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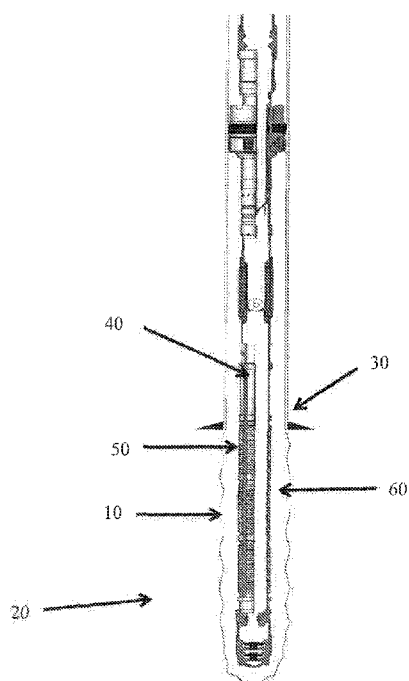


FIGURE 2

(57) Abstract: A method is provided for gravel packing an open hole section of a hydrocarbon producing well (10). The method includes injecting a slurry comprising particulates dispersed in a carrier fluid into an annular space (60) in the open hole section of the wellbore, and depositing the particulates in the annular space to form a gravel pack (70). Typically, inter-granular bonds form among the particulates, and thus form the gravel pack. In some embodiments, the inter-granular bonds generate grain-to-grain compressive strength which is strong enough to keep the gravel pack immobile.

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METHOD FOR GRAVEL PACKING A WELLBORE AND RESULTING WELL

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. provisional patent application Serial No. 62/424,209 filed November 18, 2016, and entitled “Method and Apparatus for Gravel Packing a Wellbore,” which is hereby incorporated herein by reference in its entirety.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not applicable.

BACKGROUND

[0003] This invention relates generally to the field of completion of subterranean hydrocarbon producing wells, and more particularly, to a system and method for performing gravel packing for an open hole section of hydrocarbon producing wells.

[0004] To obtain hydrocarbons from subterranean formations, wellbores are drilled into hydrocarbon-bearing formations or producing zones. After drilling a wellbore to the desired depth, a completion string containing various completion and production devices is installed in the wellbore to produce the hydrocarbons from the production zone to the surface. In one configuration, no casing or liner is installed across the wellbore in the production zone. A fluid flow restriction device, usually containing one or more serially connected screens, is placed adjacent the production zone. Gravel is then injected as a gravel slurry and deposited into the annular space between the wellbore and the screens. Such completions are called “open hole” completions, and the systems used to gravel pack in an open hole completion are called open hole gravel pack systems.

[0005] Hydrocarbon producing wells are often completed with an open hole in unconsolidated producing formations containing fines and sand, which flow with fluids produced from the formations. The sand in the produced fluids can abrade and otherwise damage tubing and pumps, and must be removed from the produced fluids before use in a refinery. The gravel, if properly packed, forms a barrier to filter out the fines and sand in the produced fluids and thus prevent the fines from entering the screens, while allowing the hydrocarbon formation fluid to pass freely through and be produced.

[0006] In a typical gravel packing installation, a screen element is placed in the wellbore and positioned within the unconsolidated production zone which is to be completed. The screen is typically connected to a work or production string, which is in turn connected to a production packer and a cross-over. Gravel is pumped in a slurry down the work or production string, and through the cross-over where it flows into the annular space between the screen element and the wellbore. Carrier fluid in the slurry leaks off into the production zone and through the screen which is sized to prevent the gravel in the slurry from flowing in. As the fluid “leaks off” into the formation and back into the screen, the gravel is deposited in the annular space around the screen element where it forms a gravel pack. The size of the gravel in the gravel pack is selected such that it prevents particles such as formation fines from flowing into the wellbore with produced fluids.

[0007] The performance of a gravel pack depends, in part, on its stability, or immobility of the particulates constituting the gravel pack. For optimal performance of a gravel pack, it is desirable that the particulates remain immobile over time. In reality, however, the particulates constituting the gravel pack can unintentionally move as the result of one or more of the following events during the production of a well, especially when gravel packing in an open hole environment: compaction and settling, high flow velocities of the production fluid,

formation of void areas, sanding events, degradation of some particulates over time, flow interruptions by topside equipment, and water and gas break.

[0008] Consequently, it is always desirable to complete a wellbore with a gravel pack that remains immobile during production, which effectively prevents loss of annular gravels and protects sand screen integrity.

BRIEF SUMMARY

[0009] The scope of the present invention is defined by the appended claims, and is not affected by the statements within this summary.

[0010] These and other needs in the art are addressed in one embodiment by a method for gravel packing an open hole section of a hydrocarbon producing well, including injecting a slurry comprising particulates dispersed in a carrier fluid into an annular space in the open hole section of the wellbore, and depositing the particulates in the annular space to form a gravel pack. Typically, inter-granular bonds form among the particulates, and form the gravel pack. Typically, the inter-granular bonds form after the particulates are deposited in the annular space.

