth formations penetrated by a well and relates more particularly to the selective plugging of such earth formations containing water.

For various purposes, wells are drilled from the surface of the earth through the underlying earth strata or formations. For example, wells are drilled from the surface of the earth to comparatively deep formations containing hydrocarbons, either oil or gas, for the purpose of recovering the hydrocarbons from these formations. These wells may be production wells or injection wells. In production wells, the hydrocarbons flow by natural means, or are caused to flow by artificial means, from the producing formation into the well and are recovered from the well. In injection wells, a driving fluid, such as water, is injected into the producing formation from the well to drive the hydrocarbons through the formation to a production well from which they are recovered.

Problems are encountered in the production of hydrocarbons by reason of the production or injection well penetrating a permeable zone containing water. Thus, water can flow into a production well from such a zone and is produced along with the hydrocarbons necessitating subsequent separation of the water from the hydrocarbons. The water zone may be a formation other than the formation producing the hydrocarbons or may be a portion of the formation producing the hydrocarbons. In the latter case, the formation producing the hydrocarbons is said to be subject to water coning and the water flows from the lower portion of the formation to the production well while the hydrocarbons flow from the upper portion of the formation into the production well. In an injection well, injected water can flow into the water zone and, to the extent that such flow occurs, the function of the injected water to displace hydrocarbons is not performed.

The entrance of water into a production well from a water zone or the loss of injection water from an injection well can be corrected by reducing the permeability of the water zone to the flow of fluid. Reduction in permeability of a water zone can be effected by introducing a plugging agent into the zone and permitting the agent to set within the zone. In certain of the procedures for plugging a water zone, however, it is necessary to isolate the water zone from the formation or formations, or portion thereof, containing hydrocarbons in order to avoid plugging these latter formations. This, in turn, requires that the formations containing hydrocarbons and the water zone be precisely located. Often these precise locations are unknown. Further, even where the precise locations are known, difficulty is encountered in matching with these locations the locations of packers, casing or other means employed for effecting the desired isolation.

It is an object of this invention to provide a method for plugging a water zone penetrated by a well.

It is another object of this invention to avoid the necessity for isolating a water zone from a formation containing hydrocarbons penetrated by a well prior to plugging the water zone.

It is another object of this invention to provide a method for correcting water coning in a subterranean formation containing hydrocarbons.

It is another object of this invention to provide a method for plugging a subterranean formation contain-

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ing water which does not require that the precise location of the formation in a well penetrating the formation be known.

It is more generally an object of this invention to provide a method for treating subterranean formations penetrated by a well to plug a water zone selectively.

In accordance with the invention, there is provided a method which involves as one step placing a viscous hydrocarbon into a well. The well penetrates a permeable earth formation of which a portion at least contains hydrocarbons and a permeable formation of which a portion at least contains water. A pressure is then imposed upon the viscous hydrocarbon whereby the viscous hydrocarbon preferentially enters the formation or the portion thereof containing hydrocarbons. Thereafter, as another step, an aqueous solution of a plugging agent is placed in the well. A pressure is imposed upon the aqueous solution whereupon the aqueous solution preferentially enters the water zone, i.e., the formation or the portion thereof containing water. The pressure is then maintained upon the aqueous solution until the plugging agents sets within the water zone.

The flow of a liquid in a permeable formation is a function of the relative permeability of the formation to the liquid and of the mobility of the liquid. The relative permeability of the formation to the liquid is a function of the extent to which the formation is saturated with the liquid. The mobility of the liquid is a function of the relative permeability of the formation to the liquid and of the viscosity of the liquid. Where the formation has a high saturation with respect to a liquid, the relative permeability of the formation to the liquid will be high and the liquid will flow more easily in the formation. Conversely, where the formation has a low saturation with respect to a liquid, the relative permeability of the formation to the liquid will be low and the liquid will flow more difficultly, or not at all, in the formation. Further, where the viscosity of the liquid is high, and the relative permeability of the formation to the liquid is low, the mobility of the liquid will be low and the liquid will flow more difficultly through the formation. On the other hand, where the viscosity of the liquid is high and the relative permeability of the formation to the liquid is high, the mobility of the liquid will be higher and the liquid will flow more easily through the formation.

