(19) AUSTRALIAN PATENT OFFICE

(11) Application No. AU 2005298469 C1

(54) Title
Methods for producing fluids from acidized and consolidated portions of subterranean formations

(51)[6] International Patent Classification(s)
E21B 43/27 (2006.01) 2BHEP E21B
E21B 43/02 (2006.01) 43/02
E21B 43/27 20060101ALI2006101
20060101AFI2006101 2BHEP
PCT/GB2005/003845

(21) Application No: 2005298469

(22) Application Date: 2005 .10 .06

(87) WIPO No: WO06/045998

(30) Priority Data

(31) Number	(32) Date	(33) Country
10/977,673	2004 .10 .29	US

(43) Publication Date : 2006 .05 .04

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(56) Related Art
US 6732800
US 3902557

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

PCT

(43) International Publication Date
4 May 2006 (04.05.2006)

(10) International Publication Number
WO 2006/045998 A3

(51) International Patent Classification:
E21B 43/27 (2006.01) *E21B 43/02* (2006.01)

(21) International Application Number: PCT/GB2005/003845

(22) International Filing Date: 6 October 2005 (06.10.2005)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10/977,673 29 October 2004 (29.10.2004) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*
before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

(88) Date of publication of the international search report: 12 October 2006

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

WO 2006/045998 A3

(54) Title: METHODS FOR PRODUCING FLUIDS FROM ACIDIZED AND CONSOLIDATED PORTIONS OF SUBTERRANEAN FORMATIONS

(57) Abstract: A method of stimulating and stabilizing an area of a subterranean formation comprising placing an acid fluid into an area of a subterranean formation and allowing the acid to at least partially dissolve a portion of the area of the subterranean formation; placing a consolidation fluid into the area of the subterranean formation; and, placing an afterflush fluid into the area of the subterranean formation. A method of stimulating and stabilizing an area of a subterranean formation comprising placing an acid fluid into an area of a subterranean formation and allowing the acid to at least partially dissolve a portion of the area of the subterranean formation; placing a consolidation fluid into the area of the subterranean formation; and, placing a fracturing fluid into the area of the subterranean formation at a pressure sufficient to create or extend at least one fracture therein.

METHODS FOR PRODUCING FLUIDS FROM ACIDIZED AND CONSOLIDATED PORTIONS OF SUBTERRANEAN FORMATIONS

BACKGROUND

The present invention relates to methods for enhancing and maintaining well productivity in subterranean formations. More particularly, the present invention relates to improved methods for producing fluids from acidized and consolidated portions of subterranean formations.

Hydrocarbon wells are often located in subterranean formations that comprise unconsolidated particulates. The term "unconsolidated particulates" refers to particulates that are loose within a portion of a formation or that are weakly bonded to the formation such that the movement of fluids within the formation might cause the particulates to migrate. Unconsolidated particulates (such as formation particulates and proppant particulates) may migrate out of a formation with produced fluids. Unconsolidated portions of a subterranean formations include those that contain loose particulates that are readily entrained by produced fluids and those wherein the particulates making up the zone are bonded together with insufficient bond strength to withstand the forces produced by mobile fluids within the subterranean formation. The presence of unconsolidated particulates in produced fluids may be disadvantageous and undesirable in that such particulates may abrade pumping and other producing equipment and may reduce the fluid production capabilities of the producing portions of the subterranean formation.

One method of controlling unconsolidated particulates involves placing a filtration bed of gravel near the well bore to prevent the transport of unconsolidated formation particulates with produced fluids. Typically, such operations are referred to as "gravel packing operations," and they usually involve pumping and placing a quantity of particulates adjacent to a portion of an unconsolidated formation so as to form a gravel pack between the sand screen and perforated, cased well bore or open formation walls. Although used frequently, such methods can be time-consuming and expensive to perform. Another conventional method used to control loose formation particulates in unconsolidated formations involves consolidating a portion of a subterranean formation from which the formation particulates tend to flow by applying a curable resin composition to that portion. In one example of such a technique, an operator preflushes the formation, applies a resin composition, and then applies an afterflush fluid to remove excess resin from the pore spaces within the formation.

In addition to controlling particulates in subterranean formations, certain treatments are often required to stimulate production from the formation. Such treatments generally operate to increase the permeability of the formation to allow for easier fluid flow within the stimulated portion of the formation. Generally, these treatments involve the injection of a treatment fluid into a subterranean formation. One known stimulation treatment is matrix acid stimulation (*e.g.*, "acidizing"). Acidizing involves introducing an acidizing fluid into the formation at a pressure low enough to prevent formation fracturing, and allowing the acidizing fluid to dissolve acid-soluble materials that clog or constrict formation channels. In this way, fluids may more easily flow from the formation into the well bore. Acidizing also may facilitate the flow of injected treatment fluids from the well bore into the formation. When acid is pumped into a formation, such as a carbonate (*e.g.*, limestone or dolomite) formation, the acid flows preferentially into the portion of the formation with the highest solubility or permeability (*i.e.*, large pore spaces, voids, or natural fractures). Acidizing often results in the formation of large, highly conductive flow channels that form close to the well bore.

