A multi-tank system for preparing fluids for hydraulic fracturing of reservoirs and methods of injecting the prepared fluid upstream from pumping units are disclosed. The multi-tank system allows for a proppant slurry to be continuously formed and mixed with a proppant carrier in staggered phases to form a fracturing fluid. This fracturing fluid can then be injected into the reservoir at normal injection pressures, thus reducing wear and downtime on the blender, and allowing continuous flow of proppant.
LOW PRESSURE DIRECT PROPPANT INJECTION

FIELD OF THE DISCLOSURE

[0001] The disclosure generally relates to methods, materials, and systems for hydraulic fracturing of reservoirs to increase production therefrom.

BACKGROUND OF THE DISCLOSURE

[0002] Hydraulic fracturing is the fracturing of rock by a pressurized liquid. Some hydraulic fractures form naturally—certain veins or dikes are examples. Induced hydraulic fracturing (also hydrofracturing or fracking) is a mining technique in which a high-pressure liquid fluid is injected into a wellbore under pressure in order to create small fractures (usually less than 1.0 mm wide) in the deep-rock formations in order to allow natural gas, petroleum, and brine to migrate to the well.

[0003] Most induced hydraulic fracturing occurs in the oil and gas industry. The first experimental use of hydraulic fracturing was in 1947, and the first commercially successful applications of hydraulic fracturing were in 1949. Worldwide, as of 2012, 2.5 million hydraulic fracturing jobs have been performed on oil and gas wells—more than one million of which were performed in the US.

[0004] In order to keep the fractures open even after the pressure is reduced and fluid travels back out of the fractures, small grains of material called "proppants" are co-injected into the well. The proppants (typically sand or aluminum oxide) hold open the small fractures once the deep rock achieves geologic equilibrium. Hereinafter, this type of treatment is referred as conventional fracturing treatment and the type of proppant placed therein is referred as homogeneous proppant pack.

[0005] FIG. 1 displays a schematic of a typical hydraulic fracturing process. A pressurized mixture is injected into a well and the pressure inside the well causes the reservoir rock to crack. The mixture can also flow from the well into the cracks to propagate the fractures. Recovered fracturing fluid and released hydrocarbons can then be produced, separated and processed.

[0006] The ideal fracturing fluid should:

[0007] Be able to transport the propping agent in the fracture
[0008] Be compatible with the formation rock and fluid
[0009] Generate enough pressure drop along the fracture to create a wide fracture
[0010] Minimize friction pressure losses during injection
[0011] Be formulated using chemical additives that are approved by the local environmental regulations
[0012] Exhibit controlled-break to a low-viscosity fluid for cleanup after the treatment
[0013] Be cost-effective

[0014] Water-based fracturing fluids have become the predominant type of coalbed methane fracturing fluid. However, fracturing fluids can also be based on oil, methanol, or a combination of water and methanol. Methanol is used in lieu of, or in conjunction with, water to minimize fracturing fluid leakoff and enhance fluid recovery. Polymer-based fracturing fluids made with methanol usually improve fracturing results, but require 50 to 100 times the amount of breaker (e.g., acids used to degrade the fracturing fluid viscosity, which helps to enhance post-fracturing fluid recovery).

[0015] In some cases, nitrogen or carbon dioxide gas is combined with the fracturing fluids to form foam as the base fluid. Foams require substantially lower volumes to transport an equivalent amount of proppant. Diesel fuel is another component of some fracturing fluids although it is not used as an additive in all hydraulic fracturing operations.

[0016] A variety of other fluid additives (in addition to the proppants) may be included in the fracturing fluid mixture to perform essential tasks such as formation clean up, foam stabilization, leakoff inhibition, or surface tension reduction. These additives include biocides, fluid-loss agents, enzyme breakers, acid breakers, oxidizing breakers, friction reducers, and surfactants such as emulsifiers and non-emulsifiers. Several products may exist in each of these categories. On any one fracturing job, different fluids may be used in combination or alone at different stages in the fracturing process. Experienced service company engineers will devise the most effective fracturing scheme, based on formation characteristics, using the fracturing fluid combination they deem most effective.