In the procedure of the invention, a viscous hydrocarbon is placed in the well and a pressure is imposed upon it. A formation or a portion thereof having a high saturation with respect to hydrocarbons, i.e., containing hydrocarbons, will have a high relative permeability to the viscous hydrocarbon. With high relative permeability of the formation to the viscous hydrocarbon, the viscous hydrocarbon can readily flow in the formation. Accordingly, the viscous hydrocarbon can readily displace the hydrocarbons contained in the formation and will enter the formation. On the other hand, a formation or portion thereof having a high saturation with respect to water, i.e., containing water, will have a low relative permeability to the viscous hydrocarbon. With low relative permeability of the water zone to the viscous hydrocarbon, the viscous hydrocarbon will move difficultly in the water zone. Accordingly, the viscous hydrocarbon can displace the water in the water zone only with difficulty and will enter the water zone only with difficulty. Thus, in the first step of the invention, the viscous hydrocarbon will preferentially enter the formation or a portion thereof containing the hydrocarbons.

In another and subsequent step of the invention, an aqueous solution of a plugging agent is placed in the well and a pressure is imposed upon it. A water zone, having a high saturation with respect to water, i.e., containing water, will have a high relative permeability to the aque-

ous solution. With high relative permeability of the water zone to the aqueous solution, the aqueous solution can readily flow in the water zone. Accordingly, the aqueous solution can displace the water in the water zone and will enter the water zone. On the other hand, the formation or portion thereof having a high saturation with respect to hydrocarbons, i.e., containing the viscous hydrocarbon employed in the first step of the invention, will have a low permeability to the aqueous solution. With low relative permeability of the hydrocarbon-containing formation to the aqueous solution, the aqueous solution can flow in the hydrocarbon-containing formation only with difficulty. Accordingly, the aqueous solution can displace the viscous hydrocarbon in the hydrocarbon-containing formation only with difficulty and will enter the hydrocarbon-containing formation only with difficulty. Thus, in this subsequent step of the invention, the aqueous solution of plugging agent will preferentially enter the water zone.

In the step of passing the aqueous solution of plugging agent in the well and imposing pressure upon it, the mobility of the viscous hydrocarbon in the hydrocarbon-containing formation or portion thereof is less than that of the hydrocarbons initially contained in this formation or portion thereof. Thus, the viscous hydrocarbon resists displacement by and entry into the formation of the aqueous solution of plugging agent to a greater degree than would be possible by the hydrocarbons initially contained in the formation. Thus, as a result of the introduction of the viscous hydrocarbon into the hydrocarbon-containing formation or portion thereof, a greater amount of aqueous solution of plugging agent enters into the water zone and a lesser amount enters into the hydrocarbon-containing formation than would occur in the absence of the step of introducing the viscous hydrocarbon into the well and imposing pressure upon it.

The viscous hydrocarbon passed into the hydrocarbon-containing formation or portion thereof must have a viscosity greater than the viscosity of the hydrocarbons initially contained in the formation. Thus, the viscous hydrocarbon is enabled to resist displacement by the aqueous solution of plugging agent to a greater degree than the hydrocarbons initially contained in the formation. The viscous hydrocarbon must also have a viscosity of at least 30 centipoises. As I have found, where the viscosity of the hydrocarbon is more than about 30 centipoises, the viscous hydrocarbon is highly resistant to displacement from the formation by the aqueous solution of the plugging agent. On the other hand, the viscosity of the viscous hydrocarbon should not be so high that difficulty is encountered from the standpoint of the pressures required to be imposed upon it to effect passage from the well into the hydrocarbon-containing formation. Preferably, the viscosity of the hydrocarbon should not be greater than about 1,000 centipoises. At viscosities greater than about 1,000 centipoises, the pressure required to pass the viscous hydrocarbon into the hydrocarbon-containing formation becomes sufficiently high to involve high costs for pumping and to present the possibility of the formation being fractured.