Another common stimulation technique is hydraulic fracturing, in which a treatment fluid is injected through a well bore into a portion of a formation at a sufficient pressure to create or enhance at least one fracture therein. This often results in a channel for fluid flow through the formation back to the well bore, called a "fracture." Usually a particulate material, often referred to as a "proppant particulate," is deposited into the fracture to help prop the fracture open to enhance produced fluid flow back after the hydraulic pressure is released. Various formations may be treated by creating fractures in the formations and depositing proppant particulates in the fractures to maintain them in open positions. In addition, proppant particulates may be consolidated within the fractures, often resulting in the formation of hard permeable masses that can reduce the migration of particulates during production from the formation. Furthermore, hydraulic fracturing and gravel packing may be combined in one operation commonly referred to as "frac-packing."

Hydraulic fracturing and acidizing may be combined in one treatment commonly referred to as "fracture acidizing." Typically, fracture acidizing involves using hydraulic fracturing to form a fracture and then acidizing the fracture to etch the face of the fracture.

When the pressure in the formation is released, the resultant fracture should not completely close because the removal of formation material creates a gap between the fracture faces. *See, e.g.*, U.S. Patent Number 3,768,564. Proppant particulates also may be used in conjunction with fracture acidizing. *See, e.g.*, U.S. Patent Number 3,842,911.

However, some formations such as carbonates, unconsolidated sandstones, shales, and chalk formations, may be too weak to effectively and economically use acidizing treatments, either matrix acidizing or fracture acidizing. When acidized, these formations have a tendency to produce formation particulates, *e.g.*, formation fines and sand, along with the produced fluid. This may result in a drastic drop in production as the formation particulates enter and block the proppant particulate pack, flow channels, and formation pore spaces.

SUMMARY

The present invention relates to methods for enhancing and maintaining well productivity in subterranean formations. More particularly, the present invention relates to improved methods for producing fluids from acidized and consolidated portions of subterranean formations.

One embodiment of the present invention provides a method of stimulating and stabilizing an area of a subterranean formation comprising placing an acid fluid into an area of a subterranean formation and allowing the acid to at least partially dissolve a portion of the area of the subterranean formation; placing a consolidation fluid into the area of the subterranean formation; and, placing an afterflush fluid into the area of the subterranean formation.

One embodiment of he present invention provides a method of stimulating and stabilizing an area of a subterranean formation comprising placing an acid fluid into an area of a subterranean formation and allowing the acid to at least partially dissolve a portion of the area of the subterranean formation; placing a consolidation fluid into the area of the subterranean formation; and, placing a fracturing fluid into the area of the subterranean formation at a pressure sufficient to create or extend at least one fracture therein.

The features and advantages of the present invention will be readily apparent to those skilled in the art upon a reading of the description of the embodiments that follows.

DETAILED DESCRIPTION

The present invention relates to methods for enhancing and maintaining well productivity in subterranean formations. More particularly, the present invention relates to improved methods for producing fluids from acidized and consolidated portions of subterranean formations.

In general, the methods of the present invention involve stimulating and stabilizing a subterranean formation by acidizing and consolidating the formation. This involves treating an area of a subterranean formation with an acid fluid capable of at least partially dissolving a portion of the area of the subterranean formation and then placing a consolidation fluid into the acidized area of the formation. The acid fluid dissolves a portion of the area of the subterranean formation, thereby creating cavities, or hollow spaces. The terms "dissolve" and "dissolution" refer to at least a partial removal of solid material from a subterranean formation. Once cavities are formed, a consolidation fluid may be placed in the subterranean formation to consolidate the unconsolidated particulates (*e.g.*, formation particulates, proppant particulates, or both) within the cavities of the formation.

By acidizing the area of the subterranean formation before placing the consolidation fluid, the consolidation fluid may be able to penetrate further into the subterranean formation then it would have been able to penetrate into the formation has the acidizing not occurred. Thus is thought to be due, at least in part, to the fact that when the consolidation fluid is placed after acidizing the consolidation fluid can fill into and permeating from the cavities rather than just permeating from the surfaces within the subterranean formation. The consolidation fluid acts, among other things, to stabilize the formation and to minimize the migration of formation particulates during production from the formation. The methods of the present invention are particularly well-suited for use in portions of subterranean formations that are at least partially formed of materials that are readily dissolvable under acidic conditions, such as formations comprising carbonate, chalk, limestone, aragonite, dolomite, halite, carbonate-cemented sandstones, or combinations of the above minerals.

