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(57) Abstract

A method of treating an underground formation comprising the sequential steps of: (a) contacting the formation with an aqueous medium; (b) contacting the formation with a hydrocarbon fluid; (c) contacting the formation with a solvent in the form of a glycol ether; and (d) contacting the formation with a consolidation solution of between 30 and 60 %m of monomeric and/or polymeric organic polyepoxides having more than one epoxy group per molecule and between 5 and 20 %m of a curing agent in the solvent.

METHOD OF TREATING AN UNDERGROUND FORMATION

The present invention relates to a method of treating an underground formation to improve its strength. The method is particularly suitable for treating an underground hydrocarbon-containing formation from which hydrocarbons can be produced. Such an underground hydrocarbon-containing formation is called a reservoir.

Production of hydrocarbons from such a reservoir is usually done through a well drilled from surface to the reservoir. Such a well is cased to prevent collapse of its wall. To facilitate fluids flowing into the well, the part of the well extending into or through the reservoir is either not cased or, when cased, the casing is perforated locally. If the underground formation includes sandstone, production of hydrocarbons may cause formation minerals such as sand to be loosened and to be entrained by the fluids flowing into the well, particularly after water break through. The entrained materials cause wear of production equipment through which the fluid passes, and it is expensive to separate and to dispose the material. To reduce the amount of entrained materials, the formation is strengthened using an epoxy resin system.

A particular problem is encountered when the underground formation includes 'dirty' sand, which is sand covered with contaminants such as hydrocarbon oil and water. The presence of these contaminants will adversely affect the bond between the sand particles and the epoxy resin and consequently the strength of the treated formation.

USA patent specification No. 3 481 403 discloses a method of treating an underground formation, which method

comprises contacting the underground formation with a solvent in the form of an alkyl ether of a C2 to C6 glycol containing at least one C1 to C6 alkyl group, and thereafter contacting the formation with a consolidation solution of an epoxy resin and a curing agent in a solvent of alcohol-kerosene. The solvent may be preceded by an oil pre-flush to remove water blocks. Moreover, if the formation has already produced large volumes of sand, a suspension of sand in water or oil can be injected before the treating starts to complement the lost sand.

USA patent specification No. 3,915,232 discloses a method of treating an underground formation comprising the sequential steps of:

(a) contacting the formation with an aqueous medium;

(b) contacting the formation with a hydrocarbon fluid in order to displace water; and

(c) contacting the formation with a solvent in the form of a glycol ether in order to displace the residual hydrocarbon and water.

In the known method a sand screen of bonded sand grains is to be placed in a well in the annulus between the casing and the formation. Therefore, in step (a) of the known method a slurry of sand in brine is injected through perforations in the casing into the well in order to place the sand behind the casing in the annulus. In order to bond the sand grains to form a screen, a consolidation solution containing an epoxy resin and a catalyst is injected through the perforations in the casing. The solvent used in the consolidation solution is a different solvent than the glycol ether used to displace the residual hydrocarbon and water.

Advantageously, the present invention provides an improved method wherein the formation itself is consolidated. The invention also advantageously provides a method for treating an underground formation a consolidation solution with a large concentration of epoxy resin can be used.

To this end the method of treating an underground formation according to the present invention is characterized in that step (a) is done in order to displace oil present in the pores of the formation, in that the formation is subsequently contacted with a consolidation solution of between 30 and 60%m of monomeric and/or polymeric organic polyepoxides having more than one epoxy group per molecule and between 5 and 20%m of a curing agent in the solvent, and in that the formation is subsequently contacted with a viscosified fluid containing aliphatic hydrocarbons.

In the specification and the claims the term "glycol ether" is used to refer to an ether of a C2 to C6 dihydric alcohol containing at least one C1 to C6 alkyl group, and the term "epoxy resin" will be used to refer to monomeric and/or polymeric organic polyepoxides having more than one epoxy group per molecule.

Reference is made to European patent application publication No. 463,664. This publication discloses a method of treating an underground formation, wherein the consolidation solution comprises polyepoxides, a curing agent, a glycol ether and a polyalkylene glycol. The treatment can be followed by an over-flush of a hydrocarbon solvent mixture to remove excess resin. Applicant had found that omitting the polyalkylene glycol made it possible to increase the epoxide-content of the consolidation solution without affecting the viscosity. Moreover Applicant had found that selecting an aliphatic hydrocarbon as over-flush has advantages.

In the specification and in the claims "%m" means per cent by mass of the solution.

In the method of the present invention, the formation is contacted with three pre-flushes which are injected.

into the formation one after the other. The first pre-flush is an aqueous medium, the aqueous medium is injected into the formation to displace oil present in the pores of the formation away from the zone to be treated. The displacement of oil by the aqueous medium is an immiscible displacement, and consequently some oil will not be removed. The oil that is not removed is called connate oil. Thereafter the formation is contacted with a hydrocarbon fluid to displace water present in the pores away from the zone to be treated. Moreover, the hydrocarbon fluid will dissolve any connate oil that has not been removed by the aqueous medium. The displacement of water by the hydrocarbon oil is also an immiscible displacement, and consequently some water will not be removed. However, as the displacement of connate oil by the hydrocarbon oil is miscible, substantially all connate oil is removed. Subsequently the formation is contacted with the solvent in the form of the mixture of glycol ethers to displace the residual hydrocarbon fluids and water. As the mixture of glycol ethers is miscible with both hydrocarbons and water, the displacement is miscible and substantially no hydrocarbons or water will be left in the formation. The formation is fully saturated with the solvent.

After the formation has been treated in this way, the formation is contacted with the consolidation solution of between 30 and 60 %m of monomeric and/or polymeric organic polyepoxides having more than one epoxy group per molecule and between 5 and 20 %m of a curing agent in the solvent.