The viscous hydrocarbon may be any type of hydrocarbon or hydrocarbon material having the requisite viscosity. For example, the viscous hydrocarbon may be a heavy oil such as a crude oil (lease crude), distillate, fuel oil, or lubricating oil. A light hydrocarbon containing a gelling agent to obtain the desired viscosity may also be employed.

A particular advantage is obtained where the viscous hydrocarbon employed is a light hydrocarbon containing a gelling agent which will break down with time under the conditions existing in the hydrocarbon-containing formation. After the aqueous solution of plugging agent has set in the water zone, the well may be placed on production if a production well or fluid injected into it if an injection well. The viscous hydrocarbon, because

of its high viscosity, will resist displacement by the hydrocarbons to be produced or by the fluid to be injected. Eventually, however, it will be displaced but displacement may require an undesirably long period of time. However, where the viscous hydrocarbon is a gelled hydrocarbon, a breakdown of the gel occurs within a time under the conditions of temperature and pressure existing in the formation which is short compared to displacement of a hydrocarbon having an inherently high viscosity. The breakdown product will have a viscosity substantially that of the hydrocarbon that was gelled. Accordingly, the advantage of the high viscosity of the viscous hydrocarbon, from the standpoint of insuring that little or none of the aqueous solution of plugging agent enters the hydrocarbon-containing formation is obtained along with rapid displacement following setting of the plugging agent. To obtain maximum benefit of this advantage, it is preferred that the hydrocarbon which is gelled and passed into the hydrocarbon-containing formation have as low a molecular weight as possible. Thus, the gelled hydrocarbons may include gelled gasoline, gelled diesel oil, or other gelled hydrocarbon normally having a low viscosity. The gelled hydrocarbons may also include gelled light hydrocarbons such as gelled LPG, i.e., liquefied petroleum gas.

For gelling the hydrocarbon, any suitable type of gelling agent known to the art may be employed. For example, napalm may be employed. Other types of gelling agents such as the basic aluminum alkanates may be employed. Additionally, basic aluminum octanoate soaps may be employed. Gelling of hydrocarbons and the gelling agents to be employed are well known and are not a part of this invention. Accordingly, further description thereof does not appear to be necessary.

In the practice of the invention, a sufficient quantity of the viscous hydrocarbon is passed into the hydrocarbon-containing formation to fill the formation radially for a distance from the well of at least 10 feet. However, if desired, a greater quantity of the viscous hydrocarbon may be employed. Thus, for example, a quantity of viscous hydrocarbon may be passed into the formation to fill the formation radially for a distance of 40 feet.

The plugging agent employed should be an agent which will, in aqueous solution and under the conditions of temperature and pressure prevailing in the formation, set within the formation to plug the formation to the flow of fluid. The aqueous solution of plugging agent can be, for example, an aqueous solution of sodium silicate and a setting compound, which, under the temperature and pressure conditions of the formation, will react with the sodium silicate to form a hydrosol of silicic acid which converts to a hydrogel. The hydrogel, or silica gel, formed within the formation provides a firm, unitary plug, which is impervious to fluid. The setting compound may be sodium bicarbonate, ammonium carbonate, an alkyl amide such as formamide, oxamide, or urea.

The particular setting compound to be employed with sodium silicate will depend, to some extent, upon the temperature conditions prevailing within the formation. Sodium bicarbonate, ammonium carbonate, and the low molecular weight alkyl amides will effect setting of the sodium silicate at comparatively low temperatures of the formation. On the other hand, where the formation is at higher temperatures, for example, temperatures in excess of about 145° F., the reaction with the sodium bicarbonate, ammonium carbonate, and the low molecular weight alkyl amides occurs rather rapidly and may prevent placement of sufficient amount of the aqueous solution of the plugging agent into the formation before setting occurs. Accordingly, it is preferred to employ these setting compounds only at the lower temperatures not in excess of 145° F. Where the formation is at a temperature in excess of about 145° F., it is preferred to employ urea as the setting compound.