In the methods of the present invention, an acid fluid comprising an aqueous liquid and at least one acid is placed into an area of a subterranean formation to dissolve at least a portion of the area of the subterranean formation. Generally, suitable acids comprise aqueous acids including, but are not limited to, hydrochloric acid, C_1 to C_{12} carboxylic acids, hydrofluoric acid, acetic acid, formic acid, citric acid, ethylene diamine tetra acetic acid (EDTA), slowly released acids in the form of hydrolyzable esters, including ethylene glycol monoformate, ethylene glycol diformate, poly(lactic acid), poly(gylcolic acid), diethylene glycol diformate, glyceryl monoformate, glyceryl diformate, glyceryl triformate, triethylene glycol diformate and formate esters of pentaerythritol, and combinations thereof. When selecting an aqueous acid for use in the present invention, consideration should be given to the formation temperature, the acid-reactivity of the formation, the porosity of the formation, formation permeability, and injection rate. By way of example and not of limitation, in a formation having a relatively high acid-reactivity and a relatively high temperature, more intricate cavities may be achieved by using a relatively weak acid such as acetic acid. More intricate cavities may allow for a more uniform distribution of the consolidation fluid into the subterranean formation. In addition to considering the type of acid used, the concentration of acid must also be considered. Selection of the concentration of acid to be used is related to the same considerations listed above with respect to selection of the type of acid. It is within the ability of one skilled in the art, with the benefit of this disclosure, to consider the formation at issue, the consolidation desired, and the acid chosen to select an appropriate acid concentration. In some embodiments, the aqueous acid may be used at a concentration of from about 1% to about 70% by volume of the acid fluid. In some embodiments, the aqueous acid may be used at a concentration of from about 5% to about 25% by volume of the acid fluid. Examples of aqueous acids and methods of using aqueous acids are described in U.S. Patent Numbers. 3,768,564; 3,842,911; 4,245,702; 4,683,954; 4,739,832; 4,959,432; 5,238,068; and 6,531,427, the relevant disclosures of which are incorporated herein by reference.

As mentioned above, the consolidation fluids of the present invention are introduced into an area of an acidized subterranean formation and allowed to penetrate into the area of the subterranean formation. The consolidation fluids are generally placed into the area of the subterranean formation at a matrix flow rate such that a sufficient portion of the consolidation fluids may penetrate the formation. Consolidation fluids suitable for use in the present invention can be any substance capable of inhibiting the migration of unconsolidated particulates from a portion of a subterranean formation during production. Suitable consolidation fluids include resin compositions, tackifying agents (both nonaqueous tackifying agents and aqueous tackifying agents), and silyl-modified polyamide compounds.

Resin compositions suitable for use in the consolidation fluids of the present invention include all resins known in the art that are capable of forming a hardened, consolidated mass. Many such resins are commonly used in subterranean consolidation operations, and some suitable resins include two-component epoxy-based resins, novolac resins, polyepoxide resins, phenol-aldehyde resins, urea-aldehyde resins, urethane resins, phenolic resins, furan resins, furan/furfuryl alcohol resins, phenolic/latex resins, phenol formaldehyde resins, polyester resins and hybrids and copolymers thereof, polyurethane resins and hybrids and copolymers thereof, acrylate resins, and mixtures thereof. Some suitable resins, such as epoxy resins, may be cured with an internal catalyst or activator so that when pumped downhole, they may be cured using only time and temperature. Other suitable resins, such as furan resins generally require a time-delayed catalyst or an external catalyst to help activate the polymerization of the resins if the cure temperature is low (*i.e.*, less than 250°F), but will cure under the effect of time and temperature if the formation temperature is above about 250°F, preferably above about 300°F.

Selection of a suitable resin may be affected by the temperature of the subterranean formation to which the fluid will be introduced. By way of example, for subterranean formations having a bottom hole static temperature ("BHST") ranging from about 60°F to about 250°F, two-component epoxy-based resins comprising a hardenable resin component and a hardening agent component containing specific hardening agents may be preferred. For subterranean formations having a BHST ranging from about 300°F to about 600°F, a furan-based resin may be preferred. For subterranean formations having a BHST ranging from about 200°F to about 400°F, either a phenolic-based resin or a one-component HT epoxy-based resin may be suitable. For subterranean formations having a BHST of at least about 175°F, a phenol/phenol formaldehyde/furfuryl alcohol resin may also be suitable. It is within the ability of one skilled in the art, with the benefit of this disclosure, to select a suitable resin for use in embodiments of the present invention and to determine whether a catalyst is required to trigger curing.

