METHODS FOR CONTROLLING WATER AND PARTICULATE PRODUCTION IN SUBTERRANEAN WELLS

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Appl. No.: 12/008,083
Filed: Jan. 8, 2008

Related U.S. Application Data
Continuation-in-part of application No. 11/545,136, filed on Oct. 10, 2006, which is a continuation-in-part of application No. 11/183,028, filed on Jul. 15, 2005.

ABSTRACT
Improved methods for stabilizing unconsolidated subterranean formation particulates and reducing permeability of a subterranean formation to water. Some methods describe methods of stabilizing unconsolidated subterranean formation particulates and reducing the permeability of water comprising providing a portion of a subterranean formation that comprises unconsolidated formation particulates; introducing a fluid comprising a relative permeability modifier into at least a portion of the subterranean formation so as to at least partially reduce the permeability of that portion of the subterranean formation to water; and, introducing a fluid comprising a consolidating agent into at least a portion of the subterranean formation so as to at least partially consolidate the unconsolidated formation particulates.
METHODS FOR CONTROLLING WATER AND PARTICULATE PRODUCTION IN SUBTERRANEAN WELLS

CROSS REFERENCE TO RELATED APPLICATIONS


BACKGROUND

[0002] The present invention relates to the stabilization of subterranean formations. More particularly, the present invention relates to methods for stabilizing unconsolidated portions of a subterranean formation and controlling the production of water from those portions.

[0003] Hydrocarbon wells are often located in subterranean formations that contain unconsolidated particulates that may migrate out of the subterranean formation with the oil, gas, water, and/or other fluids produced by the wells. The presence of particulates, such as formation sand and even loose propellant, in produced fluids is undesirable in that the particulates may abrade pumping and other producing equipment and reduce the fluid production capabilities of the producing zones. Unconsolidated portions of a subterranean formation include those that contain loose particulates and those wherein the bonded particulates have insufficient bond strength to withstand the forces created by the production of fluids through the formation.

[0004] One method of controlling particulates in such unconsolidated portions has been to produce fluids from the formations at low flow rates, so that the near well stability of sand bridges and the like may be substantially preserved. The collapse of such sand bridges, however, may occur due to unintentionally high production rates and/or pressure cycling as may occur from repeated shut-ins and start-ups of a well. The frequency of pressure cycling is critical to the longevity of the near well formation, especially during the depletion stage of the well when the pore pressure of the formation has already been significantly reduced.

[0005] Another method of controlling particulates in unconsolidated formations involves placing a filtration bed containing gravel near the well bore to present a physical barrier to the transport of unconsolidated formation fines with the production of hydrocarbons. Typically, such “gravel-pack” operations involve the pumping and placement of a quantity of a desired particulate into the unconsolidated formation in an area adjacent to a well bore. One common type of gravel-pack operation involves placing a gravel-pack screen in the well bore and packing the surrounding annulus between the screen and the well bore with gravel of a specific size designed to prevent the passage of formation sand. The gravel-pack screen is generally a filter assembly used to retain the gravel placed during the gravel-pack operation. A wide range of sizes and screen configurations are available to suit the characteristics of the gravel-pack sand used. Similarly, a wide range of sizes of gravel is available to suit the characteristics of the unconsolidated particulates in the subterranean formation. The resulting structure presents a barrier to migrating sand from the formation while still permitting fluid flow. When installing the gravel pack, the gravel is carried to the formation in the form of a slurry by mixing the gravel with a viscous treatment fluid. Once the gravel is placed in the well bore, the viscosity of the treatment fluid is reduced, and it is returned to the surface.

[0006] Gravel packs act, inter alia, to stabilize the formation while causing minimal impairment to well productivity. The gravel, inter alia, acts to prevent formation particulates from occluding the screen or migrating with the produced fluids, and the screen, inter alia, acts to prevent the gravel from entering the production tubing. Such packs may be time consuming and expensive to install. Due to the time and expense needed, it is sometimes desirable to place a screen without the gravel. Even in circumstances in which it is practical to place a screen without gravel, it is often difficult to determine an appropriate screen size to use as formation sands tend to have a wide distribution of grain sizes. When small quantities of sand are allowed to flow through a screen, formation erosion becomes a significant concern. As a result, the placement of gravel as well as the screen is often necessary to assure that the formation sands are controlled. Expandable sand screens have been developed and implemented in recent years. As part of the installation, an expandable sand screen may be expanded against the well bore, cased hole, or open hole for sand control purposes without the need for gravel packing. However, screen erosion and screen plugging are the main disadvantages of expandable screens.

[0007] Another method used to control particulates in unconsolidated formations involves consolidating unconsolidated subterranean producing zones into stable, permeable masses by applying a resin followed by a spacer fluid, a catalyst, and an after-flush fluid. Such resin application may be problematic when, for example, an insufficient amount of spacer fluid is used between the application of the resin and the application of the external catalyst. The resin may come into contact with the external catalyst in the well bore itself rather than in the unconsolidated subterranean producing zone. When resin is contacted with an external catalyst an exothermic reaction occurs that may result in rapid polymerization, potentially damaging the formation by plugging pore channels, halting pumping when the well bore is plugged with solid material, or resulting in a downhole explosion as a result of the heat of polymerization. Also, using these conventional processes to treat long intervals of unconsolidated regions is not practical due to the difficulty in determining if the entire interval has been successfully treated with both the resin and the external catalyst. Further, conventional consolidation techniques have often resulted in limited or inadequate penetration distances of consolidating agent into formations.

[0008] Often, unconsolidated formation sands migrate out of the formation when water is produced from the formation. This migration of formation sands is due, in part, to the fact that most natural cementation between formation sand grains disintegrates when in contact with an aqueous moving phase. The production of water from a subterranean producing zone is disadvantageous due to its effect on mobilizing formation sands, and because water production constitutes a major expense in the recovery of hydrocarbons from subterranean formations, especially in light of the energy expended in producing, separating, and disposing of the water.

SUMMARY

[0009] The present invention relates to the stabilization of subterranean formations. More particularly, the present
invention relates to methods for stabilizing unconsolidated portions of a subterranean formation and controlling the production of water from those portions.

[0010] Some embodiments of the present invention provide methods of treating a portion of a subterranean formation that comprises unconsolidated formation particulates, the method comprising: introducing a fluid comprising a relative permeability modifier into at least a portion of the subterranean formation; and then, introducing a fluid comprising a consolidating agent into at least a portion of the subterranean formation so as to at least partially consolidate the unconsolidated formation particulates.

[0011] Other embodiments of the present invention provide methods of treating a portion of a subterranean formation that comprises unconsolidated formation particulates, the method comprising introducing a treatment fluid comprising a relative permeability modifier and a consolidating agent into at least a portion of the subterranean formation so as to at least partially consolidate the unconsolidated formation particulates.

[0012] Still other embodiments of the present invention provide methods of stabilizing unconsolidated subterranean formation particulates and reducing the permeability of water comprising: providing a portion of a subterranean formation that comprises unconsolidated formation particulates; introducing a fluid comprising a relative permeability modifier into at least a portion of the subterranean formation so as to at least partially reduce the permeability of that portion of the subterranean formation to water; and, introducing a fluid comprising a consolidating agent into at least a portion of the subterranean formation so as to at least partially consolidate the unconsolidated formation particulates.

[0013] The features and advantages of the present invention will be apparent to those skilled in the art. While numerous changes may be made by those skilled in the art, such changes are within the spirit of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] These drawings illustrate certain aspects of some of the embodiments of the present invention and should not be used to limit or define the invention.

[0015] FIG. 1 shows a cross-sectional view of a subterranean formation penetrated by a well bore after treatment with a consolidating agent and a relative permeability modifier fluid, in which the consolidating agent has been introduced at a rate and pressure below the fracture pressure of the subterranean formation.

[0016] FIG. 2A shows a cross-sectional view of a subterranean formation penetrated by a well bore after treatment with a consolidating agent, followed by treatment with a relative permeability modifier fluid which has been introduced at a rate and pressure sufficient to create or enhance at least one fracture in the subterranean formation.

[0017] FIG. 2B shows a cross-sectional view of the subterranean formation of FIG. 2A wherein a fracturing fluid comprising proppant particulates has been used to extend further the fracture into the formation.

DESCRIPTION OF PREFERRED EMBODIMENTS

[0018] The present invention relates to the stabilization of subterranean formations. More particularly, the present invention relates to methods for stabilizing unconsolidated portions of a subterranean formation and controlling the production of water from those portions.

[0019] 1. Examples of Methods of the Present Invention

[0020] One embodiment of the present invention describes a method of stabilizing an unconsolidated subterranean formation that is penetrated by a well bore comprising introducing a fluid comprising a consolidating agent into at least a portion of the subterranean formation so as to transform a portion of the subterranean formation surrounding the well bore into a consolidated region; and introducing a relative permeability modifier fluid into the subterranean formation through the well bore so as to penetrate at least a portion of the consolidated region. The relative permeability modifier fluid, in some embodiments, may penetrate beyond the consolidated region.

[0021] Another embodiment of the present invention described a method that comprises introducing a relative permeability modifier fluid into at least a portion of a subterranean formation to form a treated portion of the subterranean formation; and introducing a fluid comprising a consolidating agent into the treated portion of the subterranean formation so as to transform at least a section of the treated portion of the subterranean formation into a consolidated region. In some embodiments, the subterranean formation may have been previously stimulated via hydraulically fracturing or any other known stimulation method.

[0022] Another embodiment of the present invention described a method that comprises introducing a fluid that comprises a relative permeability modifier fluid and a consolidating agent into at least a portion of a subterranean formation so as to transform at least a section of the subterranean formation into a treated, consolidated region. In some embodiments, the subterranean formation may have been previously stimulated via hydraulically fracturing or any other known stimulation method.