The solution of sodium silicate employed may be a solution of any type of sodium silicate heretofore em-

ployed for plugging a permeable formation. The solution may be a commercial aqueous solution of the sodium silicate. In these solutions, the concentration of the sodium silicate can be about 35 to 45 percent by weight. The molar ratio of the sodium oxide to silicon dioxide in the sodium silicate may be within the range of about 1:3.0 to 1:4.0. For example, the molar ratio of sodium oxide to silicon dioxide may be within the range of 1:3.0 to 1:3.5. Preferably, the molar ratio of sodium oxide to silicon dioxide is 1:3.22.

The aqueous solution of sodium silicate and setting compound introduced into the permeable formation should contain at least about 2 or 3 percent by weight of the sodium silicate. However, the amount of sodium silicate may be as high as about 30 percent by weight. On the other hand, the viscosity of an aqueous solution containing about 30 percent by weight of sodium silicate is sufficiently high to present difficulty in pumping. Accordingly, depending upon the available pumping pressure, it may be desirable to employ solutions wherein the amount of sodium silicate does not exceed about 27 percent by weight.

The amount of the setting compound in the aqueous solution will depend upon the particular setting compound employed. Where sodium bicarbonate, ammonium carbonate, or the lower molecular weight alkyl amides are employed, the amount of the setting compound should be at least about one percent by weight. On the other hand, the amount of the setting compound may be as high as 8 percent by weight. However, where urea is employed, the amount can depend upon the temperature of the formation. The setting of the plugging agent occurs more rapidly as the ratio of urea to sodium silicate in the solution increases and as the temperature in the formation increases. Accordingly, as the temperature in the formation increases, the amount of the urea in the aqueous solution may be decreased. For the treatment of formations having temperatures of the order of 145° F., the amount of the urea in the solution should be at least about 16 percent by weight. On the other hand, in formations having higher temperatures, the amount of urea may be decreased. At formation temperatures of the order of 170° F. and above, the amount of the urea in the solution may be decreased to about 9 percent by weight. At formation temperatures as high as 300° F., the amount of the urea in the solution may be as low as 1.5 percent by weight. Amounts of urea in excess of 25 percent by weight, regardless of temperature, provide no advantage from the standpoint of the setting time or the strength of the hydrogel.

The aqueous solution of the plugging agent should be passed into the permeable formation in an amount to fill the formation for a distance radially from the wellbore of at least about 10 feet. However, if desired, a greater quantity of the aqueous solution may be employed. Thus, for example, a quantity of aqueous solution of plugging agent sufficient to fill the formation radially from the wellbore for a distance of 40 feet may be employed.

The pressure imposed upon the viscous hydrocarbon and upon the aqueous solution of plugging agent need only be sufficient to effect entrance of the viscous hydrocarbon or the aqueous solution into the oil-containing zone or the water zone. Higher pressures can be employed particularly where it is desired to decrease the time required to effect entrance of the desired amount of viscous hydrocarbon or aqueous solution into the respective zones. However, pressures sufficiently high to effect fracturing of a formation penetrated by the well should be avoided.

The procedure of the invention may be employed for the treatment of any well penetrating a hydrocarbon-containing zone and a water zone. For example, the well may penetrate a formation or formations having a stratification or stratifications containing hydrocarbons and a stratification or stratifications containing water. An

entire formation or formations may contain hydrocarbons and an entire formation or formations may contain water. As stated, the well may penetrate a formation in which water coning may be occurring. In each of these instances, the viscous hydrocarbon is passed into the well and pressure is imposed upon the viscous hydrocarbon to effect a passage of the hydrocarbon into the hydrocarbon-containing formation or formations or portion thereof, respectively. Thereafter, the aqueous solution of plugging agent is passed into the well and pressure is imposed on it to effect passage of the solution into the water-containing formation or formations or portion thereof. Since the aqueous solution of the setting agent enters preferentially the water zone, it is not necessary to isolate precisely the water zone thereof from a formation or portion thereof containing hydrocarbons. However, in the interest of reducing the amount of viscous hydrocarbon to be employed, the water zone or portion thereof can be isolated as by being packed off. However, isolation of the precise water zone thereof will not be necessary since only the general location, which may include a hydrocarbon-containing formation or portion thereof, need be isolated.