The present invention is based on the finding that solvent in the form of the mixture of glycol ethers provides miscible displacement of both water and oil, and that the solvent is an excellent solvent for the epoxy resin and the curing agent. The latter feature allows

contacting the formation with a concentrated consolidation solution of the epoxy resin, which consolidation solution has an acceptable viscosity. Moreover, as it is the same liquid as the liquid used in the last pre-flush, there are no compatibility problems.

The aqueous medium used in the first pre-flush may be a brine for example an aqueous solution of 2%m of KCl.

To restore permeability, after the formation has been contacted with the consolidation solution of step (d) the formation is contacted with a viscosified hydrocarbon fluid, which hydrocarbon fluid is a mixture of aliphatic hydrocarbons., This so-called over-flush will displace the majority of the resin phase and restore permeability. The viscosity of the over-flush is larger than the viscosity of the hydrocarbon pre-flush.

The oil can be any hydrocarbon oil, such as diesel oil or crude oil.

Suitable glycol ethers for the solvent are mono ethers of the dihydric alcohols. Very suitable are the glycol ethers selected from the group including methoxypropanol, butoxyethanol, hexoxyethanol and the isomers of these glycol ethers.

To adjust the viscosity of the solvent, the solvent may further contain a minor amount, for example less than 10%m, of a polyethylene glycol having an average molecular mass of about 400.

The invention will now be described in more detail with reference to the experiments.

To illustrate that the consolidation solution of solvent and combination of polyepoxides and curing agent is not viscous the viscosity of several consolidation solutions was determined in a CONTRAVES LS-30 Low Shear viscosimeter at a temperature of 25°C. The epoxy resin used was EPIKOTE 828 (Trade Name, EPIKOTE 828 is obtained by reacting diphenylol-propane with epichlorohydrin, it

has a molecular mass of between 300 and 450), the curing agent used was methylene dianiline. The results for different consolidation solutions have been summarized in Table 1. The term 'solids content' is used to refer to the content of epoxy resin and curing agent.

Table 1. Viscosities in mPa.s of several consolidation solutions.

	Solids content in %m				
solvent	30	40	50	60	70
methoxypropanol	4.84	8.04	14.1	26.1	70.5
hexoxyethanol	10.5	20.5	29.0	58.4	110

To illustrate the effect of method of the present on the unconfined compression strength, several samples were made and subjected to two treatments, a treatment according to the invention and a treatment not according to the invention. For each test three samples were made of Nieuwe Pekela sand (grain diameters in the range of from 0.075 to 0.150 mm) in a glass tube, each sample had a diameter of 3.5 cm and a length of 17 cm. After the sand had been placed in the tube the porosity, Φ (in %), was determined. The sand pack was flushed with butane to remove air, and thereafter the sand pack was flushed with an aliphatic hydrocarbon in which butane dissolves to remove the butane. Then the initial permeability, K_i (in Darcy), was determined.

To simulate formation conditions, the following fluids were injected: (1) methoxypropanol; (2) brine (2 %m KCl); and (3) about 10 pore volumes of crude oil to establish irreducible water saturation.

The samples were subjected to two treatments, a first one according to the invention, and a second one not according to the invention.

The treatment according to the invention comprises contacting the samples filled with crude oil at irreducible water saturation in the following sequence:

(a) contacting the sample with 2 pore volumes of a 2 %m KCl brine;

(b) contacting the sample with 2 pore volumes of gasoil;

(c) contacting the sample with 2 pore volumes of methoxypropanol;

(d) contacting the sample with 1 pore volume of a consolidation solution of EPIKOTE 828 (Trade Name) and methylene dianiline in methoxypropanol, the solids content being 60 %m; and

(e) contacting the sample with 2 pore volumes of viscosified aliphatic hydrocarbons.

After the treatment the final permeability, K_e (in Darcy), and the unconfined compression strength, UCS (in bar), were determined. The results are summarized in Table 2.

Table 2. Results of the treatments according to the present invention.

	Φ in %	K_i in D	K_e in D	UCS in bar
Average	36.07	4.72	4.19	143

In the treatment not according to the invention, the steps (a), (b) and (c) have been omitted. Thus the samples with crude oil at irreducible water saturation were only treated in accordance with steps (d) and (e) of the above example.

After the treatment the final permeability, K_e (in Darcy), and the unconfined compression strength, UCS (in bar), were determined. The results are summarized in Table 3.

Table 3. Results of the treatments not according to the present invention.

	Φ in %	K_i in D	K_e in D	UCS in bar
Average	35.21	4.68	4.71	83

From the above data it can be concluded that the unconfined compression strength in the experiment with the method according to the present invention is larger than the unconfined compression strength with the method not according to the present invention.

Throughout this specification and the claims which follow, unless the context requires otherwise, the word "comprise", or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A method of treating an underground formation comprising the sequential steps of:

(a) contacting the formation with an aqueous medium;

(b) contacting the formation with a hydrocarbon fluid in order to displace water; and

(c) contacting the formation with a solvent in the form of a glycol ether as herein defined in order to displace the residual hydrocarbon and water,

wherein step (a) is done in order to displace oil present in the pores of the formation, and wherein after step (c) the formation contacted with a consolidation solution of between 30 and 60%m of monomeric and/or polymeric organic polyepoxides having more than one epoxy group per molecule and between 5 and 20%m of a curing agent in the solvent, and wherein the formation is subsequently contacted with a viscosified fluid containing aliphatic hydrocarbons.

2. Method according to claim 1, wherein the glycol ether is selected from the group including methoxypropanol, butoxyethanol, hexoxyethanol and the isomers of these glycol ethers.

3. Method substantially as hereinbefore described with reference to the Examples.

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