[0023] As an example of one embodiment of the methods of the present invention, FIG. 1 shows a cross-sectional view of subterranean formation 100 penetrated by well bore 110. First portion 120 of subterranean formation 100 has been treated with a consolidating agent to consolidate first portion 120 and form a consolidated region. Prior to the consolidation of first portion 120, an after-flush fluid may optionally be introduced into subterranean formation 100 to restore the permeability of first portion 120 after introduction of the consolidating agent. Further, after introduction of an after-flush fluid, well bore 110 may optionally be shut-in for a period of time to allow for consolidation of first portion 120. Second portion 130 of the subterranean formation 100 may be treated by a relative permeability modifier fluid introduced into subterranean formation through well bore 110 so as to penetrate first portion 120.

[0024] As another example of one embodiment of the methods of the present invention, FIG. 2A shows a cross-sectional view of subterranean formation 200 penetrated by well bore 210. First portion 220 of subterranean formation 200 has been treated with a consolidating agent to consolidate first portion 220 and form a consolidated region. A relative permeability modifier fluid has been introduced at a rate and pressure sufficient to create or enhance fracture 240 in subterranean formation 200. The relative permeability modifier fluid may flow into and treat second portion 230. Referring
now to FIG. 2B, a fracturing fluid has been introduced at a rate and pressure sufficient to extend fracture 240 in subterranean formation 200. Fracture 240 may be packed with proppant to keep fracture 240 open. In this way, the relative permeability modifier fluid may treat regions that are beyond first portion 220 that have been consolidated using the consolidating agent and extend into second portion 230.

[0025] The term, “unconsolidated subterranean formation,” as used herein, refers to both unconsolidated and weakly consolidated formations. The term, “consolidating agent,” as used herein, refers to any agent that may consolidate a portion of the subterranean formation, which may, at least in part, stabilize particulates such that loose or weakly consolidated particulates are prevented from shifting or migrating once the consolidation treatment is complete. The term, “relative permeability modifier fluid,” as used herein refers to any fluid, which may, among other things, treat a portion of the subterranean formation so as to reduce the permeability of the treated portion to water without substantially reducing the formation permeability as to hydrocarbons.

[0026] Optionally, other embodiments may include the use of a preflush fluid and/or an after-flush fluid. Additional embodiments may include introducing a fracturing fluid to create or enhance fractures in the subterranean formation. The term, “create or enhance,” as used herein also includes the action of extending previously created, or natural, fractures. In still other embodiments portions of the subterranean formation may have been previously hydraulically fractured to stimulate production through that portion. Further, the well bore may be shut in for a period of time after introduction of the consolidating agent to allow for consolidation of the portion of the subterranean formation.

[0027] The term, “preflush fluid,” as used herein refers to any fluid that may be suitable for preparing the subterranean formation for the later placement of the consolidating agent by, among other things, removing oil and/or debris from the pore spaces within the formation matrix of the unconsolidated portion. The term, “after-flush fluid,” as used herein refers to any fluid that may, among other things, restore the permeability of the treated portion of the subterranean formation by displacing at least a portion of the consolidating agent from the pore channels of the subterranean formation and forcing the displaced portion of the consolidating agent further into the subterranean formation where it may have negligible impact on subsequent hydrocarbon production.

[0028] In embodiments of the present invention wherein an optional preflush fluid is desired, it may be placed into the subterranean formation either before the placement of the fluid comprising a consolidating agent or before the placement of the relative permeability modifier fluid. In some preferred embodiments, the preflush fluid is placed directly before the fluid comprising a consolidating agent. The preflush fluid acts, inter alia, to prepare the subterranean formation for the later placement of the consolidating agent and/or relative permeability modifier. Typically, injection of a preflush fluid may occur prior to consolidating a portion of a subterranean formation. Injecting a volume of a preflush fluid into an unconsolidated portion of a subterranean formation may, among other things, help to remove oil and/or debris from the pore spaces within the formation matrix of the subterranean formation portion. Generally, the volume of the preflush fluid placed into the formation is between 0.1 times to 50 times the volume of the fluid comprising the consolidating agent and/or relative permeability modifier fluid. Preflush fluids suitable for use with the present invention are described in more detail below.

[0029] Introducing a volume of consolidating agent into the unconsolidated portion may among other things, transform a portion of the subterranean formation into a consolidated region. Consolidating the region surrounding the well bore may be advantageous in preventing well bore sloughing, formation sand production, and the migration of fines.

[0030] In certain embodiments, the consolidation of a portion of a subterranean formation may result in diminishing the permeability of that portion. In certain embodiments, fracturing a portion of the formation may be required to reconnect the well bore with portions of the formation (e.g., the reservoir formation) outside the consolidated region, as discussed in more detail below. In other embodiments, typically when no fracturing step is used, an after-flush fluid may be used to restore permeability to the portion of the subterranean formation.

[0031] In certain embodiments of the present invention, after the placement of the consolidating agent and/or relative permeability modifier into the subterranean formation, an optional after-flush fluid may be placed into the subterranean formation, inter alia, to restore the permeability of the treated portion of the subterranean formation. When used, the after-flush fluid is preferably placed into the subterranean formation while the consolidating agent is still in a flowing state. For example, an after-flush fluid may be placed into the formation prior to a shut-in period. Among other things, the after-flush fluid acts to displace at least a portion of the consolidating agent from the pore channels of the subterranean formation and to force the displaced portion of the consolidating agent further into the subterranean formation where it may have negligible impact on subsequent hydrocarbon production. Generally, the after-flush 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. For example, the after-flush may be an aqueous-based brine, a hydrocarbon fluid (such as kerosene, diesel, or crude oil), or a gas (such as nitrogen or carbon dioxide). In some preferred embodiments, the after-flush fluid is a brine. The after-flush fluid may be placed into the formation at a matrix flow rate such that a sufficient portion of the consolidating agent may be displaced from the pore channels to restore the formation to a desired permeability. Generally, a substantial amount of the consolidating agent, however, should not be displaced therein. For example, sufficient amounts of the consolidating agent should remain in the treated portion to provide effective stabilization of the unconsolidated portions of the subterranean formation therein.

[0032] Generally, the volume of after-flush fluid placed in the subterranean formation ranges from about 0.1 times to about 50 times the volume of the fluid comprising the consolidating agent. In some embodiments of the present invention, the volume of after-flush fluid placed in the subterranean formation ranges from about 0.1 times to about 5 times the volume of the consolidating agent.

[0033] In another embodiment of the present invention, no after-flush fluid is placed into the subterranean formation after placement of a consolidating agent into the subterranean
formation. Where no after-flush fluid is used, the permeability of the subterranean formation may be significantly reduced, because the consolidating agent may remain in the pore spaces therein and may convert into a consolidated substance. While a significant reduction in the permeability may occur, the unconsolidated portions of the formation may be stabilized due, inter alia, to the consolidating agent remaining in the pore spaces of the formation. In embodiments in which no after-flush fluid is used, a portion of the formation may be fractured so as to reconnect the well bore with portions of the formation outside the consolidated region. In embodiments wherein no after-flush fluid is placed after the placement of the fluid comprising a consolidating agent, it may be desirable to perform a stimulation operation, such as hydrajetting or mini-frac operation, to create one or more conduits through the consolidated portion of the subterranean formation. However, stimulations operations are not required. Retained permeability of a treated formation is function of, among other things, the volume and concentration of the consolidating agent, and the volume of any after-flush fluid. For example, in embodiments wherein a relatively low amount of consolidating agent is used in the fluid comprising the consolidating agent, the treated portion of the subterranean formation may show relatively low consolidation strength is obtained and high retained permeability, even without applying after-flush fluid. In other embodiments, wherein a relatively high amount of consolidating agent is used in the fluid comprising the consolidating agent, the retained permeability may be low, in which case a stimulation operation, or use of a higher volume of after-flush fluid may be useful to restore formation permeability and for the production of hydrocarbons.

According to the methods of the present invention, after placement of the consolidating agent, the subterranean formation may be shut in for a period of time to allow the consolidating agent to consolidate at least a portion of the subterranean formation. The shutting-in of the well bore for a period of time may, inter alia, stabilize unconsolidated portions of the subterranean formation, for example, by enhancing the coating and curing of the resin between formation particulates. Additionally, if a relative permeability modifier is placed in the subterranean formation after the placement of the consolidating agent rather than before, the shutting in of the well bore may also minimize the washing away of the consolidating agent during later placement of a relative permeability modifier.

Typically, the shut-in period of the well bore occurs after placement of the consolidating agent. In embodiments using an after-flush fluid, the shut-in period preferably occurs after the use of the after-flush fluid. In embodiments in which a fracturing step is performed subsequent to introducing the consolidating agent into the subterranean formation, preferably, no shut-in period is used.

The necessary shut-in time period is dependent, among other things, on the composition of the consolidating agent used and the temperature of the formation. Generally, the chosen period of time will be between about 0.5 hours and about 72 hours or longer. Determining the proper period of time to shut in the formation is within the ability of one skilled in the art with the benefit of this disclosure. Generally, the relative permeability modifier fluid should reduce the permeability of the treated portion to water without substantially reducing the hydrocarbon permeability.

In some embodiments wherein the relative permeability modifier fluid is introduced into the formation after the consolidating agent, the relative permeability modifier fluid may displace excess portions of the consolidating agent into the formation and at least partially restore the permeability to hydrocarbons in that treated portion. Relative permeability modifier fluids may be introduced into the subterranean formation through the well bore. For example, in some embodiments, the relative permeability modifier fluids may penetrate through the consolidated region and into portion of the subterranean formation (e.g., unconsolidated portions) that are adjacent to the consolidated region.

In certain embodiments, a relative permeability modifier fluid is introduced into a portion of a subterranean formation after a consolidating agent has been placed into at least a portion of that portion of a subterranean formation. In such embodiments, the relative permeability modifier fluid may be introduced into the subterranean formation either before or after an after-flush fluid has been placed into the portion of the subterranean formation. In certain embodiments, the relative permeability modifier fluids may be introduced into the subterranean formation at a rate and pressure sufficient to create or enhance at least one fracture in a portion of the subterranean formation. In such embodiments, it may be desirable that the fracture or fractures extend from a consolidated region of the subterranean formation into an unconsolidated region of the subterranean formation. In such embodiments, the relative permeability modifier fluid may leak off into the unconsolidated portion of the formation along the fracture; this affecting regions of the formation beyond the consolidated region of the formation. In certain embodiments, following the placement of, at least, a consolidating agent and a relative permeability modifier fluid an after-flush fluid may be used to displace at least a portion of the relative permeability fluid further into the formation.