[0011] In some embodiments, inter-granular bonds can form among the particulates, because the particulates constituting the gravel packing operation are coated with resins. Typically, a first portion of the particulates is at least partially coated with a liquid hardenable resin component, and a second portion of the particulates is at least partially coated with a liquid hardening agent component. In one embodiment, at least about 30% of the particulates are coated with either the liquid hardenable resin component or the liquid hardening agent component. Typically, the ratio of the first portion to the second portion of the particulates is in the range from about 0.3:1 to about 1:0.3. Typically, the inter-granular bonds generate grain-to-grain compressive strength which is strong enough to keep the gravel pack immobile. In some embodiments, the grain-to-grain compressive strength is at least about 10 psi.

[0012] Particulates suitable for use in a method according to the present invention can be sand, proppant, or a combination of sand and proppant.

[0013] One embodiment of the present invention is a completed open hole hydrocarbon producing well having a screen element in an open hole section of the hydrocarbon producing well, an annular space between the wellbore and the screen element, and a gravel pack comprised of particulates, disposed with respect to the annular space and having a grain-to-grain compressive strength of at least about 10 psi. Typically, the grain-to-grain compressive strength is generated by inter-granular bonds formed among the particulates. In some embodiments, the grain-to-grain compressive strength is strong enough to keep the gravel pack immobile.

[0014] In some embodiments, the particulates constituting the gravel packing operation are coated with resins. Typically, a first portion of the particulates is at least partially coated with a liquid hardenable resin component, and a second portion of the particulates is at least partially coated with a liquid hardening agent component. In some embodiments, at least about 30% of the particulates are coated with either the liquid hardenable resin component or the liquid hardening agent component. Typically, the ratio of the first portion to the second portion of the particulates is in the range from about 0.3:1 to about 1:0.3.

[0015] Particulates suitable for use in a completed open hole hydrocarbon producing well according to the present invention can be sand, proppant, or a combination of sand and proppant.

[0016] The foregoing has outlined rather broadly the features and technical advantages of the invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter that form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and the specific embodiments disclosed may be readily utilized as a

basis for modifying or designing other structures for carrying out the same purposes of the invention. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] For a detailed description of the preferred embodiments of the invention, reference will now be made to the accompanying drawings in which:

[0018] FIGURE 1 is a side-cross sectional schematic representation of a wellbore with a top-set open hole gravel pack system according to one embodiment.

[0019] FIGURE 2 is a side-cross sectional schematic representation of an open hole gravel pack apparatus according to one embodiment of the invention.

DETAILED DESCRIPTION

[0020] For simplicity and illustrative purposes, the principles of the present teachings are described by referring mainly to exemplary embodiments thereof, namely as implemented into a method for gravel packing an open hole section of a hydrocarbon producing wellbore. As used herein, the term “open hole section” refers to any portion of a wellbore (including vertical, horizontal, deviated and multilateral wells) that is neither cased nor installed with a liner.

[0021] Referring now to FIGURE 1 and FIGURE 2, which illustrate non-limiting embodiments of the present invention. Examples of open hole sections of hydrocarbon producing wellbores are illustrated in a simplified form in both figures. Specifically, a wellbore 10 is drilled to the top of a hydrocarbon-bearing formation 20. The wellbore is then cased at this level with casing 30, and left open at the bottom. A production string 40 is installed, and a screen element 50 is placed in wellbore 10 with connections to production string 40. A slurry comprised of particulates and a carrier fluid is then injected down production string 40 into

annular space 60, which is between screen element 50 and wellbore 10. The particulates in the slurry are thus deposited in annular space 60 and form a gravel pack (which is labeled in FIGURE 1 as 70, but not explicitly shown in FIGURE 2) within a reasonable amount of time, which typically is about four hours or less.

[0022] While a vertical open hole completion with a top-set open hole gravel pack system is illustrated in FIGURE 1, it is contemplated that, with the benefit of this disclosure, one can apply the disclosed methods to open hole horizontal wells and open hole deviated wells. Similarly, while an open hole completion without underreaming is illustrated in FIGURE 1, it is contemplated that, with the benefit of this disclosure, one can apply the disclosed methods to gravel pack an open hole well with underreaming.

[0023] As used herein, the term “particulates” refers to particular material that constitutes the gravel pack, typically including sand, proppant, or a combination of sand and proppant. A wide variety of particulate materials may be used in accordance with the present invention, including, but not limited to, sand, bauxite, ceramic materials (for example, CARBO Ceramics Inc. provides a variety of ceramic proppants), glass materials, resin precoated proppant (e.g., commercially available from Borden Chemicals, Santrol and CARBO Ceramics, for example, all from Houston, Texas), polymer materials, “TEFLONTM” (tetrafluoroethylene) materials, nut shells, ground or crushed nut shells, seed shells, ground or crushed seed shells, fruit pit pieces, ground or crushed fruit pits, processed wood, composite particulates prepared from a binder with filler particulate including silica, alumina, fumed carbon, carbon black, graphite, mica, titanium dioxide, meta-silicate, calcium silicate, kaolin, talc, zirconia, boron, fly ash, hollow glass microspheres, solid glass, or mixtures thereof. The particulate material used may have a particle size in the range of from about 2 to about 400 mesh, U.S. Sieve Series. (Mesh size equals to the counts of openings in one linear inch of screen. For example, 2 mesh screen means there are two little square openings across one inch of screen. A particulate material of 2

mesh means at least 90% of the particulates can pass through a 2 mesh screen.) In one embodiment, the particulate material is graded sand having a particle size in the range of from about 10 to about 70 mesh, U.S. Sieve Series. Typical sand particle size distribution ranges are one or more 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 particulate materials.