[0017] The viscosity of the fracturing fluid is an important point of differentiation in both the execution and in the expected fracture geometry. “Slickwater” treatments, use low-viscosity fluids pumped at high rates to generate narrow, complex fractures with low-concentrations of propping agent (0.2-5 lbm proppant added (PPA) per gallon). In order to minimize risk of premature screenout, pumping rates must be sufficiently high to transport proppant over long distances (often along horizontal wellbores) before entering the fracture. By comparison, for conventional wide biwing fractures the carrier fluid must be sufficiently viscous (normally 50 to 1000 cp at nominal shear rates from 40-100 sec^-1) to transport higher proppant concentrations (1-10 PPA per gallon). These treatments are often pumped at lower pump rates and may create wider fractures (normally 0.2 to 1.0 inch).

[0018] The density of the carrier-fluid is also important. The fluid density affects the surface injection pressure and the ability of the fluid to flow back after the treatment. Water-based fluids generally have densities near 8.4 ppg. Oil-base fluid densities will be 70 to 80% of the densities of water-based fluids. Foam-fluid densities can be substantially less than those of water-based fluids. In low-pressure reservoirs, low-density fluids, like foam, can be used to assist in the fluid cleanup. Conversely, in certain deep reservoirs (including offshore frac-pack applications), there is a need for higher density fracturing fluids whose densities can span up to 12 ppg.

[0019] Heterogeneous proppant placement (HPP) is a new approach in hydraulic fracturing, invented by Kevin England of Schlumberger Technology Corporation (U.S. Pat. No. 6,767,235). The well productivity is increased by sequentially injecting into the wellbore alternate stages of fracturing fluids having a contrast in their ability to transport propping agents to improve proppant placement, or having a contrast in the amount of transported propping agents. The propped fractures obtained following this process have a pattern characterized by a series of bundles of proppant spread along the fracture. In another words, the bundles form "pillars" that keep the fracture opens along its length and provide channels for the formation fluids to circulate.

[0020] The large volume of proppant that is currently being used in hydraulic fracturing operations has led to excessive
wear and damage to service equipment. Erosion damage of all wetted parts is an issue, but is particularly high in the pump and blender units. Efforts to repair or replace such equipment contributes to downtime and increases costs.

A previous concept to mitigate the erosion damage to the pumps and blenders was described in US20100243525, also by Schlumberger Technology Corporation. This application describes a hydraulic fracturing method wherein a concentrated sand slurry is injected directly into the fracturing base fluid at high pressure, but downstream from the pumping units. Although this method has not been commercially implemented to date, initial evidence suggests it has potential for bypassing much of the wear on the pumping and blending units. However, the method does not eliminate erosion and further improvements could be made to optimize the implementation of this concept.

What is needed in the art are yet further improvements to methods, materials and systems for use in hydraulic fracturing, particularly if such improvements could reduce erosion and damage to oilfield equipment.

SUMMARY OF THE DISCLOSURE

The proposed system utilizes the basic concept described in US20100243525, but with one or more modifications to further optimize the method. Instead of using direct proppant injection at the high-pressure area downstream from the pump units, it is proposed to instead utilize a direct proppant injection system on the low-pressure side of the process. This would replace the existing blender unit with a system of comparable functionality, but significantly lower wear due to the decreased pressure. Since the proppant is being introduced into the fluid upstream from the high-pressure pumps, there would be no change in the wear on the pumping units compared to current operations, but wear on the blender is greatly reduced, plus a continuous stream of proppant is now possible.

The proposed system utilizes multiple displacement tanks in order to avoid disruption of proppant flow during operations. This would allow at least one tank to be discharging at any given time, while other tanks are being refilled with proppant and/or fluid. A conceptual diagram for a system with three displacement tanks can be seen in FIG. 3.

The diagram in FIG. 3 also implements various features for proppant carrier fluid dilution and separating the clean fluid used for the proppant displacement from the proppant carrier fluid. Maintaining separation of the clean fluid and the proppant carrier fluid is important because the proppant has a very slow settling rate in viscous fluids, and therefore the filling and wetting of proppant within the displacement tanks would most likely take too long if the thick proppant carrier and clean fluid were combined.

It is proposed to utilize non-gelled clean fluids for the proppant displacement tanks in order to provide the fastest cycle times and reduce the volume of tank space required for the system. The non-gelled clean fluid can also be used to dilute the proppant carrier fluid before it is mixed with the proppant.

Another innovative part of the concept is that the clean fluid required to displace the proppant from the tank full of proppant slurry (Tank #2) is partially taken from the tank that was displaced with clean fluid in the previous process step (Tank #1). Therefore, tank #1 will be partially drained, and the remaining space can then be refilled with proppant without having any excess fluid overflow. The portion of the clean fluid filling Tank #2 can then be used to displace the proppant slurry in a third tank (Tank #3). This system design feature can be seen in the process steps (Table 3) and diagram of FIG. 3.