The consolidation fluids used in the methods of the present invention should preferably be controlled to ensure that they have a viscosity sufficient to penetrate the unconsolidated portions of the subterranean formation. For example, where the portion of the subterranean formation being consolidated is a portion neighboring a well bore, from about 3 inches to about 1.5 feet of penetration into the portion neighboring the well bore may be desired. Where the portion of the subterranean formation being consolidated is a portion neighboring a propped fracture, for example, at least about 0.25 inches of penetration into a neighboring fracture wall may be sufficient. To achieve these penetration levels, the viscosity of the consolidation fluid is important. In some embodiments of the present invention the consolidation fluid viscosity is kept below about 100 cP. In other embodiments of the present invention the consolidation fluid viscosity is kept below about 40 cP. In other embodiments of the present invention the consolidation fluid viscosity is kept below about 10 cP. The viscosities are recited herein are measured at room temperature, using a Brookfield DV-II viscometer, with a No. 2 spindle at 100 RPM.

Accordingly, any solvent that is compatible with the resin is suitable for use in achieving the desired consolidation fluid viscosity. In some embodiments, the solvent may comprise an aqueous dissolvable solvent, but traditional higher flash point solvents (*e.g.*, flash point above about 125°F) that are not readily dissolvable in aqueous fluids also may be suitable. Examples of some suitable higher flash point solvents include butyl lactate, butylglycidyl ether, dipropylene glycol methyl ether, dipropylene glycol dimethyl ether, dimethyl formamide, diethyleneglycol methyl ether, ethyleneglycol butyl ether, diethyleneglycol butyl ether, propylene carbonate, methanol, butanol, d'limonene, fatty acid methyl esters, and combinations thereof. Suitable aqueous dissolvable solvents include, but are not limited to, methanol, isopropanol, butanol, glycol ether solvents, and combinations thereof. Suitable glycol ether solvents include, but are not limited to, diethylene glycol methyl ether, dipropylene glycol methyl ether, 2-butoxy ethanol, ethers of a C_2 to C_6 dihydric alkanol containing at least one C_1 to C_6 alkyl group, mono ethers of dihydric alkanols, methoxypropanol, butoxyethanol, hexoxyethanol, and isomers thereof. To achieve a suitable viscosity the resin:solvent ratio generally ranges from about 1:0.2 to about 1:20. In some embodiments, the resin:solvent ratio ranges from about 1:1 to about 1:3. Selection of an appropriate solvent, and amount of solvent, is dependent on the resin chosen and is within the ability of one skilled in the art with the benefit of this disclosure.

Nonaqueous tackifying agents suitable for use in the consolidation fluids of the present invention comprise any compound that, when in liquid form or in a solvent solution, will form a nonhardening coating upon a surface. One example of a group of suitable nonaqueous tackifying agents comprise polyamides that are liquids or in solution at the temperature of the subterranean formation such that they are, by themselves, nonhardening when introduced into the formation. Other suitable nonaqueous tackifying agents include condensation reaction products comprised of commercially available polyacids and polyamines. Such commercial products include compounds such as mixtures of C_{36} dibasic acids containing some trimer and higher oligomers and also small amounts of monomer acids that are reacted with polyamines. Other polyacids include trimer acids, synthetic acids produced from fatty acids, maleic anhydride, acrylic acid, and the like. Such acid compounds are commercially available from companies such as Witco Corporation, Union Camp, Chemtall, and Emery Industries. The reaction products are available from, for example, Champion Technologies, Inc. and Witco Corporation. Additional compounds which may be used as nonaqueous tackifying agents include liquids and solutions of, for example, polyesters, polycarbonates and polycarbamates, natural resins such as shellac, and the like. Other suitable nonaqueous tackifying agents are described in U.S. Patent Number 5,853,048 issued to Weaver, *et al.* and U.S. Patent Number 5,833,000 issued to Weaver, *et al.*, the relevant disclosures of which are incorporated herein by reference.

Nonaqueous tackifying agents suitable for use in the present invention may be used either such that they form a nonhardening coating or they may be combined with a multifunctional material capable of reacting with the nonaqueous tackifying agent to form a hardened coating. A "hardened coating," as used herein, means that the reaction of the nonaqueous tackifying agent with the multifunctional material will result in a substantially nonflowable reaction product that exhibits a higher compressive strength in a consolidated agglomerate than the nonaqueous tackifying agent alone with a particulate. In this instance, the nonaqueous tackifying agent may function similarly to a resin (described above). Multifunctional materials suitable for use in the present invention include, but are not limited to, aldehydes such as formaldehyde, dialdehydes such as glutaraldehyde, hemiacetals or aldehyde releasing compounds, diacid halides, dihalides such as dichlorides and dibromides, polyacid anhydrides such as citric acid, epoxides, furfuraldehyde, glutaraldehyde or aldehyde condensates and the like, and combinations thereof. In some embodiments of the present invention, the multifunctional material may be mixed with the nonaqueous tackifying agent in an amount of from about 0.01% to about 50% by weight of the nonaqueous tackifying agent to effect formation of the reaction product. In other embodiments, the multifunctional material is present in an amount of from about 0.5% to about 1% by weight of the nonaqueous tackifying agent. Suitable multifunctional materials are described in U.S. Patent