[0024] The term “screen element” used as herein refers to a filter assembly used to support and retain the particulates (i.e., the gravel) placed during the gravel pack operation, by permitting flow of fluids through while blocking the flow of particulates. A wide range of sizes and screen configurations is available to suit the characteristics of the wellbore to be completed, the production fluid, and any particulates in the subterranean formation. Suitable screen element include, but are not limited to, mesh screens, screened pipes, pre-packed screens, expandable-type screens and/or liners, other commercially available screens, or combinations of the above.

[0025] In some embodiments of the present invention, the gravel pack is formed via formation of inter-granular bonds among the particulates. Inter-granular bonds can form by a chemical reaction, physical interaction, cross-linking, polymerization, microwave sintering, surface diffusion, magnetism, colloid destabilization, mechanical entanglement, interlocking, in-situ dimpling, or any combination of the above.

[0026] In some embodiments, the particulates used in the gravel packing operation are coated with resins to facilitate consolidation of the particulates and/or to prevent unwanted shifting or drifting of the proppant. The term “resin” as used herein refers to any of numerous physically similar polymerized synthetics or chemically modified natural resins including thermoplastic materials and thermosetting materials. A typical resin coating material is a two component resin system including a liquid hardenable resin component and a liquid hardening agent

component. Once the two components get mixed together, the hardenable resin component becomes activated by the hardening agent component thus becoming tackified. As used herein, the term “tacky”, in all its forms, generally refers to a substance having a nature such that it is (or may be activated to become) somewhat sticky to the touch. A variety of chemical activators are available which may be used in accordance with the present invention, for example, FUSION technology provided by CARBO Ceramics Inc. Other suitable chemical activators include, but are not limited to, the component A in SandTrap[®] ABC, SandTrap[®] 225 and SandTrap[®] 350 system provided by Halliburton Energy Services, Inc., Duncan, Okla., the EPON[™] family of resins, for example, EPON[™] 828 and EPON[™] 816, provided by Momentive Specialty Chemicals Inc., Columbus, Ohio, and D.E.R.[™] 331 provided by The Dow Chemical Company, Midland, Michigan.

[0027] In some embodiments, the inter-granular bonds are formed by having a first portion of the particulates at least partially coated with a liquid hardenable resin component, and having a second portion of the particulates at least partially coated with a liquid hardening agent component. This second portion is not coated with the liquid hardenable resin component. The term “coated” does not imply any particular degree of coverage of the particulates with a resin. The particulates may be coated by any suitable method as recognized by one skilled in the art.

[0028] Resins suitable for use in the present invention include all resins known and used in the art. One type of resin coating material suitable for use is a two component epoxy based resin having a liquid hardenable resin component and a liquid hardening agent component. The liquid hardenable resin component is comprised of a hardenable resin and an optional solvent. The solvent may be added to the resin to reduce its viscosity for ease of handling, mixing and transferring, and to achieve a viscosity suitable to the subterranean conditions. Factors that may affect this decision include geographic location of the well, the surrounding weather conditions, and the desired long term stability of the hardenable resin composition. An

alternative way to reduce the viscosity of the liquid hardenable resin is to heat it. This method avoids the use of a solvent altogether, which may be desirable in certain circumstances. The liquid hardening agent component is comprised of a hardening agent, a silane coupling agent, a surfactant, and an optional liquid carrier fluid for, among other things, reducing the viscosity of the liquid hardening agent component.

[0029] Examples of hardenable resins that can be used in the liquid hardenable resin component include, but are not limited to, organic resins such as bisphenol A diglycidyl ether resin, butoxymethyl butyl glycidyl ether resin, bisphenol A-epichlorohydrin resin, bisphenol F resin, polyepoxide resin, novolak resin, polyester resin, phenol-aldehyde resin, urea-aldehyde resin, furan resin, urethane resin, a glycidyl ether resin, other similar epoxide resins and combinations of the above. The hardenable resin used may be included in the liquid hardenable resin component in an amount in the range of from about 5% to about 95% by weight of the liquid hardenable resin component. In other embodiments, the hardenable resin used may be included in the liquid hardenable resin component in an amount in the range of from about 15% to about 85% by weight of the liquid hardenable resin component. In other embodiments, the hardenable resin used may be included in the liquid hardenable resin component in an amount in the range of from about 20% to about 75% by weight of the liquid hardenable resin component. In other embodiments, the hardenable resin used may be included in the liquid hardenable resin component in an amount in the range of from about 20% to about 65% by weight of the liquid hardenable resin component. In still other embodiments, the hardenable resin used may be included in the liquid hardenable resin component in an amount in the range of from about 25% to about 55% by weight of the liquid hardenable resin component. One can determine how much of the hardenable resin component may be needed to achieve the desired results. Factors that may affect this decision include which type of hardenable resin component and hardening agent component are used. The concentration of the liquid hardenable resin

component that may be coated on the particulates is in the range of from about 0.1% to about 5% (volume by weight of proppant), with about 0.5% to about 2% being typical. In some embodiments, the concentration of the liquid hardenable resin component that may be coated on the particulates is in the range of from about 0.3% to about 3% (volume by weight of proppant).