In some embodiments in which a fracture is initiated through the use of a relative permeability modifier fluid, the fracture may be extended and packed using any suitable fracturing methodology known to one skilled in the art with the benefit of this disclosure. For example, a fracture may be extended using a crosslinked gelled fracturing fluid to further extend the fracture into the formation followed by a crosslinked gelled fluid containing proppant, or a viscoelastic surfactant fluid containing proppant. The proppant may be coated with a curable resin or consolidating agent to form a hard, permeable solid mass in the fracture or fractures, among other things, to prevent proppant flow back during production from the well. The proppant also may be blended with fibrous particulates that may act to form a stable network with the proppant and/or to control proppant flow back.

In certain embodiments a relative permeability modifier fluid may be placed into a portion of a subterranean formation before a consolidating agent is placed into the subterranean formation. In addition, in some embodiments, the relative permeability modifier fluid is placed into the subterranean formation at a rate and pressure sufficient to create or an enhance at least one fracture in that portion of the subterranean formation. In such embodiments, the relative permeability modifier fluid may be used as a component in a fracturing fluid. It may be desirable to place the relative permeability modifier fluid before placing a fluid comprising a consolidating agent in situations wherein, if placed first, the consolidating agent might coat the subterranean formation.
surfaces, preventing the relative permeability modifier from optimally performing its function. Generally, the placement of a relative permeability modifier will not act to prevent a consolidating agent from performing its function. Some embodiments may also involve the placement of a relative permeability modifier fluid before a stimulation treatment, such as fracturing, frac-packing, or hydfracturing, followed by the placement of a fluid comprising a consolidating agent. Placing a relative permeability modifier before performing a stimulation operation may act to increase the fluid efficiency of the fracturing fluid by improving the fluid loss characteristics and in reducing the amount of water inflow into the propped fracture. Moreover, if the relative permeability modifier is placed before a fluid comprising a consolidating agent, the placement of the consolidating agent may act to displace the relative permeability modifier further into the subterranean formation and further away from the well bore.

[0041] In certain embodiments a relative permeability modifier fluid may be placed into a portion of a subterranean formation substantially simultaneously along with a consolidating agent. In some such embodiments, a treatment fluid comprising a relative permeability modifier and a consolidating agent may be placed into a portion of a subterranean formation as a pre-pad to a hydraulic fracturing or frac-pack completion. Such a pre-pad frac-pack placement may, among other things, allow the pre-pad fluid to enter the regions of a subterranean formation surrounding fracture faces to, among other things, mitigate the production of water from the portion of the subterranean formation and to control particulate migration. As used herein, the term “frac-pack completion” refers to subterranean operations wherein fracturing and gravel packing are preformed in a single operation. In other embodiments, a treatment fluid comprising a relative permeability modifier and a consolidating agent may be placed into a portion of a subterranean formation as a pre-pad to a gravel pack completion. In embodiments wherein a fluid comprising both a relative permeability modifier and a consolidating agent is used, are those in which a water-soluble consolidating agent is chosen that does not contain significant quantities of anionic substances. In still other embodiments where it is desirable to use an oil-soluble consolidating agent, the fluid comprising both a relative permeability modifier and a consolidating agent may be formed into a stable emulsion. Such a pre-pad gravel pack placement may, among other things, allow the pre-pad fluid to enter the regions of a subterranean formation surrounding a gravel pack to, among other things, mitigate the production of water from the portion of the subterranean formation and to control particulate migration. In other embodiments, a treatment fluid comprising a relative permeability modifier and a consolidating agent may be placed into a portion of a subterranean formation as a remedial treatment. Such remedial treatment placement may be used in portions of well bores that are experiencing undesirable production of water and/or particulates to, among other things, mitigate the production of water from the portion of the subterranean formation and to control particulate migration. In other embodiments, a treatment fluid comprising a relative permeability modifier and a consolidating agent may be placed into a portion of a subterranean formation as an after treatment following an acidizing treatment to that portion of a subterranean formation. Such remedial post-acidizing placement may be used to mitigate the production of water from the portion of the subterranean formation and to control particulate migration.

[0042] The methods described herein may be performed repeatedly as desired. In those instances in which steps are repeated, it may be desirable, for example, to recommence the steps described herein starting first with the lowest zones of the formation and moving up to higher zones.

[0043] II. Examples of Fluids Useful in the Methods of the Present Invention

[0044] A. Examples of Preflush Fluids

[0045] Preflush fluids suitable for use with the present invention may comprise a brine, a mutual solvent, a surfactant, or any mixture thereof.

[0046] The prefush fluid of the present invention may include any fluid that does not adversely interact with the other components used in accordance with this invention or with the subterranean formation. For example, the prefush fluid may be an aqueous-based fluid or a hydrocarbon-based fluid. In certain embodiments of the present invention, the prefush fluid may comprise an aqueous fluid and a surfactant. The aqueous-fluid component may be fresh water, salt water, brine, or seawater, or any other aqueous-based fluid that does not adversely react with the other components used in accordance with this invention or with the subterranean formation. Any surfactant compatible with the later-used consolidating agent and relative permeability modifier capable of aiding the consolidating agent in flowing to the contact points between adjacent particulates in the formation may be used in the present invention. Such surfactants include, but are not limited to, ethoxylated nonyl phenol phosphate esters, mixtures of one or more cationic surfactants, one or more nonionic surfactants, and an alkyl phosphonate surfactant. Suitable mixtures of one or more cationic and nonionic surfactants are described in U.S. Pat. No. 6,311,773, the relevant disclosure of which is incorporated herein by reference. A C₁₂₋₂₂ alkyl phosphonate surfactant is preferred. The surfactant or surfactants used are included in the prefush fluid in an amount sufficient to prepare the subterranean formation to receive a treatment of a consolidating agent. In some embodiments of the present invention, the surfactant is present in the prefush fluid in an amount in the range of from about 0.1% to about 5% by weight of the aqueous fluid.

[0047] B. Examples of Consolidating Agents

[0048] Suitable consolidating agents include any suitable composition for consolidating a portion of the subterranean formation to stabilize unconsolidated particulates therein. Examples of suitable consolidating agents include resins, tackifying agents, and gelable liquid compositions.

[0049] 1. Examples of Resins

[0050] Resins suitable for use in the consolidation fluids of the present invention include any suitable resin that is 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, novolak resins, polyeoxide 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 down-
hole, 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. 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
tigger curing.

[0051] 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 speci
cific 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.

[0052] Any solvent that is compatible with the chosen resin
and achieves the desired viscosity effect is suitable for use in
the present invention. Some preferred solvents are those hav
ning high flash points (e.g., about 125° F.) because of, among
other things, environmental and safety concerns; such solv
ents include butyl lactate, butylglycidyl ether, dipropylene
glycol methyl ether, dipropylene glycol dimethyl ether, dim
ethyl formamide, diethylene glycol methyl ether, ethylene
glycol butyl ether, diethylene glycol butyl ether, propylene car
bonate, methanol, butyl alcohol, d’limonene, fatty acid
methyl esters, and combinations thereof. Other preferred solv
ents include aqueous dissoluable solvents such as, 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-butoxyethanol, ethers of a C₄ to C₆ dihydric
alkanol containing at least one C₂ to C₆ alkyl group, mono
ethers of dihydric alkanols, methoxypropanol, butoxyetha
anol, hexoxyethanol, and isomers thereof. Selection of an
appropriate solvent is dependent on the resin chosen and is
within the ability of one skilled in the art with the benefit of
this disclosure. In general, the amount of solvent needed is
based on the final desired viscosity of the fluid comprising the
resin consolidating agent.

[0053] 2. Examples of Tackifying Agents

[0054] Tackifying agents suitable for use in the methods of
the present invention exhibit a sticky character and, thus,
impart a degree of consolidation to unconsolidated particu
lates in the subterranean formation. As used herein, a “tack
ifying agent” refers to a composition having a nature such that
it is (or may be activated to become) somewhat sticky to the
touch. Examples of suitable tackifying agents suitable for use
in the present invention include non-aqueous tackifying
agents; aqueous tackifying agents; and silyl-modified poly
mides.

[0055] One type of tackifying agent suitable for use in the
present invention is a non-aqueous tackifying agent. An
example of a suitable tackifying agent may comprise poly
mides that are liquids or in solution at the temperature of the
subterranean formation such that they are, by themselves,
non-hardening when introduced into the subterranean forma
tion. A particularly preferred product is a condensation reac
tion product comprised of commercially available polyacids
and a polyanine. Such commercial products include com
pounds such as mixtures of C₂₈ dibasic acids containing some
trimer and higher oligomers and also small amounts of mono
mer 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 Corpora
tion. Additional compounds which may be used as non-aque
ous tackifying compounds include liquids and solutions of,
for example, polyesters, polycarbonates and polycarbarnates,
organic resins such as shellac and the like. Other suitable
non-aqueous tackifying agents are described in U.S. Pat. Nos.
5,853,048 and 5,853,000, the entire disclosures of which are
herein incorporated by reference.

[0056] Non-aqueous tackifying agents suitable for use in
the present invention may be either used such that they form
a non-hardening coating, or they may be combined with a
multiphase material capable of reacting with the non
aqueous tackifying agent to form a hardened coating. A
“hardened coating,” as used herein, means that the reaction of
the tackifying compound with the multifunctional material
will result in a substantially non-flowable reaction product
that exhibits a higher compressive strength in a consolidated
aggregate than the tackifying compound alone with the
particulates. In this instance, the non-aqueous tackifying
agent may function similarly to a hardenable resin. Multi
function materials suitable for use in the present invention
include, but are not limited to, alkyldehydes such as formaldehy
de, dialdehydes such as glutaraldehyde, hexamethacylic
or aldehyde releasing compounds, diacid halides, dihalides
such as diesters and dibromides, polyacid anhydrides such as
citric acid, epoxides, furfuraldehyde, glutaraldehyde or alde
hyde condensates and the like, and combinations thereof. In
some embodiments of the present invention, the multifunc
tional material may be mixed with the tackifying compound
in an amount of from about 0.01 to about 50 percent by weight
of the tackifying compound to effect formation of the reaction
product. In some preferable embodiments, the compound is
present in an amount of from about 0.5 to about 1 percent by
weight of the tackifying compound. Suitable multifunction
al materials are described in U.S. Pat. No. 5,839,510, the entire
disclosure of which is herein incorporated by reference.