Number 5,839,510 issued to Weaver, *et al.*, the relevant disclosure of which is incorporated herein by reference. Other suitable nonaqueous tackifying agents are described in U.S. Patent Number 5,853,048 issued to Weaver, *et al.*, the relevant disclosure of which is incorporated herein by reference.

Solvents suitable for use with the nonaqueous tackifying agents include those that are described above in connection with the resin compositions, as well as, *e.g.*, butyl bottom alcohol, butyl acetate, furfuryl acetate, butyl lactate, dimethyl sulfoxide, and combinations thereof. Selection of an appropriate solvent, and amount of solvent, is dependent on the nonaqueous tackifying agent chosen and is within the ability of one skilled in the art with the benefit of this disclosure.

Suitable aqueous tackifying agents are capable of forming at least a partial coating upon a surface (such as the surface of a proppant particulate). Generally, suitable aqueous tackifying agents are not significantly tacky until they are "activated" (that is destabilized, coalesced, and/or reacted) to transform the aqueous tackifying agent into a sticky, tackifying compound at a desirable time. Such activation may occur before, during, or after the aqueous tackifying agent is placed in the subterranean formation. In some embodiments, a pretreatment may be contacted first with the surface of a particulate to prepare it to be coated with an aqueous tackifying agent. Suitable aqueous tackifying agents are generally charged polymers that comprise compounds that, when in an aqueous solvent or solution, will form a nonhardening coating (by itself or with an activator) and, when placed on a particulate, will increase the continuous critical resuspension velocity of the particulate when contacted by a stream of water. Continuous critical resuspension velocities are further described in Example 7 of U.S. Patent Application Number 10/864,061, filed June 9, 2004, the disclosure of which is incorporated herein by reference. The aqueous tackifying agent may enhance the grain-to-grain contact between the individual particulates within the formation (be they proppant particulates, formation particulates, or other particulates), which in turn may help to bring about the consolidation of the particulates into a cohesive, flexible, and permeable mass.

Examples of aqueous tackifying agents suitable for use in the present invention include, but are not limited to, acrylic acid polymers, acrylic acid ester polymers, acrylic acid derivative polymers, acrylic acid homopolymers, acrylic acid ester homopolymers (such as poly(methyl acrylate), poly(butyl acrylate), and poly(2-ethylhexyl acrylate)), acrylic acid ester copolymers, methacrylic acid derivative polymers, methacrylic acid homopolymers, methacrylic acid ester homopolymers (such as poly(methyl methacrylate), poly(butyl methacrylate), and poly(2-ethylhexyl methacryate)), acrylamido-methyl-propane sulfonate polymers, acrylamido-methyl-propane sulfonate derivative polymers, acrylamido-methyl-propane sulfonate copolymers, and acrylic acid/acrylamido-methyl-propane sulfonate copolymers, and combinations thereof. Methods of determining suitable aqueous tackifying agents and additional disclosure on aqueous tackifying agents can be found in U.S. Patent Application Number 10/864,061 filed June 9, 2004 and U.S. Patent Application Number 10/864,618 filed June 9, 2004, the disclosures of which are incorporated herein by reference.

Silyl-modified polyamide compounds suitable for use as in a consolidation fluid in the methods of the present invention may be described as substantially self-hardening compositions that are capable of at least partially adhering to particulates in the unhardened state, and that are further capable of self-hardening themselves to a substantially nontacky state to which individual unconsolidated particulates, such as formation fines, will not adhere to, for example, in the pore throats of a formation or a proppant particulate pack. Such silyl-modified polyamides may be based, for example, on the reaction product of a silating compound with a polyamide or a mixture of polyamides. The polyamide or mixture of polyamides may be one or more polyamide intermediate compounds obtained, for example, from the reaction of a polyacid (*e.g.*, a diacid or higher) with a polyamine (*e.g.*, a diamine or higher) to form a polyamide polymer with the elimination of water. Other suitable silyl-modified polyamides and methods of making such compounds are described in U.S. Patent Number 6,439,309 issued to Matherly, *et al.*, the relevant disclosure of which is incorporated herein by reference.