[0030] Any solvent that is compatible with the hardenable resin and achieves the desired viscosity effect may be suitable for use in the liquid hardenable resin component. Suitable solvent may include butyl lactate, dipropylene glycol methyl ether, dipropylene glycol dimethyl ether, dimethyl formamide, diethyleneglycol methyl ether, ethyleneglycol butyl ether, diethyleneglycol butyl ether, propylene carbonate, methanol, ethanol, butyl alcohol, d'limonene, fatty acid methyl esters, and combinations of the above. Other preferred solvents may include aqueous dissolvable solvents such as, methanol, ethanol, isopropanol, glycol ether solvents, and combinations of the above. Suitable glycol ether solvents include, but are not limited to, diethylene glycol methyl ether, dipropylene glycol methyl ether, 2-butoxy ethanol, ethers of a C₂ to C₆ dihydric alkanol containing at least one C₁ to C₆ alkyl group, mono ethers of dihydric alkanols, methoxypropanol, butoxyethanol, hexoxyethanol, and isomers thereof. Selection of an appropriate solvent is dependent on the resin composition chosen.

[0031] As described above, use of a solvent in the liquid hardenable resin component is optional but may be desirable to reduce the viscosity of the liquid hardenable resin component for ease of handling, mixing and transferring. In some embodiments, the amount of the solvent used in the liquid hardenable resin component may be in the range of from about 0.1% to about 80% by weight of the liquid hardenable resin component. In other embodiments, the amount of the solvent used in the liquid hardenable resin component may be in the range of from about 2% to about 50% by weight of the liquid hardenable resin component. In still other embodiments, the amount of the solvent used in the liquid hardenable resin component may be

in the range of from about 5% to about 10% by weight of the liquid hardenable resin component. Optionally, the liquid hardenable resin component may be heated to reduce its viscosity, in place of, or in addition to, using a solvent.

[0032] Examples of the hardening agents that can be used in the liquid hardening agent component of the resin compositions utilized in the present invention include, but are not limited to, piperazine, derivatives of piperazine (e.g., aminoethylpiperazine), 2H-pyrrole, pyrrole, imidazole, pyrazole, pyridine, pyrazine, pyrimidine, pyridazine, indolizine, isoindole, 3H-indole, indole, 1H-indazole, purine, 4H-quinolizine, quinolone, isoquinoline, phthalazine, naphthyridine, quinoxaline, quinazoline, 4H-carbazole, carbazole, β -carboline, phenanthridine, acridine, phenathroline, phenazine, imidazolidine, phenoxazine, cinnoline, pyrrolidine, pyrroline, imidazoline, piperdine, indoline, isoindoline, quinuclidine, morpholine, azocine, azepine, 2H-azepine, 1,3,5-triazine, thiazole, pteridine, dihydroquinoline, hexa methylene imine, indazole, amines, aromatic amines, polyamines, aliphatic amines, cyclo-aliphatic amines, amides, polyamides, 2-ethyl-4-methyl imidazole, 1,1,3-trichlorotrifluoroacetone, and combinations of the above. The chosen hardening agent often affects the range of temperature over which a hardenable resin is able to cure. By way of example and not of limitation, in subterranean formations having a temperature from about 60°F to about 250°F, amines and cyclo-aliphatic amines such as piperidine, trimethylamine, N,N-dimethylaminopyridine, benzyldimethylamine, tris(dimethylaminomethyl) phenol, and 2-(N₂N-dimethylaminomethyl)phenol are preferred. In subterranean formations having higher temperatures, 4,4'-diaminodiphenyl sulfone may be a suitable hardening agent. Hardening agents that comprise piperazine or a derivative of piperazine, such as aminoethyl piperazine, have been shown capable of curing various hardenable resins from temperatures as low as about 70°F to as high as about 350°F.

[0033] The hardening agent used may be included in the liquid hardening agent component in an amount sufficient to consolidate the coated particulates. In some embodiments of the present invention, the hardening agent used is included in the liquid hardening agent component in the range of from about 5% to about 95% by weight of the liquid hardening agent component. In other embodiments, the hardening agent used may be included in the liquid hardening agent component in an amount of about 15% to about 85% by weight of the liquid hardening agent component. In other embodiments, the hardening agent used may be included in the liquid hardening agent component in an amount of about 25% to about 55% by weight of the liquid hardening agent component. The concentration of the liquid hardening agent component that may be coated on the particulates is in the range of from about 0.1% to about 5% (volume by weight of proppant), with about 0.5% to about 2% being typical.

[0034] The silane coupling agent may be used, among other things, to act as a mediator to help bond the resin to formation particulates and/or proppant. Examples of suitable silane coupling agent include, but are not limited to, N- β -(aminoethyl)- γ -aminopropyl trimethoxysilane, N-2-(aminoethyl)-3-aminopropyl trimethoxysilane, 3-glycidoxypropyltrimethoxysilane, and combinations of the above. The silane coupling agent used is included in the liquid hardening agent component in an amount capable of sufficiently bonding the resin to the particulate. In some embodiments of the present invention, the silane coupling agent used may be included in the liquid hardening agent component in the range of from about 0.1% to about 3% by weight of the liquid hardening agent component.