[0057] Solvents suitable for use with the non-aqueous
tackifying agents of the present invention include any solvent
that is compatible with the non-aqueous tackifying agent and
achieves the desired viscosity effect. The solvents that can be
used in the present invention preferably include those having
high flash points (most preferably above about 125° F.).
Examples of solvents suitable for use in the present invention
include, but are not limited to, butylglycidyl ether, dipropyl
ene glycol methyl ether, butyl bottom alcohol, dipropylene
glycol dimethyl ether, diethylene glycol methyl ether, ethyl
eneglycol butyl ether, methanol, butyl alcohol, isopropyl
alcohol, diethylene glycol butyl ether, propylene carbonate, d’limonene, 2-butoxy ethanol, butyl acetate, furlfuryl acetate, butyl lactate, dimethyl sulfoxide, dimethyl formamide, fatty acid methyl esters, and combinations thereof. It is within the ability of one skilled in the art, with the benefit of this disclosure, to determine whether a solvent is needed to achieve a viscosity suitable to the subterranean conditions and, if so, how much. In general, the amount of solvent needed is based on the final desired viscosity of the fluid comprising the non-aqueous tackifier consolidating agent. In some embodiments, the amount of solvent needed is based on a target viscosity of less than about 20 cP; in still other embodiments, the target viscosity may be less than about 5 cP.

[0058] Aqueous tackifier agents suitable for use in the present invention are preferably not significantly tacky when placed onto a particulate, but are capable of being “activated” (that is, destabilized, coalesced, and/or reacted) to transform the compound into a sticky, tackifying compound at a desirable time. Such activation may occur before, during, or after the aqueous tackifier agent is placed in the subterranean formation. In some embodiments, a pretreatment may be first contacted with the surface of a particulate to prepare it to be coated with an aqueous tackifier agent. Suitable aqueous tackifying agents are generally charged polymers that comprise compounds that, when in an aqueous solvent or solution, will form a non-hardening 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. The aqueous tackifier agent may enhance the grain-to-grain contact between the individual particulates within the formation (for example, by the formation of formation fines, or other particulates, helping bring about the consolidation of the particulates into a cohesive, flexible, and permeable mass.

[0059] Examples of aqueous tackifier 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[butoxy acrylate], and poly(2-ethylhexyl acrylate)), acrylic acid ester co-polymers, methacrylic acid derivative polymers, methacrylic acid homopolymers, methacrylic acid ester homopolymers, and poly(methyl methacrylate), poly(butoxy methacrylate), and poly(2-ethylhexyl methacrylate), acrylamido-methyl-propane sulfonate polymers, acrylamido-methyl-propane sulfonate derivative polymers, acrylamido-methyl-propane sulfonate co-polymers, and acrylamide/acylamido-methyl-propane sulfonate co-polymers, and combinations thereof. Methods of determining suitable aqueous tackifier agents and additional disclosure on aqueous tackifier agents can be found in U.S. patent application Ser. No. 10/864,061, filed Jun. 9, 2004, and U.S. Pat. No. 7,131, 491 issued Nov. 7, 2006, the entire disclosures of which are hereby incorporated by reference. In some embodiments, the concentration of aqueous tackifier agent is from about 0.1% to 10% vol. of the fluid comprising a consolidating agent. In other embodiments, the concentration of aqueous tackifier agent is from about 0.1% to 2% vol. of the fluid comprising a consolidating agent.

[0060] Silyl-modified polyamide compounds suitable for use in the tackifying agents 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 non-tacky state to which individual particulates such as formation fines will not adhere to, for example, in formation or proppant pack pore throats. 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 compouds obtained, for example, from the reaction of a polyacid (e.g. dianic or higher) with a polyamine (e.g., 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. Pat. No. 6,439,309, the entire disclosure of which is herein incorporated by reference. In some embodiments, the concentration of silyl-modified polyamide is from about 0.01% to 10% wt./vol. of the fluid comprising a consolidating agent. In other embodiments, the concentration of silyl-modified polyamide is from about 1% to 3% wt. vol. of the fluid comprising a consolidating agent.

[0061] 3. Exemplary Gelable Liquid Compositions

[0062] The gelable liquid composition may be any gelable liquid composition capable of converting into a gelled substance capable of substantially plugging the permeability of the formation while allowing the formation to remain flexible. That is, the gelled substance should negatively impact the ability of the formation to produce desirable fluids such as hydrocarbons. As discussed above, the permeability of the formation may be restored through use of an after-flush fluid or by fracturing through the consolidated region. As referred to herein, the term “flexible” refers to a state wherein the treated formation is relatively malleable and elastic and able to withstand substantial pressure cycling without substantial breakdown of the formation. Thus, the resultant gelled substance should be a semi-solid, immovable, gel-like substance, which, among other things, stabilizes the treated portion of the formation while allowing the formation to absorb the stresses created during pressure cycling. As a result, the gelled substance may aid in preventing breakdown of the formation both by stabilizing and by adding flexibility to the formation sands. Examples of suitable gelable liquid compositions include, but are not limited to, resin compositions that cure to form flexible gels, gelable aqueous silicate compositions, crosslinkable aqueous polymer compositions, and polymerizable organic monomer compositions.

[0063] Certain embodiments of the gelable liquid compositions of the present invention comprise curable resin compositions. Curable resin compositions are well known to those skilled in the art and have been used to consolidate portions of unconsolidated formations and to consolidate proppant materials into hard, permeable masses. While the curable resin compositions used in accordance with the present invention may be similar to those previously used to consolidate sand and proppant into hard, permeable masses, they are distinct in that resins suitable for use with the present invention do not cure into hard, permeable masses; rather they cure into flexible, gelled substances. That is, suitable curable resin compositions form resilient gelled substances between the particulates of the treated zone of the unconsolidated formation and thus allow that portion of the formation to remain flexible and to resist breakdown. It is not necessary or desirable for the cured resin composition to solidify and harden to provide high consolidation strength to the treated
portion of the formation. On the contrary, upon being cured, the curable resin compositions useful in accordance with this invention form semi-solid, immovable, gelled substances.

Generally, the curable resin compositions useful in accordance with this invention may comprise a curable resin, a diluent, and a resin curing agent. When certain resin curing agents, such as polyamides, are used in the curable resin compositions, the compositions form the semi-solid, immovable, gelled substances described above. Where the resin curing agent used may cause the organic resin compositions to form hard, brittle material rather than a desired gelled substance, the curable resin compositions may further comprise one or more “flexibilizer additives” (described in more detail below) to provide flexibility to the cured compositions.

Examples of curable resins that can be used in the curable resin compositions of the present invention include, but are not limited to, organic resins such as polyoxepoxide resins (e.g., bisphenol A-epichlorohydrin resins), polyester resins, urea-formaldehyde resins, furan resins, urethane resins, and mixtures thereof. Of these, polyoxepoxide resins are preferred. One of skill in the art will be able to determine a desired amount of curable resin to be included in the fluid through, for example, porosity fill calculation determinations based on estimated depth of coverage for the volume and quantity of resin needed for the particular formation. In some embodiments, the concentration of curable resin is from about 0.1 to 25% wt./vol. of the fluid comprising a consolidating agent. In other embodiments, the concentration of curable resin is from about 1 to 5% wt. vol. of the fluid comprising a consolidating agent.

Any diluent that is compatible with the curable resin and achieves the desired viscosity effect is suitable for use in the present invention. Examples of diluents that may be used in the curable resin compositions of the present invention include, but are not limited to, phenols; formalddehydes; furfuryl alcohol; diluents; ethers such as butyl glycidyl ether and cresyl glycidyl etherphenyl glycidyl ether; and mixtures thereof. In some embodiments of the present invention, the diluent comprises butyl lactate. The diluent may be used to reduce the viscosity of the curable resin composition to about 3 to about 3,000 centipoises (“cP”) at 80°F. Among other things, the diluent acts to provide flexibility to the cured composition. The diluent may be included in the curable resin composition in an amount sufficient to provide the desired viscosity effect. Generally, the diluent used is included in the curable resin composition in an amount of from about 5% to about 75% by weight of the curable resin.

Generally, any resin curing agent that may be used to cure an organic resin is suitable for use in the present invention. When the resin curing agent chosen is an amide or a polyamide, generally no flexibilizer additive will be required because, inter alia, such curing agents cause the curable resin composition to convert into a semi-solid, immovable, gelled substance. Other suitable curing agents (such as an amine, a polyamine, methylene diamine, and other curing agents known in the art) will tend to cure into a hard, brittle material and will thus benefit from the addition of a flexibilizer additive. Generally, the resin curing agent used is included in the curable resin composition, whether a flexibilizer additive is included or not, in an amount in the range of from about 5% to about 75% by weight of the curable resin. In some embodiments of the present invention, the resin curing agent used is included in the curable resin composition in an amount in the range of from about 20% to about 75% by weight of the curable resin.

As noted above, flexibilizer additives may be used, inter alia, to provide flexibility to the gelled substances formed from the curable resin compositions. Flexibilizer additives should be used where the resin curing agent chosen would cause the organic resin composition to cure into a hard and brittle material—not the desired gelled substances described herein. For example, flexibilizer additives may be used where the resin curing agent chosen is not an amide or polyamide. Examples of suitable flexibilizer additives include, but are not limited to, an organic ester, an oxygenated organic solvent, an aromatic solvent, and combinations thereof. Of these, ethers, such as dibutyl phthalate, are preferred. Where used, the flexibilizer additive may be included in the curable resin composition in an amount in the range of from about 5% to about 80% by weight of the curable resin. In some embodiments of the present invention, the flexibilizer additive may be included in the curable resin composition in an amount in the range of from about 20% to about 45% by weight of the curable resin.