Following placing of the aqueous solution of plugging agent into the water zone, pressure is maintained upon the aqueous solution to retain it in the zone until the plugging agents sets. Thereafter, this pressure is released. The well may then be placed upon production or upon injection.

Where a gelled hydrocarbon has been employed as the viscous hydrocarbon, the gel will, under the conditions of pressure and temperature within the formation, break down. Thus, a more rapid attainment of flow in the formation will be attained than where a hydrocarbon having an inherently high viscosity is employed as the viscous hydrocarbon. In certain instances it may be desirable, where a gelled hydrocarbon has been employed, to accelerate the attainment of flow in the hydrocarbon-containing zone. In these instances, a gel breaker is injected into the zone containing the gelled hydrocarbon after the aqueous solution of plugging agent has set in the water zone. Any of the conventional gel breaking agents effective for the gelled hydrocarbon passed into the hydrocarbon-containing zone may be employed.

Having thus described my invention, it will be understood that such description has been given by way of illustration and example and not by way of limitation, reference for the latter purpose being had to the appended claims.

I claim:

1. In a well in the earth wherein said well penetrates at least a portion of a formation containing water and at least a portion of a formation containing hydrocarbons, the procedure for selectively plugging said portion of said formation containing water comprising placing in said well adjacent said portion at least of said formation containing water and said portion at least of said formation containing hydrocarbon a viscous hydrocarbon having a viscosity greater than the viscosity of said hydrocarbon contained in said formation and at least 30 centipoises, imposing a pressure upon said hydrocarbon wherein said viscous hydrocarbon preferentially enters said portion of said formation containing hydrocarbons, thereafter placing in said well adjacent said portion at least of said formation containing hydrocarbons and adjacent to said portion at least of said formation containing water an aqueous solution of a plugging agent which under the conditions prevailing in an earth formation will set to seal the formation to the flow of a fluid, imposing a pressure upon said aqueous solution whereby said aqueous solution preferentially enters said portion of said formation containing water, and maintaining said pressure upon said aqueous solution until said plugging agent sets.

2. The procedure of claim 1 wherein the viscosity of

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said viscous hydrocarbon placed in said well is not in excess of 1,000 centipoises.

3. The procedure of claim 1 wherein said aqueous solution of a plugging agent is an aqueous solution of sodium silicate containing a setting compound which will covert said sodium silicate to silica hydrogel. 5

4. The procedure of claim 3 wherein said aqueous solution contains said sodium silicate in an amount between about 2 percent and 30 percent by weight of said aqueous solution.

5. The procedure of claim 1 wherein said aqueous solution of a plugging agent is an aqueous solution of sodium silicate containing, as a setting compound, a compound selected from the group consisting of sodium bicarbonate, ammonium carbonate, low molecular weight alkyl amide, oxamide, and urea. 10 15

6. The procedure of claim 5 wherein said setting compound is a compound selected from the group consisting of sodium bicarbonate, ammonium carbonate, low molecular weight alkyl amide, and oxamide and is in an amount between about 1 percent and 8 percent by weight of said aqueous solution. 20

7. The procedure of claim 5 wherein said setting compound is urea and is in an amount between about 1.5 percent and 25 percent by weight of said aqueous solution. 25

8. The procedure of claim 7 wherein said portion of said formation containing water is at a temperature of the order of 145° F. and said urea is in a concentration between about 16 percent and 25 percent by weight of said aqueous solution. 30

9. The procedure of claim 7 wherein said portion of

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said formation containing water is at a temperature of the order of 170° F. and above and said urea is in the amount between about 9 percent and 25 percent by weight of said aqueous solution.

10. The procedure of claim 1 wherein said hydrocarbon placed in said well is a gelled, normally liquid hydrocarbon.

11. The procedure of claim 1 wherein said hydrocarbon placed in said well is gelled liquefied petroleum gas.

12. The procedure of claim 1 wherein said hydrocarbon placed in said formation is a liquid hydrocarbon containing a gelling agent to effect gelling of said hydrocarbons and, subsequent to the setting of said plugging agent, a gel breaker is placed in said well and a pressure is imposed upon said gel breaker to pass said gel breaker into said formation to effect breakdown of said gelled hydrocarbon.

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