In some embodiments, the methods of the present invention further comprise the step of placing a displacement fluid into the area of the subterranean formation between the placement of the acid fluid and the placement of the consolidation fluid. A displacement fluid may be used to push the spent acid further into the subterranean formation, substantially out of the treated area and it may also be used (where desired) to neutralize any unspent acid. In other embodiments, a displacement fluid may be chosen that allows the formation to remain acidic. For example, an acid formation may be preferred when the chosen consolidation fluid is one that cures in the presence of as acid (as may be the case when the consolidation fluid is a furan/furfuryl alcohol resin). It is within the ability of one skilled in the art, with the benefit of this disclosure, to determine if a displacement fluid should be used, and if used, the type and amount of displacement fluid suitable for use.

Generally, the choice of displacement fluid will depend on the acid used and/or the consolidation fluid chosen for use. Further, where the displacement fluid is capable of neutralizing the unspent acid, stronger acids may require more basic displacement fluids. In many cases, however, the displacement fluid may not need to be a strong base because the acid may be spent as it dissolves the materials in the formation. For example, when epoxy-based consolidation fluids are chosen to consolidate the acidized portion of the formation it may be particularly useful to use a displacement fluid because epoxy-based consolidation fluids may not function properly in acidic environments. Generally, suitable displacement fluids are aqueous liquids such as fresh water, seawater, salt water, brine, or a combination thereof. In embodiments wherein acid neutralization is desired the displacement fluid may further comprise a base. Suitable bases include, but are not limited to, ammonium bicarbonate solutions and sodium bicarbonate solutions.

When the methods of the present invention are used on a producing area of a subterranean formation, to restore permeability (and thus the ability of the area to produce) the consolidation fluid should either be substantially removed from the cavities and pore spaces or a fracturing or some other stimulation treatment should be performed on the treated area once the consolidate fluid has cured. Thus, in some embodiments, the methods of the present invention further comprise the step of placing an afterflush fluid into the area of the subterranean formation after the placement of the consolidation fluid. The afterflush fluid may be used, among other things, to at least partially displace the consolidation fluid from the cavities and pore spaces in the formation. The afterflush fluid is preferably placed into the subterranean formation while the consolidation fluid is still in a flowing state. In addition to substantially clearing the pore spaces and cavities, the use of an afterflush fluid may act to force the displaced portion of the consolidation fluid further into the formation so that it produces a negligible impact on subsequent production. In certain embodiments, the afterflush fluid may contain an activator or external catalyst, *e.g.*, to activate a furan/furfuryl alcohol consolidation fluid applied to a low-temperature formation. The afterflush fluid is generally placed into the formation at a matrix flow rate such that a sufficient portion of the consolidation fluid may be displaced from the pore channels to restore the formation to a desired permeability. However, enough of the consolidation fluid should remain in the treated area of the formation to provide effective consolidation of the unconsolidated particulates therein.

Generally, the afterflush fluid may be any fluid that does not adversely react with the other components used in accordance with this invention or with the subterranean formation. In some embodiments, the afterflush fluid may be an aqueous liquid such as fresh water, salt water, brine, seawater, or some combination thereof. In other embodiments the afterflush fluid may be a hydrocarbon fluid, such as a mineral oil, a synthetic oil, an ester, kerosene, diesel, crude oil, or a combination thereof. Generally, the volume of afterflush fluid placed in the subterranean formation ranges from about 0.1 times to about 50 times the volume of the consolidation fluid. In some embodiments of the present invention, the volume of afterflush fluid placed in the subterranean formation ranges from about 2 times to about 5 times the volume of the consolidation fluid.

The methods of the present invention also may be used in conjunction with fracturing operations and frac-packing operations. For instance, in the case of hydraulic fracturing operations, one or more fractures may be introduced into the formation before or after the formation is acidized and consolidated.

Thus, in certain embodiments, the present invention provides methods that comprise: creating or extending a fracture within a subterranean formation; placing an acid fluid into the fracture and allowing it to acidize the formation surrounding the fracture and thus form cavities extending from the face of the fracture into the cavities and formation; placing a consolidation fluid into the into the fracture and allowing it to penetrate into the formation surrounding the fracture; and, placing an afterflush fluid into the formation surrounding the fracture.

In other embodiments of the present invention a fracturing step may be performed after the area of the formation has been acidized. Thus, in certain embodiments, the present invention provides methods that comprise: placing an acid fluid into the fracture and allowing it to acidize the area of the subterranean formation and thus form cavities extending into the formation; creating or extending a fracture within a subterranean formation; placing a consolidation fluid into the into the fracture and allowing it to penetrate into the formation surrounding the fracture; and, placing an afterflush fluid into the formation surrounding the fracture.