A method of using the above system to generate a fracturing fluid slurry utilizes a three-stage operation, which is illustrated in Table 3 for a three tank system. Each tank undergoes all the stages sequentially, but staggered in time. Thus, tank 1 undergoes stage 1 when tank 2 undergoes stage 2, tank three undergoes stage 3 and so on. Such a process design prevents disruption in the proppant slurry flow because at least one tank is always discharging the slurry to the gel to prepare the final fracturing fluid for downhole use. Thus, the system allows continuous production of proppant for use downhole.

While the above system and method are exemplified using a three-tank system, minor changes can be made to accommodate more tanks. Furthermore, while multiples of three tanks are advantageous to the three-stage method design, it is not required. A 4, 5, 7 or 8 tank system can easily implement the system.

One could possibly use only 1 or 2 tanks, but it would not allow for continuous operation, and there would be operational drawbacks to such design.

The invention includes one or more of the following embodiments, in any combination:

- Fracturing injection system having multiple displacement tanks for sequential proppant mixing with a clean fluid such that the resulting proppant slurry is continuous produced and means of combining the proppant slurry with concentrated gel. Optional lines for proppant carrier fluid dilution using the clean fluid is also possible.
- The disclosure provides the following one or more embodiments, in any combinations thereof:
- Methods of producing a continuous flow of proppant slurry using a multi-stage washing, blending, and dispensing system.
- Methods of producing a fracturing fluid for injection using a continuous flow of proppant slurry and a concentrated proppant carrier fluid.
- Methods of injecting a fracturing fluid into a low-pressure area of a direct proppant injector system upstream from the pumping units.
- An apparatus for preparing a proppant fluid for injection into a reservoir comprising:
  - a) a first vessel, a second vessel and a third vessel, wherein each vessel has a hopper containing particulates above the vessel, such that the particulates can gravity feed into the vessel;
  - b) a clean fluid line in fluid communication with each vessel, the clean fluid line transporting a clean fluid from a source to each vessel;
  - c) a concentrated proppant carrier fluid line in fluid communication with each vessel, the concentrated proppant carrier fluid line transporting a concentrated proppant carrier fluid;
  - d) a recycle fluid line in communication with each vessel, the recycle fluid line transporting a clean fluid from the vessel to form a make-up flow for the clean fluid line;
  - e) a displaced proppant slurry line in fluid communication with each vessel, wherein the proppant slurry line feeds into the concentrated proppant carrier fluid line to form a proppant fluid for introduction into a hydrocarbon-containing reservoir;
[0043] wherein an optional dilution line having a dilution pump connects the clean fluid line and the concentrated proppant carrier fluid line such that the clean fluid can dilute the concentrated proppant carrier fluid before the proppant carrier fluid combines with the proppant slurry line.

[0044] A method of preparing a proppant fluid for injection into a reservoir using the apparatus as herein described comprising:

- filling the first vessel with a clean fluid;
- partially displacing the clean fluid from the first vessel, wherein the displaced clean fluid serves as a make-up flow for the clean water fluid into a subsequent vessel;
- adding particulates into the first vessel to refill the first vessel without creating fluid overflow;
- mixing the particulates and clean fluid in the first vessel to form a proppant slurry;
- displacing the proppant slurry and flushing the first vessel with a fluid mixture, wherein the fluid mixture comprises clean fluid and displaced clean fluid from another vessel;
- combining the displaced proppant slurry with the concentrated proppant carrier fluid to form the proppant fluid for injection into a reservoir;

- repeating steps a)-f) n the second vessel and the third vessel sequentially; and

- introducing the proppant fluid into a low pressure side of a direct proppant injection system.

[0053] A method of fracturing a reservoir, the method comprising:

- injecting a first fluid into a reservoir at an injection pressure high enough to fracture the reservoir forming fractures;

- continuously combining a proppant slurry with a proppant carrier to make a proppant fluid, wherein the proppant slurry is continuously made in at least three tanks in staggered phases such that one tank is being washed with water partially obtained from a previously washed tank, a second tank is partially full of wash water and is receiving proppant, and a third tank is dispensing proppant slurry; and

- injecting the proppant fluid into the reservoir to prop open the fractures.

[0057] An apparatus or method as herein described, further comprising a makeup fluid line connecting the recycle fluid line to the displaced proppant slurry line.