[0035] Any surfactant compatible with the hardening agent and capable of facilitating the coating of the resin onto particulates in the subterranean formation may be used in the liquid hardening agent component. Such surfactants include, but are not limited to, an alkyl phosphonate surfactant (e.g., a C₁₂-C₂₂ alkyl phosphonate surfactant), an ethoxylated nonyl phenol phosphate ester, one or more cationic surfactants, and one or more nonionic surfactants.

Suitable cationic surfactants may include, but are not limited to, the reaction product of an alcohol, epichlorohydrin and triethylenediamine, wherein monohydric aliphatic alcohols having in the range of from about 12 to about 18 carbon atoms are reacted with from 2 to 3 moles of epichlorohydrin per mole of alcohol followed by reaction with an excess of triethylenediamine (where a mole is defined by the amount of carbon atoms there are in 12g of carbon-12). The alcohol epichlorohydrin reaction product contains an ethoxylation chain having pendent chlorides. The subsequent reaction with triethylenediamine provides a cationic and a tertiary amine functionality to the resulting surfactant product. Suitable nonionic surfactants may include, but are not limited to, ethoxylated fatty acids produced by reacting fatty acids containing from about 12 to about 22 carbon atoms with from about 5 to about 20 moles of ethylene oxide per mole of acid to produce a mixture of various quantities of ethoxylated acids and unreacted acids. Mixtures of one or more cationic and nonionic surfactants also may be suitable. In some embodiments, the surfactant used may be included in the liquid hardening agent component in the range of from about 1% to about 10% by weight of the liquid hardening agent component.

[0036] Another resin suitable for use in the method of the present invention is furan-based resins. Suitable furan-based resins include, but are not limited to, furfuryl alcohol resins, mixtures of furfuryl alcohol resins and aldehydes, and a mixture of furan resins and phenolic resins. Of these, furfuryl alcohol resins are preferred. A furan-based resin may be combined with a solvent to control viscosity if desired. Suitable solvents for use in the furan-based resins include, but are not limited to, 2-butoxy ethanol, butyl lactate, butyl acetate, tetrahydrofurfuryl methacrylate, tetrahydrofurfuryl acrylate, esters of oxalic, maleic and succinic acids, and furfuryl acetate. Of these, 2-butoxy ethanol is preferred.

[0037] Still another resin suitable for use in the method of the present invention is phenolic-based resins. Suitable phenolic-based resins include, but are not limited to, terpolymers of

phenol, phenolic formaldehyde resins, and a mixture of phenolic and furan resins. Of these, a mixture of phenolic and furan resins is preferred. A phenolic-based resin may be combined with a solvent to control viscosity if desired. Suitable solvents for use in the phenolic-based resins include, but are not limited to, butyl acetate, butyl lactate, furfuryl acetate, and 2-butoxy ethanol. Of these, 2-butoxy ethanol is preferred.

[0038] Yet another resin-type coating material suitable for use in the methods of the present invention is a phenol/phenol formaldehyde/furfuryl alcohol resin including from about 5% to about 30% phenol, from about 40% to about 70% phenol formaldehyde, from about 10% to about 40% furfuryl alcohol, from about 0.1% to about 3% of a silane coupling agent, and from about 1% to about 15% of a surfactant. In the a phenol/phenol formaldehyde/furfuryl alcohol resins suitable for use in the methods of the present invention, suitable silane coupling agents include, but are not limited to, N-2-(aminoethyl)-3-aminopropyltrimethoxysilane, 3-glycidoxypropyltrimethoxysilane, and n-beta-(aminoethyl)-gamma-aminopropyl trimethoxysilane. Suitable surfactants include, but are not limited to, an ethoxylated nonyl phenol phosphate ester, mixtures of one or more cationic surfactants, and one or more non-ionic surfactants and an alkyl phosphonate surfactant.

[0039] Generally, any treatment fluid suitable for a subterranean operation may be used as carrier fluid in accordance with the methods of the present invention, including aqueous gels, viscoelastic surfactant gels, foamed gels and emulsions. Suitable aqueous gels are generally comprised of water and one or more gelling agents. Suitable emulsions can be comprised of two immiscible liquids such as an aqueous liquid or gelled liquid and a hydrocarbon. Foams can be created by addition of a gas, such as carbon dioxide or nitrogen. In certain embodiments of the present invention, the treatment fluids are aqueous gels comprised of water, a gelling agent for gelling the water and increasing its viscosity, and optionally, a crosslinking agent for crosslinking the gel and further increasing the viscosity of the fluid. The increased viscosity of

the gelled, or gelled and cross-linked, treatment fluid, inter alia, reduces fluid loss and allows the treatment fluid to transport significant quantities of suspended particulates. The water used to form the treatment may be fresh water, salt water, brine, sea water, or any other aqueous liquid that does not adversely react with the other components. The density of the water can be increased to provide additional particle transport and suspension in the present invention.