In still other embodiments of the present invention a fracturing step may be performed after the area of the formation has been consolidated. Thus, in certain embodiments, the present invention provides methods that comprise: placing an acid fluid into the fracture and allowing it to acidize the area of the subterranean formation and thus form cavities extending into the formation; placing a consolidation fluid into the into the fracture and allowing it to penetrate into the formation surrounding the fracture; and, creating or extending a fracture within a subterranean formation. In some such embodiments the fracturing fluid may act not only to fracture the subterranean formation but may also act as an afterflush fluid but in other embodiments it may be desirable to place an afterflush fluid into the area of the subterranean formation after the consolidation fluid is placed and before the fracture is created or extended.

In embodiments of the present invention wherein a fracturing operation is included in the method, proppant particulates may be used to pack the fracture and, at times, to pack the fracture and create a gravel pack (as in a frac-packing operation). As will be understood by one skilled in the art, if proppant particulates are placed before the acid, the proppant particulate material selected should be capable of withstanding the acid without substantial degradation. Moreover, one skilled in the art will recognize that placing proppant particulates before placing the consolidation fluid may allow the consolidation fluid to aid in consolidating not only formation particulates but also the proppant particulates themselves. A wide variety of particulate materials may be used as proppant particulates in accordance with the present invention, including, but not limited to, sand; nut shells; seed shells; resinous materials; a combination of nut shells or seed shells with a resinous material; bauxite; ceramic materials; glass materials; polymeric materials; Teflon® materials; fruit pits; processed wood; composite particulates prepared from a binder and filler particulates (such as silica, alumina, fumed carbon, carbon black, graphite, mica, titanium dioxide, meta-silicate, calcium silicate, kaolin, talc, zirconia, boron, fly ash, hollow glass microspheres, and solid glass); mixtures thereof, and the like. Proppant particulates used in accordance with the present invention are generally of a size such that formation particulates that can migrate with produced fluids are prevented from being produced from the subterranean formation, *e.g.*, the proppant particulates may filter out migrating sand. The proppant particulates used may have a particle size in the range of from about 2 mesh to about 400 mesh, U.S. Sieve Series. In certain embodiments, the proppant particulate may have a particle size in the range of from about 10 mesh to about 70 mesh, U.S. Sieve Series. In other embodiments, the proppant particulate may have a particle size distribution ranges of 10–20 mesh, 20–40 mesh, 40–60 mesh, or 50–70 mesh, depending on the particle size and distribution of the formation particulates to be screened out by the proppant particulates.

Fracturing fluids (which may be used for fracturing and/or frac-packing) that may be used in accordance with the present invention include any fracturing fluid that is suitable for use in subterranean operations, such as gelled water-based fluids, viscoelastic surfactant gels, hydrocarbon-based fluids, foams, and emulsions. In one embodiment of the present invention, the fracturing fluid used to create the one or more fractures may be a viscoelastic surfactant fluid comprising worm-like micelles. In another embodiment of the present invention, the fracturing fluid may be a gelled treatment fluid that comprises water (*e.g.*, fresh water, salt water, brine, or sea water) and a gelling agent for increasing the viscosity of the fracturing fluid. The increased viscosity, among other things, reduces fluid loss and allows the fracturing fluid to transport significant concentrations of proppant particulates into the created fractures. The selection of an appropriate fracturing fluid is within the ability of one of ordinary skill in the art, with the benefit of this disclosure.

Therefore, the present invention is well adapted to attain the ends and advantages mentioned as well as those that are inherent therein. While numerous changes may be made by those skilled in the art, such changes are encompassed within the spirit of this invention as defined by the appended claims.

EDITORIAL NOTE

PATENT NUMBER - 2005298469

The following Claim pages 2-5 should be numbered 15-18 respectively.

The claims defming the invention are as follows:

1. A method of stimulating and stabilizing an area of a subterranean formation including: placing an acid fluid into an area of a subterranean formation; allowing the acid to at least partially dissolve a portion of the area of the subterranean formation; placing a consolidation fluid that includes a tackifying agent into the area of the subterranean formation; and, placing an afterflush fluid into the area of the subterranean formation.

2. The method of claim 1, wherein the area of the subterranean formation is at least partially formed from a material that is at least partially dissolvable under acidic conditions.

3. The method of claim 2, wherein the material that is at least partially dissolvable under acidic conditions includes a material chosen from the group consisting of: carbonate, chalk, limestone, aragonite, dolomite, halite, a carbonate cemented sandstone, and combinations thereof

4. The method of any one of claims 1 to 3, further including the step of placing a displacement fluid into the subterranean formation directly after the step of placing the acid fluid into the area of the subterranean formation.

5. The method of claim 4, wherein the displacement fluid includes an aqueous liquid.

6. The method of claim 5, wherein the aqueous liquid is fresh water, salt water, seawater, brine or a combination thereof

7. The method of any one of claims 4 to 6, wherein the displacement fluid further includes a component selected from the group consisting of: ammonium bicarbonate, sodium bicarbonate, and combinations thereof.