In other embodiments, the gelable liquid compositions of the present invention may comprise a gelable aqueous silicate composition. Generally, the gelable aqueous silicate compositions that are useful in accordance with the present invention generally comprise an aqueous alkali metal silicate solution and a temperature activated catalyst for gelating the aqueous alkali metal silicate solution.

The aqueous alkali metal silicate solution component of the gelable aqueous silicate compositions generally comprises an aqueous liquid and an alkali metal silicate. The aqueous liquid component of the aqueous alkali metal silicate solution generally may be fresh water, salt water (e.g., water containing one or more salts dissolved therein), brine (e.g., saturated salt water), seawater, or any other aqueous liquid that does not adversely react with the other components used in accordance with this invention or with the subterranean formation. Examples of suitable alkali metal silicates include, but are not limited to, one or more of sodium silicate, potassium silicate, lithium silicate, rubidium silicate, or cesium silicate. Of these, sodium silicate is preferred. While sodium silicate exists in many forms, the sodium silicate used in the aqueous alkali metal silicate solution preferably has a NaO-SiO₂ weight ratio in the range of from about 1:2 to about 1:4. Most preferably, the sodium silicate used has a NaO-SiO₂ weight ratio in the range of from about 1:3.2. Generally, the alkali metal silicate is present in the aqueous consolidating fluid in an amount in the range of from about 0.1% to about 42% by weight of the aqueous consolidating fluid. Typically, the alkali metal silicate is present in the aqueous consolidating fluid in an amount in the range of from about 3% to about 8% by weight of the aqueous consolidating fluid.

The temperature activated catalyst component of the gelable aqueous silicate gelable liquid compositions is used, inter alia, to convert the gelable aqueous silicate compositions into the desired semi-solid, immovable, gelled substance described above. Selection of a temperature activated catalyst is related, at least in part, to the temperature of the subterranean formation to which the gelable aqueous silicate composition will be introduced. The temperature activated
catalysts which can be used in the gelable aqueous silicate compositions of the present invention include, but are not limited to, ammonium sulfate, which is most suitable in the range of from about 60°F to about 240°F; sodium acid pyrophosphate, which is most suitable in the range of from about 60°F to about 240°F; citric acid, which is most suitable in the range of from about 60°F to about 120°F; and ethyl acetate, which is most suitable in the range of from about 60°F to about 120°F. Generally, the temperature activated catalyst is present in the aqueous consolidating fluid in the range of from about 0.1% to about 5% by weight of the aqueous consolidating fluid.

[0072] In other embodiments, the gelable liquid composition consolidating fluids of the present invention may comprise crosslinkable aqueous polymer compositions. Generally, suitable crosslinkable aqueous polymer compositions may comprise an aqueous solvent, a crosslinkable polymer, and a crosslinking agent.

[0073] The aqueous solvent may be any aqueous solvent in which the crosslinkable composition and the crosslinking agent may be dissolved, mixed, suspended, or dispersed therein to facilitate gel formation. For example, the aqueous solvent used may be fresh water, salt water, brine, seawater, or any other aqueous liquid that does not adversely react with the other components used in accordance with this invention or with the subterranean formation.

[0074] Examples of crosslinkable polymers that can be used in the crosslinkable aqueous polymer compositions include, but are not limited to, carboxylate-containing polymers and acrylamide-containing polymers. Preferred acrylamide-containing polymers include polyacrylamide, partially hydrolyzed polyacrylamide, copolymers of acrylamide and acrylate, and carboxylate-containing terpolymers and tetrapolymers of acrylate. Additional examples of suitable crosslinkable polymers include hydroxylated polymers comprising polysaccharides and derivatives thereof and that contain one or more of the monosaccharide units galactose, man- nose, glucoside, glucose, xylose, arabino, fructose, glucoronic acid, or pyranosyl sulfate. Suitable natural hydro-kraylable polymers include, but are not limited to, guar gum, locust bean gum, tara, konjak, tamarind, starch, cellulose, karaya, xanthan, tragacanth, and carrageenan, and derivatives of all of the above. Suitable hydroxylated synthetic polymers and copolymers that may be used in the crosslinkable aqueous polymer compositions include, but are not limited to, polyacrylates, polymethacrylates, polyacrylamides, maleic anhy- dride, methylvinyl ether polymers, polyvinyl alcohols, and polyvinylpyrrolidone. The crosslinkable polymer should be included in the crosslinkable aqueous polymer composition in an amount sufficient to form the desired gelled substance in the subterranean formation. In some embodiments of the present invention, the crosslinkable polymer is included in the crosslinkable aqueous polymer composition in an amount in the range of from about 1% to about 30% by weight of the aqueous solvent. In another embodiment of the present invention, the crosslinkable polymer is included in the crosslinkable aqueous polymer composition in an amount in the range of from about 1% to about 20% by weight of the aqueous solvent.

[0075] The crosslinkable aqueous polymer compositions of the present invention may further comprise a crosslinking agent for crosslinking the crosslinkable polymers to form the desired gelled substance. In some embodiments, the crosslinking agent may be a molecule or complex containing a reactive transition metal cation. A most preferred crosslinking agent comprises trivalent chromium cations complexed or bonded to anions, atomic oxygen, or water. Examples of suitable crosslinking agents include, but are not limited to, compounds or complexes containing chromic acid and chronic chloride. Other suitable transition metal cations include chromium VI within a redox system, aluminum III, iron II, iron III, and zirconium IV.

[0076] The crosslinking agent should be present in the crosslinkable aqueous polymer compositions of the present invention in an amount sufficient to provide, inter alia, the desired degree of crosslinking. In some embodiments of the present invention, the crosslinking agent is present in the crosslinkable aqueous polymer compositions of the present invention in an amount in the range of from 0.01% to about 5% by weight of the crosslinkable aqueous polymer composition. The exact type and amount of crosslinking agent or agents used depends upon the specific crosslinkable polymer to be crosslinked, formation temperature conditions, and other factors known to those individuals skilled in the art.

[0077] Optionally, the crosslinkable aqueous polymer compositions may further comprise a crosslinking delaying agent, such as a polysaccharide crosslinking delaying agents derived from guar, guar derivatives, or cellulose derivatives. The crosslinking delaying agent may be included in the crosslinkable aqueous polymer compositions, inter alia, to delay crosslinking of the crosslinkable aqueous polymer compositions until desired. One of ordinary skill in the art, with the benefit of this disclosure, will know the appropriate amount of the crosslinking delaying agent to include in the crosslinkable aqueous polymer compositions for a desired application.

[0078] In other embodiments, the gelled liquid compositions of the present invention may comprise polymerizable organic monomer compositions. Generally, suitable polymerizable organic monomer compositions may comprise an aqueous-base fluid, a water-soluble polymerizable organic monomer, an oxygen scavenger, and a primary initiator.

[0079] The aqueous-base fluid component of the polymerizable organic monomer composition generally may be fresh water, salt water, brine, seawater, or any other aqueous liquid that does not adversely react with the other components used in accordance with this invention or with the subterranean formation.

[0080] A variety of monomers are suitable for use as the water-soluble polymerizable organic monomers in the present invention. Examples of suitable monomers include, but are not limited to, acrylic acid, methacrylic acid, acrylamide, methacylamide, 2-methacrylamido-2-methylpropane sulfonic acid, 2-dimethylacrylamide, vinyl sulfonic acid, N,N-dimethylaminomethylacrylate, 2-triethylammonium- methylmethacrylate chloride, N,N-dimethyl-aminopropylmethacrylamide, methacylamidopropyltrimethylammonium chloride, N-vinyl pyrrolidone, vinyl-phosphonic acid, and methacryloyloxyethyl trimethylammonium sulfate, and mixtures thereof. Preferably, the water-soluble polymerizable organic monomer should be self crosslinking. Examples of suitable monomers which are self crosslinking include, but are not limited to, hydroxyethylacrylate, hydroxyethylmethacrylate, hydroxyethylmethacrylate, N-hydroxymethylacryla-
mide, N-hydroxymethyl-methacrylamide, polyethylene glycol acrylate, polyethylene glycol methacrylate, polypropylene glycol acrylate, polypropylene glycol methacrylate, and mixtures thereof. Of these, hydroxyethylacrylate is preferred. An example of a particularly preferable monomer is hydroxyethylcellulose-vinyl phosphoric acid.

[0081] The water-soluble polymerizable organic monomer (or monomers where a mixture thereof is used) should be included in the polymerizable organic monomer composition in an amount sufficient to form the desired gelled substance after placement of the polymerizable organic monomer composition into the subterranean formation. In some embodiments of the present invention, the water-soluble polymerizable organic monomer(s) are included in the polymerizable organic monomer composition in an amount in the range of from about 1% to about 30% by weight of the aqueous-base fluid. In another embodiment of the present invention, the water-soluble polymerizable organic monomer(s) are included in the polymerizable organic monomer composition in an amount in the range of from about 1% to about 20% by weight of the aqueous-base fluid.

[0082] The presence of oxygen in the polymerizable organic monomer composition may inhibit the polymerization process of the water-soluble polymerizable organic monomer or monomers. Therefore, an oxygen scavenger, such as stannous chloride, may be included in the polymerizable monomer composition. In order to improve the solubility of stannous chloride so that it may be readily combined with the polymerizable organic monomer composition on the fly, the stannous chloride may be pre-dissolved in a hydrochloric acid solution. For example, the stannous chloride may be dissolved in a 0.1% by weight aqueous hydrochloric acid solution in an amount of about 10% by weight of the resulting solution. The resulting stannous chloride-hydrochloric acid solution may be included in the polymerizable organic monomer composition in an amount in the range of from about 0.1% to about 10% by weight of the polymerizable organic monomer composition. Generally, the stannous chloride may be included in the polymerizable organic monomer composition in an amount in the range of from about 0.005% to about 0.1% by weight of the polymerizable organic monomer composition.