[0040] A variety of gelling agents may be used, including hydratable polymers that contain one or more functional groups such as hydroxyl, carboxyl, sulfate, sulfonate, amino, or amide groups. Suitable gelling agents typically comprise polymers, synthetic polymers, or a combination of the above. A variety of gelling agents may be used in conjunction with the methods of the present invention, including, but not limited to, hydratable polymers that contain one or more functional groups such as hydroxyl, cis-hydroxyl, carboxylic acids, derivatives of carboxylic acids, sulfate, sulfonate, phosphate, phosphonate, amino, or amide. In some embodiments, the gelling agents may be polymers including polysaccharides, and derivatives thereof that contain one or more of these monosaccharide units: galactose, mannose, glucoside, glucose, xylose, arabinose, fructose, glucuronic acid, or pyranosyl sulfate. Examples of suitable polymers include, but are not limited to, guar gum and derivatives thereof, such as hydroxypropyl guar and carboxymethylhydroxypropyl guar, and cellulose derivatives, such as hydroxyethyl cellulose. Additionally, synthetic polymers and copolymers that contain the above-mentioned functional groups may be used. Examples of such synthetic polymers include, but are not limited to, polyacrylate, polymethacrylate, polyacrylamide, polyvinyl alcohol, and polyvinylpyrrolidone. In other embodiments, the gelling agent molecule may be depolymerized. The term “depolymerized” as used herein, generally refers to a decrease in the molecular weight of the gelling agent molecule. Suitable depolymerized gelling agents that may be used in conjunction with the methods of the present invention include, but are not limited to, depolymerized polysaccharides, such as depolymerized guar derivative polymers

selected from the group consisting of hydroxypropylguar, carboxymethylhydroxypropylguar, carboxymethylguar, hydroxyethylguar, hydroxyethyl cellulose, grafted hydroxyethyl cellulose, carboxymethyl cellulose, carboxymethylhydroxyethyl cellulose and the like. Suitable gelling agents that may be used in conjunction with the methods of the present invention may be present in the treatment fluid in an amount in the range of from about 0.5% to about 10% by weight of the water therein. In some embodiments, the gelling agents may be present in the treatment fluid in an amount in the range of from about 2.5% to about 6% by weight of the water therein.

[0041] Crosslinking agents may be used to crosslink gelling agent molecules to form crosslinked gelling agents. Crosslinkers typically have at least one metal ion that is capable of crosslinking molecules. Examples of suitable crosslinkers include, but are not limited to, zirconium compounds (such as zirconium lactate, zirconium lactate triethanolamine, zirconium acetylacetonate, zirconium citrate, and zirconium diisopropylamine lactate), titanium compounds (such as titanium lactate, titanium citrate, titanium ammonium lactate, titanium triethanolamine, and titanium acetylacetonate), aluminum compounds (such as aluminum lactate or aluminum citrate), antimony compounds, chromium compounds, iron compounds, copper compounds, zinc compounds, or a combination of the above. An example of suitable commercially available zirconium-based crosslinker is “CL-24” available from Halliburton Energy Services, Inc., Duncan, Okla. An example of commercially available titanium-based crosslinker is “CL-39” available from Halliburton Energy Services, Inc., Duncan, Okla. Suitable crosslinkers that may be used in conjunction with the methods of the present invention may be present in the treatment fluid in an amount sufficient to provide, among other things, the desired degree of crosslinking between gelling agent molecules. In some embodiments of the present invention, the crosslinkers may be present in the treatment fluid in an amount in the range from about 0.01% to about 1% by weight of the water therein. In other embodiments of

the present invention, the crosslinkers may be present in the treatment fluid in an amount in the range from about 0.1% to about 0.5% by weight of the water therein. Factors that affect the decisions on the exact type and amount of crosslinker to use include the specific gelling agent used, desired viscosity, and formation conditions.

[0042] The gelled or gelled and cross-linked carrier fluids may also include internal delayed gel breakers such as enzyme, oxidizing, acid buffer, hydrolyzable esters, or temperature-activated gel breakers. Examples of suitable hydrolyzable esters include, but are not limited to, a mixture of dimethylglutarate, dimethyladipate, and dimethylsuccinate, dimethylthiolate, methyl salicylate, dimethyl salicylate, t-butylhydroperoxide, and combinations of the above. The gel breakers cause the viscous treatment fluids to revert to thin fluids that can be produced back to the surface after they have been used to place particulates in subterranean formations. The gel breaker is typically present in the treatment fluid in an amount in the range of from about 0.05% to about 2% by weight of the treatment fluid. In some embodiments, the gel breaker is present in the treatment fluid in an amount in the range from about 0.1% to about 1%. The carrier fluid may also include one or more of a variety of additives, such as gel stabilizers, fluid loss control additives, clay stabilizers, bactericides, and the like.

[0043] In some embodiments, different sizes and types of particulates may be utilized such that one type or size of particulate may be coated with one of the components of a resin system, and another type or size of particulate may be coated with the second component of the resin system. By way of example, a low-density particulate may be coated with one of the components of a two component resin system and a high-density particulate may be coated with the second component of the two component resin system. Also, for example, a large mesh-size particulate may be coated with one of the components of a two component resin system and a smaller mesh-size particulate may be coated with the second component of the two component resin system. As well understood by one skilled in the art, more than two types

or sizes of particulates may be used. This may be particularly useful in situations where it is desirable to obtain high proppant pack permeability (i.e., conductivity), high consolidation strength, or lower pack density.