2005298469 14 Jul 2010

8. The method of any one of claims 1 to 7, wherein the acid fluid includes an aqueous liquid and an aqueous acid.

9. The method of claim 8 wherein the aqueous acid is selected from the group 5 consisting of hydrochloric acid, C_1 to C_{12} carboxylic acids, hydrofluoric acid, acetic acid, formic acid, citric acid, ethylene diamine tetra acetic acid, hydrolyzable esters, ethylene glycol monoformate, ethylene glycol diformate, diethylene glycol diformate, poly(lactic acid), poly(glycolic acid), glyceryl monoformate, glyceryl diformate, glyceryl triformate, triethylene glycol diformate, formate esters of pentaerythritol, and combinations thereof.

10. The method of claim 8 or claim 9, wherein the acid fluid includes from 1% to 70% aqueous acid by volume of the acid fluid.

11. A method of stimulating and stabilizing an area of a subterranean formation including: placing an acid fluid into an area of a subterranean formation; allowing the acid to at least partially dissolve a portion of the area of the subterranean formation; placing a consolidation fluid into the area of the subterranean formation; placing a fracturing fluid into the area of the subterranean formation at a pressure sufficient to create or extend at least one fracture therein; and placing an afterflush fluid into the area of the subterranean formation after the step of placing the consolidation fluid, wherein the step of placing a fracturing fluid occurs before the step of placing an acid fluid or after the step of placing an acid fluid and before the step of placing a consolidation fluid.

12. The method of claim 11, wherein the area of the subterranean formation is at least partially formed from a material that is at least partially dissolvable under acidic conditions.

13. The method of claim 12, wherein the material that is at least partially dissolvable under acidic conditions is selected from the group consisting of

2005298469 14 Jul 2010

carbonate, chalk, limestone, aragonite, dolomite, halite, a carbonate cemented sandstone, and combinations thereof

14. The method of any one of claims 11 to 13, further including the step of placing a displacement fluid into the subterranean formation directly after the step of placing the acid fluid.

15. The method of claim 14, wherein the displacement fluid includes an aqueous liquid.

16. The method of claim 15, wherein the aqueous liquid is selected from the group consisting of: fresh water, salt water, seawater, brine, and combinations thereof.

17. The method of claim 15, wherein the displacement fluid includes ammonium bicarbonate or sodium bicarbonate.

18. The method of any one of claims 11 to 19, wherein the acid fluid includes an aqueous liquid and an aqueous acid.

19. The method of claim 18 wherein the aqueous acid is selected from the group consisting of: hydrochloric acid, C_1 to C_{12} carboxylic acids, hydrofluoric acid, acetic acid, formic acid, citric acid, ethylene diamine tetra acetic acid, hydrolysable esters, ethylene glycol monoformate, ethylene glycol diformate, diethylene glycol diformate, poly(lactic acid), poly(glycolic acid), glyceryl monoformate, glyceryl diformate, glyceryl triformate, triethylene glycol diformate, formate esters of pentaerythritolor, and combinations thereof.

20. The method of claim 18 or claim 19, wherein the acid fluid includes from 1% to 70% aqueous acid by volume of the acid fluid.

21. The method of any one of claims 1 to 20, wherein the consolidation fluid includes a resin composition selected from the group consisting of: a two-component epoxy-based resin, a novolac resin, a polyepoxide resin, a phenol-aldehyde resin, a urea-aldehyde resin, a urethane resin, a phenolic resin, a furan resin, a furan/furfuryl alcohol resin, a phenolic/latex resin, a phenol formaldehyde resin, a polyester resin and hybrids and copolymers thereof, a polyurethane resin and hybrids and copolymers thereof, an acrylate resin, and combinations thereof.

22. The method of any one of claims 1 to 21, wherein the consolidation fluid includes tackifying agent.

23. The method of claim 22, wherein the tackifying agent is selected from the group consisting of: a polyamide, a polyester, a polycarbonate, a natural resin, and combinations thereof or selected from the group consisting of: an acrylic acid polymer, an acrylic acid ester polymer, an acrylic acid derivative polymer, an acrylic acid homopolymer, an acrylic acid ester homopolymer; an acrylic acid ester copolymer, a methacrylic acid derivative polymer, a methacrylic acid homopolymer, a methacrylic acid ester homopolymer, an acrylamido-methyl-propane sulfonate polymer, an acrylamido-methyl propane sulfonate derivative polymer, an acrylamido-methyl-propane sulfonate copolymer, and an acrylic acid/acrylamido-methyl-propane sulfonate copolymer, and combinations thereof.

24. A method of stimulating and stabilizing an area of a subterranean formation, as claimed in claim 1, substantially as described herein.