[0083] The primary initiator is used, inter alia, to initiate polymerization of the water-soluble polymerizable organic monomer(s) used in the present invention. Any compound or compounds which form free radicals in aqueous solution may be used as the primary initiator. The free radicals act, inter alia, to initiate polymerization of the water-soluble polymerizable organic monomer(s) present in the polymerizable organic monomer composition. Compounds suitable for use as the primary initiator include, but are not limited to, alkali metal persulfates; peroxides; oxidation-reduction systems employing reducing agents, such as sulfites in combination with oxidizers; and azo polymerization initiators. Preferred azo polymerization initiators include 2,2'-azobisisobutyronitrile, 2,2'-azobisisobutyronitrile, 4,4'-azoxyanisole, 2,2'-azobis(2-methyl-2-phenylvaleronitrile), and 2,2'-azobis(2-methyl-2-phenylvaleronitrile). Generally, the primary initiator should be present in the polymerizable organic monomer composition in an amount sufficient to initiate polymerization of the water-soluble polymerizable organic monomer(s). In certain embodiments of the present invention, the primary initiator is present in the polymerizable organic monomer composition in an amount in the range of from about 0.1% to about 5% by weight of the water-soluble polymerizable organic monomer(s).

[0084] Optionally, the polymerizable organic monomer compositions further may comprise a secondary initiator. A secondary initiator may be used, for example, where the immature aqueous gel is placed into a subterranean formation that is relatively cool as compared to the surface mixing, such as when placed below the mud line in offshore operations. The secondary initiator may be any suitable water-soluble compound or compounds that may react with the primary initiator to provide free radicals at a lower temperature. An example of a suitable secondary initiator is triethanolamime. In some embodiments of the present invention, the secondary initiator is present in the polymerizable organic monomer composition in an amount in the range of from about 0.1% to about 5% by weight of the water-soluble polymerizable organic monomer(s).

[0085] Optionally, the polymerizable organic monomer compositions of the present invention further may comprise a crosslinking agent for crosslinking the polymerizable organic monomer compositions in the desired gelled substance. In some embodiments, the crosslinking agent is a molecule or complex containing a reactive transition metal cation. A most preferred crosslinking agent comprises trivalent chromium cations complexed or bonded to anions, atomic oxygen, or water. Examples of suitable crosslinking agents include, but are not limited to, compounds or complexes containing chromic acetate and/or chromic chloride. Other suitable transition metal cations include chromium VI within a redox system, aluminum III, iron II, iron III, and zirconium IV. Generally, the crosslinking agent may be present in polymerizable organic monomer compositions in an amount in the range of from about 0.01% to about 5% by weight of the polymerizable organic monomer composition.

[0086] C. Examples of Relative Permeability Modifier Fluids

[0087] The relative permeability modifier fluids of the present invention may comprise an aqueous fluid and a relative permeability modifier. As used herein, “relative permeability modifier” refers to any material capable of reducing the permeability of a subterranean formation to aqueous fluids without substantially reducing the permeability of the subterranean formation to hydrocarbons. A variety of additional additives suitable for use in subterranean operations also may be included in the relative permeability modifier fluids as desired. The aqueous fluid of the relative permeability modifier fluids of the present invention may include freshwater, saltwater, brine (e.g., saturated or unsaturated saltwater), or seawater. Generally, the aqueous fluid may be from any source, provided that it does not contain components that may adversely affect other components in the treatment fluid.

[0088] The relative permeability modifiers useful in the present invention may be any relative permeability modifier that is suitable for use in subterranean operations. After introducing the relative permeability modifier fluid into a portion of the subterranean formation, the relative permeability modifier preferably attaches to surfaces within the porosity of the subterranean formation, so as to reduce the permeability of the portion of the subterranean formation to aqueous fluids without substantially changing its permeability to hydrocarbons. Examples of suitable relative permeability modifiers
include water-soluble polymers with or without hydrophobic or hydrophilic modification. As used herein, “water-soluble” refers to at least 0.01 weight percent soluble in distilled water. A water-soluble polymer with hydrophobic modification is referred to herein as a “hydrophobically modified polymer.” As used herein, the term “hydrophobic modification,” or “hydrophobically modified,” refers to the incorporation into the hydrophilic polymer structure of hydrophobic groups, wherein the alkyl chain length is from about 4 to about 22 carbons. A water-soluble polymer with hydrophilic modification is referred to herein as a “hydrophilically modified polymer.” As used herein, the term “hydrophilic modification,” or “hydrophilically modified,” refers to the incorporation into the hydrophilic polymer structure of hydrophilic groups, such as to introduce branching or to increase the degree of branching in the hydrophilic polymer. Combinations of hydrophobically modified polymers, hydrophilically modified polymers, and water-soluble polymers without hydrophobic or hydrophilic modification may be included in the relative modifier fluids of the present invention.

[0089] The hydrophobically modified polymers useful in the present invention typically have molecular weights in the range of from about 100,000 to about 10,000,000. While these hydrophobically modified polymers have hydrophobic groups incorporated into the hydrophilic polymer structure, they should remain water-soluble. In some embodiments, a mole ratio of a hydrophilic monomer to the hydrophobic compound in the hydrophobically modified polymer is in the range of from about 99.98:0.02 to about 90:10, wherein the hydrophilic monomer is a calculated amount present in the hydrophilic polymer. In certain embodiments, the hydrophobically modified polymers may comprise a polymer backbone, the polymer backbone comprising polar heteroatoms. Generally, the polar heteroatoms present within the polymer backbone of the hydrophobically modified polymers include, but are not limited to, oxygen, nitrogen, sulfur, or phosphorus.

[0090] The hydrophobically modified polymers may be synthesized using any suitable method. In one example, the hydrophobically modified polymers may be a reaction product of a hydrophilic polymer and a hydrophobic compound. In another example, the hydrophobically modified polymers may be prepared from a polymerization reaction comprising a hydrophilic monomer and a hydrophobically modified hydrophilic monomer. Those of ordinary skill in the art, with the benefit of this disclosure, will be able to determine other suitable methods for the synthesis of suitable hydrophobically modified polymers.

[0091] In certain embodiments, suitable hydrophobically modified polymers may be synthesized by the hydrophobic modification of a hydrophilic polymer. The hydrophilic polymers suitable for forming hydrophobically modified polymers of the present invention should be capable of reacting with hydrophobic compounds. Suitable hydrophilic polymers include, homo-, co-, or terpolymers such as, but not limited to, polycrylamides, polyvinylamines, poly(vinylamines/vinyl alcohols), alkyl acrylate polymers in general, and derivatives thereof. Additional examples of alkyl acrylate polymers include, but are not limited to, polydimethyleno-ethyl methacrylate, polydimethylenopropyl methacryla-  
mide, poly(acrylamide/dimethylenoethyl methacrylate), poly(methacrylic acid/dimethylenoethyl methacrylate), poly(2-acrylamido-2-methyl propane sulfonic acid/dimethy- 
lamoethyl methacrylate), poly(acrylamide/dimethylno- 
pnopoly methacrylamide), poly(acrylic acid/dimethyleno- 
pnopoly methacrylamide), and poly(methacrylic acid/ 
dimethylenopropyl methacrylamide). In certain 
embodiments, the hydrophilic polymers comprise a polymer backbone and reactive amino groups in the polymer backbone or as pendant groups, the reactive amino groups capable of reacting with hydrophobic compounds. In some embodiments, the hydrophilic polymers comprise dialkyl amino pendant groups. In some embodiments, the hydrophilic polymers comprise a dimethyl amino pendant group and a monomer comprising dimethylaminoethyl methacrylate or dimethy- 
lamoenopropyl methacrylamide. In certain embodiments of the present invention, the hydrophilic polymers comprise a pol- 
ymer backbone, the polymer backbone comprising polar het-
  
eroatoms, wherein the polar heteroatoms present within the 
  
polymer backbone of the hydrophilic polymers include, but 
  
are not limited to, oxygen, nitrogen, sulfur, or phosphorus.

[0092] The hydrophobic compounds that are capable of reacting with the hydrophilic polymers of the present invention include, but are not limited to, alkyl halides, sulfonates, sulfates, organic acids, and organic acid derivatives. Examples of suitable organic acids and derivatives thereof include, but are not limited to, octenyl succinic acid; dodece-
ynyl succinic acid; and anhydrides, esters, imides, and amidates of octenyl succinic acid or dodecenyl succinic acid. In certain 
embodiments, the hydrophobic compounds may have an 
alloy chain length of from about 4 to about 22 carbons. In another embodiment, the hydrophobic compounds may have an alkyl chain length of from about 7 to about 22 carbons. In another embodiment, the hydrophobic compounds may have an alkyl chain length of from about 12 to about 18 carbons. For example, where the hydrophobic compound is an alkyl halide, the reaction between the hydrophobic compound and hydrophilic polymer may result in the quaternization of at least some of the hydrophilic polymer amino groups with an alkyl halide, wherein the alkyl chain length is from about 4 to about 22 carbons.

[0093] As previously mentioned, in certain embodiments, suitable hydrophobically modified polymers also may be prepared from a polymerization reaction comprising a hydrophilic monomer and a hydrophobically modified hydrophilic monomer. Examples of suitable methods of their preparation are described in U.S. Pat. No. 6,476,169, the entire disclosure of which is incorporated herein by reference. The hydrophobically modified polymers synthesized from the polymerization reactions may have estimated molecular weights in the range of from about 100,000 to about 10,000,000 and mole ratios of the hydrophilic monomer(s) to the hydrophobically modified hydrophilic monomer(s) in the range of from about 99.98:0.02 to about 90:10.

[0094] A variety of hydrophilic monomers may be used to form the hydrophobically modified polymers useful in the
Examples of suitable hydrophilic monomers include, but are not limited to acrylamide, 2-acrylamido-2-methyl propane sulfonic acid, N,N-dimethacrylamide, vinyl pyrrolidone, dimethylaminoethyl methacrylate, acrylic acid, dimethylaminoethyl methacrylate, vinyl amine, vinyl acetate, trimethylammonium methyl methacrylate chloride, methacrylamide, hydroxyethyl acrylate, vinyl sulfonic acid, vinyl phosphonic acid, methacrylic acid, vinyl caprolactam, N,N-vinylformamide, N,N-diallylacetamide, dimethylallyl ammonium halide, itaconic acid, styrene sulfonic acid, methacrylamidooethytrimethyl ammonium halide, quaternary salt derivatives of acrylamide, and quaternary salt derivatives of acrylic acid.