[0044] It is envisioned that in a typical gravel packing operation according to one aspect of the present invention, at least about 30% of the particulates pumped down the annular space are coated with either the liquid hardenable resin component or the liquid hardening agent component. In some embodiments, at least about 50% of the particulates pumped down the annular space are coated with either the liquid hardenable resin component or the liquid hardening agent component. In other embodiments, about 100% of the particulates pumped down the annular space are coated with either the liquid hardenable resin component or the liquid hardening agent component.

[0045] Typically, the ratio of the particulates the liquid hardenable resin component to those coated with the liquid hardening agent component is in the range from about 0.3:1 to about 1:0.3. In some embodiments, the ratio of the particulates the liquid hardenable resin component to those coated with the liquid hardening agent component is about 1:1. This ratio can vary to suit the application at issue, for example, to obtain the desired consolidation strength, curing time, etc. There are many ways to ensure the right ratio is obtained. One way to do so is by measuring the volume of the particulates. A weight ratio may also be applied when only one type of particulate is used in the process.

[0046] The particulates may be suspended in the carrier fluid by any suitable method as recognized by one skilled in the art, including using a fracturing blender. The resulting slurry can successfully work under a wide range of temperatures, i.e., temperature does not typically impact the outcome of the method. Typically, the temperature of the slurry is between about 90°F and about 250°F. However, as mentioned above in paragraph [0030], there are resin systems that can cure under temperatures lower than about 90°F and higher than about 250°F.

[0047] Typically, the inter-granular bonds formed among the particulates will generate grain-to-grain compressive strength which is strong enough to keep the gravel pack immobile. As used herein, the term “immobile” means the gravel pack as a whole does not move relative to the wellbore, neither is there shifting among the particulates constituting the gravel pack. Typically, the grain-to-grain compressive strength is at least about 10 psi. One can determine the grain-to-grain compressive strength using ASTM standard test method ASTM D7012.

[0048] While the embodiments of the invention have been shown and described, modifications thereof can be made by one skilled in the art without departing from the spirit and teachings of the invention. The embodiments described and the examples provided herein are exemplary only, and are not intended to be limiting. Many variations and modifications of the invention disclosed herein are possible and are within the scope of the invention. Accordingly, the scope of protection is not limited by the description set out above, but is only limited by the claims which follow, that scope including all equivalents of the subject matter of the claims.

[0049] The discussion of a reference is not an admission that it is prior art to the present invention, especially any reference that may have a publication date after the priority date of this application. The disclosures of all patents, patent applications, and publications cited herein are hereby incorporated herein by reference in their entirety, to the extent that they provide exemplary, procedural, or other details supplementary to those set forth herein.

CLAIMS

What is claimed is:

What is claimed is:

1. A method for gravel packing a hydrocarbon producing wellbore, comprising:
injecting a slurry comprising particulates dispersed in a carrier fluid into an annular space in an open hole section of the wellbore, wherein the annular space is between a screen element and the wellbore; and
depositing the particulates in the annular space to form a gravel pack.
2. The method of claim 1, wherein the gravel pack is formed via formation of inter-granular bonds among the particulates, and the inter-granular bonds generate grain-to-grain compressive strength to keep the gravel pack immobile.
3. The method of claim 2, wherein the grain-to-grain compressive strength is at least about 10 psi.
4. The method of claim 2, wherein the inter-granular bonds form after depositing.
5. The method of any of the proceeding claims, wherein a first portion of the particulates is at least partially coated with a liquid hardenable resin component, and a second portion of the particulates is at least partially coated with a liquid hardening agent component.
6. The method of claim 5, wherein at least about 30% of the particulates are coated with either the liquid hardenable resin component or the liquid hardening agent component.

7. The method of claim 5, wherein the ratio of the first portion to the second portion of the particulates is in the range from about 0.3:1 to about 1:0.3.
8. The method according to any one of claims 1-4, wherein the particulates can be sand, proppant or a combination thereof.
9. The method according to any one of claims 1-4, wherein the temperature of the slurry is between about 90°F and about 250°F.
10. A completed open hole hydrocarbon producing well, the well comprising:
 - a screen element in an open hole section of a hydrocarbon producing well;
 - an annular space between the wellbore and the screen element; and
 - a gravel pack comprised of particulates and disposed with respect to the annular space, having a grain-to-grain compressive strength of at least about 10 psi.
11. The open hole hydrocarbon producing well of claim 10, wherein the grain-to-grain compressive strength is generated by inter-granular bonds among the particulates and is strong enough to keep the gravel pack immobile.
12. The open hole hydrocarbon producing well according to claims 10 or 11, wherein a first portion of the particulates is at least partially coated with a liquid hardenable resin component, and a second portion of the particulates is at least partially coated with a liquid hardening agent component.
13. The open hole hydrocarbon producing well of claim 12, wherein at least about 30% of the particulates are coated with either the liquid hardenable resin component or the liquid hardening agent component.

14. The open hole hydrocarbon producing well of claim 12, wherein the ratio of the first portion to the second portion of the particulates is in the range from about 0.3:1 to about 1:0.3.
15. The open hole hydrocarbon producing well according to claims 10 or 11, wherein the particulates can be sand, proppant or a combination thereof.

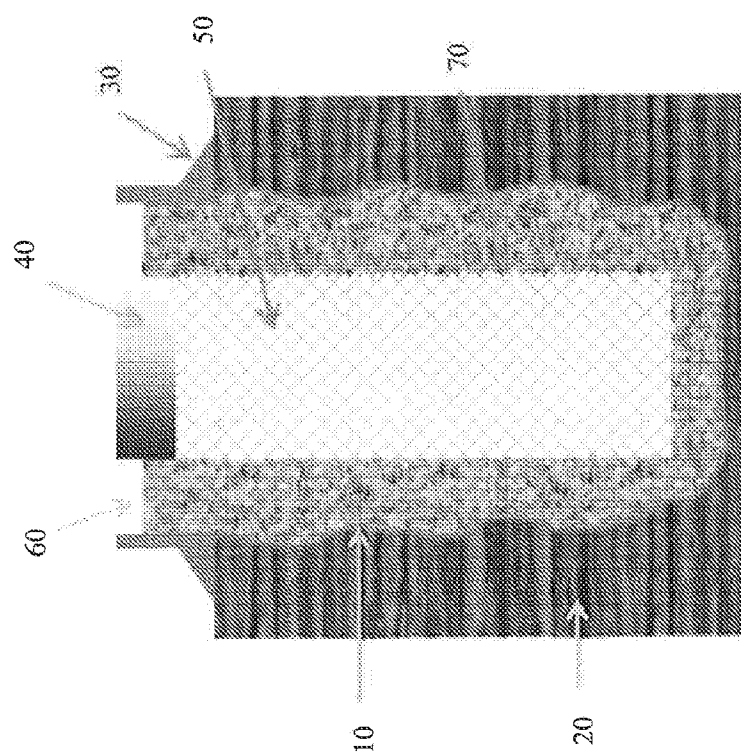


FIGURE 1

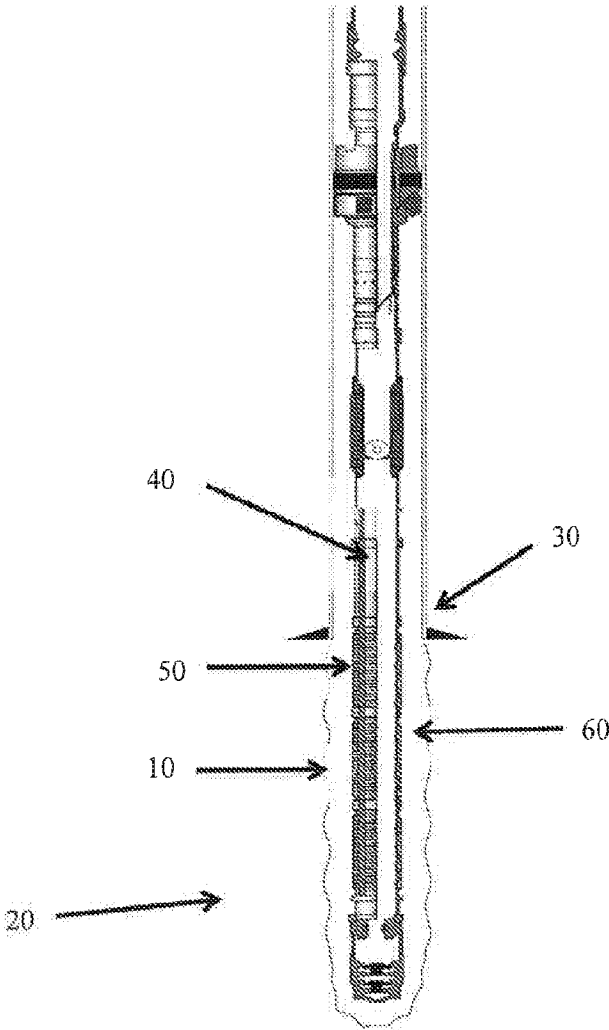


FIGURE 2

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2017/062610

A. CLASSIFICATION OF SUBJECT MATTER
 INV. E21B43/04
 ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
 E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005/019574 A1 (MCCRARY AVIS LLOYD [US]) 27 January 2005 (2005-01-27) paragraphs [0002] - [0019], [0032], [0059] - [0071], [0073] - [0092], [0101] - [0266], [0274] - [0284], [0336] - [0348]	1-15
X	US 2016/280990 A1 (LIENG THU [US] ET AL) 29 September 2016 (2016-09-29) the whole document in particular: paragraphs [0077] - [0083]; claims 1,20; figures ----- -/--	1-15



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

5 February 2018

Date of mailing of the international search report

15/02/2018

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Dekker, Derk

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/062610

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2003/224165 A1 (ANDERSON ROBERT WILLIAM [US] ET AL) 4 December 2003 (2003-12-04) the whole document in particular: claims 1,19,30,32; figure -----	1-15
X	US 2007/036977 A1 (SINCLAIR A R [US] ET AL) 15 February 2007 (2007-02-15) the whole document in particular: paragraphs [0047] - [0088], [0103] - [0152]; claims 1,20; figures -----	1-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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