A variety of hydrophobically modified hydrophilic monomers also may be used to form the hydrophobically modified polymers useful in the present invention. Examples of suitable hydrophobically modified hydrophilic monomers include, but are not limited to, alkyl acrylates, alkyl methacrylates, alkyl acrylamides, alkyl methacrylamides, alkyl dimethylammonium methyl methacrylate halides, and alkyl dimethylammoniumpropyl methacrylamide halides, wherein the alkyl groups have from about 4 to about 22 carbon atoms. In another embodiment, the alkyl groups have from about 7 to about 22 carbons. In another embodiment, the alkyl groups have from about 12 to about 18 carbons. In certain embodiments, the hydrophobically modified hydrophilic monomer comprises octadecyl(dimethylammonium)methyl methacrylate bromide, heptadecyl(dimethylammonium)methyl methacrylate bromide, hexadecyl(dimethylammonium)methyl methacrylate bromide, 2-ethylhexyl methacrylate, or hexadecyl methacrylamide.

Suitable hydrophobically modified polymers that may be formed from the above-described reactions include, but are not limited to, acrylamide/octadecyl(dimethylammonium)methyl methacrylate bromide copolymer, dimethylaminoethyl methacrylate/octadecyl(dimethylammonium)methyl methacrylate bromide copolymer, and acrylamide/2-acrylamido-2-methyl propane sulfonic acid/2-ethylhexyl methacrylate terpolymer. Another suitable hydrophobically modified polymer formed from the above-described reaction is an amino methacrylate/alkyl amino methacrylate copolymer. A suitable dimethylaminoethyl methacrylate/alkyl(dimethylammonium)methyl methacrylate copolymer is a dimethylaminoethyl methacrylate/hexadecyl(dimethylammonium)methyl methacrylate copolymer. As previously discussed, these copolymers may be formed by reactions with a variety of alkyl halides. For example, in some embodiments, the hydrophobically modified polymer may be a dimethylaminoethyl methacrylate/hexadecyl(dimethylammonium)methyl methacrylate bromide copolymer.

In another embodiment of the present invention, the relative permeability modifier fluid of the present invention may comprise a water-soluble hydrophilically modified polymer. The hydrophilically modified polymers of the present invention typically have molecular weights in the range of from about 100,000 to about 10,000,000. In certain embodiments, the hydrophilically modified polymers comprise a polymer backbone, the polymer backbone comprising polar heteroatoms. Generally, the polar heteroatoms present within the polymer backbone of the hydrophilically modified polymers include, but are not limited to, oxygen, nitrogen, sulfur, or phosphorous.

The hydrophilically modified polymers may be synthesized using any suitable method. In one example, the hydrophilically modified polymers may be a reaction product of a hydrophilic polymer and a hydrophobic compound. Those of ordinary skill in the art, with the benefit of this disclosure, will be able to determine other suitable methods for the preparation of suitable hydrophilically modified polymers.

In certain embodiments, suitable hydrophilically modified polymers may be formed by additional hydrophilic modification, for example, to introduce branching or to increase the degree of branching, of a hydrophilic polymer. The hydrophilic polymers suitable for forming the hydrophilically modified polymers used in the present invention should be capable of reacting with hydrophilic compounds. In certain embodiments, suitable hydrophilic polymers include, homo-, co-, or terpolymers, such as, but not limited to, polyacrylamides, polyvinylamines, poly(vinylalmines/vinyl alcohols), and alkyl acrylate polymers in general. Additional examples of alkyl acrylate polymers include, but are not limited to, poly(dimethylacrylamide), poly(dimethylacrylamide/ dimethylacrylamide, poly(methacrylic acid/dimethylacrylamide), poly(2-acrylamido-2-methyl propane sulfonic acid/dimethylacrylamide), and poly(methacrylic acid/dimethylacrylamide).

The hydrophilic polymers comprise a polymer backbone and reactive amino groups in the polymer backbone or as pendant groups, the reactive amino groups capable of reacting with hydrophilic compounds. In some embodiments, the hydrophilic polymers comprise dialkyl amino pendant groups. In some embodiments, the hydrophilic polymers comprise a dimethyl amino pendant group and at least one monomer comprising dimethylacrylamide or dimethylaminoethyl methacrylate. In other embodiments, the hydrophilic polymers comprise a polymer backbone comprising polar heteroatoms, wherein the polar heteroatoms present within the polymer backbone of the hydrophilic polymers include, but are not limited to, oxygen, nitrogen, sulfur, or phosphorous. Suitable hydrophilic polymers that comprise polar heteroatoms within the polymer backbone include homo-, co-, or terpolymers, such as, but not limited to, celluloses, chitosans, polyamides, polyetheramines, polyethylenimines, polyhydroxyethylenamines, polylysines, polysulfones, gums, starches, and derivatives thereof.

The reaction product of epichlorohydrin and trialkylamine.

The hydrophilic compounds suitable for reaction with the hydrophilic polymers include polyethers that comprise halogen, sulfonates, sulfates, organic acids, and organic acid derivatives. Examples of suitable polyethers include, but are not limited to, polyethylene oxides, polypropylene oxides, and polybutylene oxides, and copolymers, terpolymers, and mixtures thereof. In some embodiments, the polyether comprises an epichlorohydrin-terminated polyethylene oxide methyl ether.
range of from about 100,000 to about 10,000,000 and may have weight ratios of the hydrophilic polymers to the polyethers in the range of from about 1:1 to about 10:1. Suitable hydrophilically modified polymers having molecular weights and weight ratios in the ranges set forth above include, but are not limited to, the reaction product of polydimethylaminooethyl methacrylate and epichlorohydrin-terminated polyethyleneoxide methyl ether; the reaction product of polydimethyloximinopropyl methacrylamide and epichlorohydrin-terminated polyethyleneoxide methyl ether; and the reaction product of poly(acrylamide/dimethylamino propyl methacrylamide) and epichlorohydrin-terminated polyethyleneoxide methyl ether. In some embodiments, the hydrophilically modified polymer comprises the reaction product of a polydimethylaminooethyl methacrylate and epichlorohydrin-terminated polyethyleneoxide methyl ether having a weight ratio of polydimethylaminooethyl methacrylate to epichlorohydrin-terminated polyethyleneoxide methyl ether of about 3:1.

[0102] In another embodiment of the present invention, the water-soluble relative permeability modifiers comprise a water-soluble polymer without hydrophobic or hydrophilic modification. Examples of suitable water-soluble polymers include, but are not limited to, homo-, co-, and terpolymers of acrylamide, 2-acrylamido-2-methyl propane sulfonic acid, N,N-dimethylacrylamide, vinyl pyrrolidone, dimethylaminoethyl methacrylate, acrylic acid, dimethyloximinopropylmethacrylamide, vinyl amine, vinyl acetate, trimethylammoniumethyl methacrylate, chloroethyl methacrylamide, hydroxethyl acrylate, vinyl sulfonic acid, vinyl phosphonic acid, methacrylic acid, vinyl caprolactam, N-vinylformamide, N,N-diallylacetamide, dimethylallylammonium halide, itaconic acid, styrene sulfonic acid, methacyridylideneethyl trimethyl ammonium halide, quaternary salt derivatives of acrylamide and quaternary salt derivatives of acrylic acid.

[0103] Sufficient concentrations of a suitable relative permeability modifier may be present in the treatment fluids of the present invention to provide the desired degree of diversion. The amount of the relative permeability modifier to include in the treatment fluid depends on a number of factors including, the composition of the fluid to be diverted and the porosity of the formation. In some embodiments, a relative permeability modifier may be present in a treatment fluid of the present invention in an amount in the range of from about 0.02% to about 10% by weight of the composition. In some embodiments, a relative permeability modifier may be present in an amount in the range of from about 0.05% to about 1.0% by weight of the composition. In certain embodiments of the present invention, the relative permeability modifier may be provided in a concentrated aqueous solution prior to its combination with the other components necessary to form a treatment fluid of the present invention.

[0104] Additional additives may be included in the treatment fluids of the present invention as deemed appropriate for a particular application by one skilled in the art, with the benefit of this disclosure. Examples of such additives include, but are not limited to, acids, weighting agents, surfactants, scale inhibitors, anti-foaming agents, bactericides, salts, foaming agents, fluid loss control additives, viscosifying agents, gel breakers, clay stabilizers, and combinations thereof.

[0105] 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. The terms in the claims have their plain, ordinary meaning unless otherwise explicitly and clearly defined by the patentee.

[0106] Water control treatments are often considered as the last resort to provide solutions to the problems affecting the production and operation of the wells. Instead of treating subterranean formations with water and sand production problems separately, the present invention allows for water and sand control treatments to be performed simultaneously or one directly after the other. Although experimental testing showed that relative permeability modifiers may be applied either before or after that of a consolidation treatment, it may be more convenient and cost effective to treat the interval with RPM solution before the consolidating agent such that the action of placing the consolidating agent displaces the relative permeability modifier deeper into the formation.

[0107] To facilitate a better understanding of the present invention, the following examples of certain aspects of some embodiments are given. In no way should the following examples be read to limit, or define, the scope of the invention.

Examples

[0108] Preparation of Sand Packs. Both synthetic sand packs and brown sandstone outcrop material were used in the study. Sand-pack samples were prepared from a sand mixture composed of 88% (wt/wt) 70/170-mesh sand, 10% silica flour, and 2% smectite. The sand mixture was blended using a kitchen mixer to help ensure homogeneity of the sand pack. After being well blended, each sand mixture was hand packed into the Hassler sleeve and assembled in a consolidation chamber. The Hassler sleeve had a diameter of 2.54 cm and a length of 13.3 cm. Each sand column was packed in the Hassler sleeve in the following order of materials: 10 g of 70/170-mesh sand, 20 g of resieved 20/40-mesh Ottawa sand, 175 g of sand mixture (described above), and 10 g of resieved 20/40-mesh Ottawa sand. Screen pieces with 60-mesh size were installed on top and at the bottom of the sand pack. The chamber was equipped with a heated jacket to simulate down-hole temperatures during curing. A piston displacement ISCO pump was used to inject all fluids with a backpressure of 50 psi applied during injection and an annular confining pressure of 2,500 psi placed on the sand pack to ensure no fluid bypassed the pack. The entire system was maintained at 170° F. during treatment.

[0109] Relative Permeability Modifier. The selected relative permeability modifier was a hydrophilically modified, water-soluble polymer. A relative permeability modifier solution with concentration of 2,000 ppm was prepared in 2% KCl that was then adjusted with an acid buffer to obtain a pH of 6.0.

[0110] Consolidating Agent. The selected consolidating agent was an epoxy-based resin system capable of acting as a consolidating agent at temperatures between 170-325° F. An epoxy based resin with a volume of 30 ml., (i.e., 15 ml. of hardenable resin component and 15 ml. of internal activator component) was prepared to form a single mixture just before the consolidation treatment. This resin mixture has a viscosity of about 15 cP at 72° F.
Test 1—Consolidation Treatment of Sand Pack without RPM Treatment. This test was performed to determine the consolidation performance of the consolidating agent on the sand pack. All injections were maintained at 5 mL/min pump rate. Initial permeability values of kerosene and API brine for the sand pack were first established in the production direction. The consolidation treatment was then followed in the injection direction. The consolidation treatment typically involved injecting a preflush fluid, the resin mixture described above having a viscosity of about 15 cP at 72°F, and an after-flush fluid. Once the after-flush treatment was completed, the treated sand pack was then shut in for 48 hours at 170°F to allow complete curing of the epoxy-based resin consolidating agent. After curing, the regained permeability of the sand pack was determined with kerosene in the production direction. The consolidated sand pack was then cut into cores of desired length and unconfined compressive strengths (UCS) of the cores were determined.

Test 2—Relative Permeability Modifier Followed by a Consolidating Agent. This test was performed to determine the compatibility of a relative permeability modifier treatment with that of consolidating agent treatment in a sand pack. Following measurements of initial permeability of kerosene and API brine through the sand pack, as described above, a relative permeability modifier treatment was performed on the sand pack. The relative permeability modifier treatment typically consists of injecting an API brine, followed by a relative permeability modifier solution, followed by an after-flush brine displacement, followed by treatment with the resin mixture described above having a viscosity of about 15 cP at 72°F. The treated sand pack was then allowed to cure at 170°F for 48 hours. Both kerosene and API brine were used in determining the regained permeability with respect to kerosene and brine. The UCS, consolidation strength values were then obtained for the consolidated sand pack.

Test 3—Relative Permeability Modifier Followed by a Consolidating Agent. This test was performed to determine if consolidation of a sand pack could be achieved when a very low viscosity fluid comprising a consolidating agent is used following the placement of a relative permeability modifier. Similar to the procedure described in Test 2, above, a sand pack was first treated with a relative permeability modifier solution and followed by placement of the resin mixture described above having a viscosity of about 15 cP at 72°F.

Test 4—Treatments of Consolidating Agent and Relative Permeability Modifier on Sequential Set Up of Sand Pack and Brown Sandstone Core. This test was performed to examine the performance of a relative permeability modifier treatment in a sand pack and in a Brown sandstone core after the placement of a consolidating agent. A flow chamber which had a Hassler sleeve containing a sand pack, as described above, was set up in front of the flow chamber with Hassler sleeve containing the Brown sandstone core. The Hassler sleeve containing sandstone core was equipped with multipits where pressure transducers were installed to allow measurements of differential pressures between various interval lengths of the cores. The Brown sandstone had a 6-in. length and a 1-in. diameter. Initial values of permeability of kerosene and API brine were obtained for the sand pack and sandstone core in the production direction. A consolidation treatment was then performed on the sand pack in the injection direction. The sandstone core was never exposed to consolidating agent. Following the consolidation treatment, a relative permeability modifier treatment was applied also in the injection direction sequentially through both the sand pack and the sandstone. The treated sand pack and sandstone core were then shut in for 48 hours at 170°F. After the shut-in period, kerosene and API brine were used in regained permeability measurements by injecting in the production direction. The UCS, consolidation strength, values were then obtained for the consolidated sand pack.

Test 4

<table>
<thead>
<tr>
<th>Treatment Type</th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>Test 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>% regained permeability to kerosene</td>
<td>74</td>
<td>84</td>
<td>98</td>
<td>92</td>
</tr>
<tr>
<td>% water shut off</td>
<td>—</td>
<td>38</td>
<td>65</td>
<td>62</td>
</tr>
<tr>
<td>UCS (psi)</td>
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<td>&lt;10</td>
<td>1270</td>
</tr>
</tbody>
</table>

Therefore, the present invention is well adapted to attain the ends and advantages mentioned as well as those that are inherent therein. The particular embodiments disclosed above are illustrative only, as the present invention may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular illustrative embodiments disclosed above may be altered or modified and all such variations are considered within the scope and spirit of the present invention. In particular, every range of values (of the form, "from about a to about b," or, equivalently, "from approximately a to b," or, equivalently, "from approximately a-b") disclosed herein is
to be understood as referring to the power set (the set of all subsets) of the respective range of values, and set forth every range encompassed within the broader range of values. Moreover, the indefinite articles “a” or “an”, as used in the claims, are defined herein to mean one or more than one of the element that it introduces. Also, the terms in the claims have their plain, ordinary meaning unless otherwise explicitly and clearly defined by the patentee.

What is claimed is:

1. A method of treating a portion of a subterranean formation that comprises unconsolidated formation particulates, the method comprising:
   introducing a fluid comprising a relative permeability modifier into at least a portion of the subterranean formation; and then,
   introducing a fluid comprising a consolidating agent into at least a portion of the subterranean formation so as to at least partially consolidate the unconsolidated formation particulates.

2. The method of claim 1 wherein the portion of the subterranean formation has been previously hydraulically fracture-stimulated.

3. The method of claim 1 wherein the consolidating agent comprises at least one consolidating agent selected from the group consisting of a resin, a thickening agent, a gelable liquid composition, and any combination thereof.

4. The method of claim 1 wherein the relative permeability modifier fluid comprises at least one relative permeability modifier selected from the group consisting of a water-soluble, hydrophobically modified polymer; a water-soluble, hydrophilically modified polymer; a water-soluble polymer without hydrophobic or hydrophilic modification; and any combination thereof.

5. The method of claim 1 wherein the relative permeability modifier fluid comprises an amino methacrylate/alkyl amino methacrylate copolymer.

6. The method of claim 1 further comprising the step of allowing the consolidating agent to set for a period of time sufficient to at least partially consolidate the unconsolidated formation particulates therein.

7. The method of claim 1 further comprising the step of introducing a preflush fluid into at least a portion of the subterranean formation before the step of introducing a consolidating agent into at least a portion of the subterranean formation.

8. The method of claim 7 wherein the preflush fluid comprises at least one preflush fluid selected from the group consisting of an aqueous based-fluid, a hydrocarbon-based fluid, a mutual solvent, a surfactant, and any combination thereof.

9. The method of claim 1 further comprising the step of introducing an after-flush fluid into the portion of the subterranean formation after introduction of the consolidating agent.

10. A method of treating a portion of a subterranean formation that comprises unconsolidated formation particulates, the method comprising introducing a treatment fluid comprising a relative permeability modifier and a consolidating agent into at least a portion of the subterranean formation so as to at least partially consolidate the unconsolidated formation particulates.

11. The method of claim 10 wherein the portion of the subterranean formation has been previously hydraulically fracture-stimulated.

12. The method of claim 10 wherein the consolidating agent comprises at least one consolidating agent selected from the group consisting of a resin, a thickening agent, a gelable liquid composition, and any combination thereof.

13. The method of claim 10 wherein the relative permeability modifier fluid comprises at least one relative permeability modifier selected from the group consisting of a water-soluble, hydrophobically modified polymer; a water-soluble, hydrophilically modified polymer; a water-soluble polymer without hydrophobic or hydrophilic modification; and any combination thereof.

14. The method of claim 10 wherein the relative permeability modifier fluid comprises an amino methacrylate/alkyl amino methacrylate copolymer.

15. The method of claim 10 further comprising the step of allowing the consolidating agent to set for a period of time sufficient to at least partially consolidate the unconsolidated formation particulates therein.

16. The method of claim 10 further comprising the step of introducing a preflush fluid into at least a portion of the subterranean formation before placing the treatment fluid.

17. The method of claim 16 wherein the preflush fluid comprises at least one preflush fluid selected from the group consisting of an aqueous based-fluid, a hydrocarbon-based fluid, a mutual solvent, a surfactant, and any combination thereof.

18. The method of claim 10 further comprising the step of introducing an after-flush fluid into the portion of the subterranean formation after placing the treatment fluid.

19. A method comprising:
   providing a portion of a subterranean formation that comprises unconsolidated formation particulates;
   introducing a fluid comprising a relative permeability modifier into at least a portion of the subterranean formation so as to at least partially reduce the permeability of that portion of the subterranean formation to water; and,
   introducing a fluid comprising a consolidating agent into at least a portion of the subterranean formation so as to at least partially consolidate the unconsolidated formation particulates.

20. The method claim 19 where the step of introducing a relative permeability modifier fluid is performed before the step of introducing a consolidating agent.

21. The method claim 19 where the step of introducing a relative permeability modifier fluid is performed substantially simultaneously with the step of introducing a consolidating agent.

22. The method claim 19 where the portion of a subterranean formation that comprises unconsolidated formation particulates has been previously hydraulically fractured.

23. The method claim 19 further comprises the step of introducing a preflush fluid into at least a portion of the subterranean formation before placing the relative permeability modifier fluid.

24. The method claim 19 further comprises the step of introducing an after-flush fluid into the portion of the subterranean formation after placing the consolidating agent.

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