[0058] An apparatus or method as herein described, wherein the particulates are sand.

[0059] An apparatus or method as herein described, wherein the clean fluid is treated water.

[0060] An apparatus or method as herein described, wherein the number of the vessels is a multiple of three.

[0061] An apparatus or method as herein described, further comprising using the clean fluid to dilute the concentrated proppant carrier fluid before combination with the displaced proppant slurry.

[0062] An apparatus or method as herein described, further comprising using the displaced clean fluid to dilute the displaced proppant slurry.

[0063] An apparatus or method as herein described, further comprising adding one or more additives to the proppant slurry or the proppant carrier or the proppant fluid.

[0064] An apparatus or method as herein described, wherein the proppant carrier is in the form of a gel, emulsion, foam, micelle, or viscoelastic surfactant.

[0065] The terms “proppant” and “particulate” are used interchangeably to refer to a granular solid suitable for use in subterranean operations. Suitable solids include, but are not limited to, sand; bauxite; ceramic materials; glass materials; polymer materials; Teflon® materials; nut shell pieces; seed shell pieces; cured resinous particulates comprising nut shell pieces; cured resinous particulates comprising seed shell pieces; fruit pit pieces; cured resinous particulates comprising fruit pit pieces; wood; composite particulates and combinations thereof.

[0066] Composite particulates may also be suitable, suitable composite materials may comprise a binder and a filler material wherein suitable filler materials include silica, alumina, fumed carbon, carbon black, graphite, mica, titanium dioxide, meta-silicate, calcium silicate, kaolin, talc, zirconia, boron, fly ash, hollow glass microspheres, solid glass, and combinations thereof. The proppant pack can be either homogeneous or heterogeneous, as desired.

[0067] By “proppant slurry” what is meant is a fluid mixture having granular solid with a liquid, e.g., proppant plus water.

[0068] By “proppant fluid,” or what is meant herein is the proppant carrier (aka base fluid) plus proppant slurry (plus optional additional liquids and/or additives) that is used to prop open downhole fractures.

[0069] By “proppant carrier,” or “base fluid,” what is meant is any thick and/or dense fluid that can carry the proppant under the conditions of use. Typical proppant carriers include gels, foams, viscoelastic surfactants, emulsions, micelles, and the like, that carry the proppant into the fractures. We have exemplified a gel-based carrier fluid herein, but other base fluids could be used. See Table 1 for typical base fluids and their uses.

<table>
<thead>
<tr>
<th>Base Fluid</th>
<th>Fluid Type</th>
<th>Main Composition</th>
<th>Used For</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Linear</td>
<td>Guar, HPG, HEC, CMHPG</td>
<td>Short fractures, low temperature</td>
</tr>
<tr>
<td></td>
<td>Crosslinked</td>
<td>Crosslinked + Guar, HPG, CMHPG or CMHEC</td>
<td>Long fractures, high temperature</td>
</tr>
<tr>
<td></td>
<td>Micellar</td>
<td>Electrolite + Surfactant</td>
<td>Moderate length fractures, moderate temperature</td>
</tr>
<tr>
<td>Foam</td>
<td>Water based</td>
<td>Foamer + N₂ or CO₂</td>
<td>Low-pressure formations</td>
</tr>
<tr>
<td></td>
<td>Acid based</td>
<td>Foamer + N₂</td>
<td>Low pressure, carbonate formations</td>
</tr>
<tr>
<td></td>
<td>Alcohol based</td>
<td>Methanol + Foamer + N₂</td>
<td>Low-pressure, water-sensitive formations</td>
</tr>
</tbody>
</table>
### TABLE 1-continued

<table>
<thead>
<tr>
<th>Base Fluid</th>
<th>Fluid Type</th>
<th>Main Composition</th>
<th>Used For</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>Linear Gelling agent</td>
<td>Short fractures, water sensitive formations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Crosslinked Gelling agent + Crosslinker</td>
<td>Long fractures, water-sensitive formations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water emulsion Water + Oil + Emulsifier</td>
<td>Moderate length fractures, good fluid loss control</td>
<td></td>
</tr>
<tr>
<td>Acid</td>
<td>Linear Guar or HPG</td>
<td>Short fractures, carbonate formations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Crosslinked Crosslinker + Guar or HPG</td>
<td>Longer, wider fractures, carbonate formations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Oil emulsion Acid + Oil + Emulsifier</td>
<td>Moderate length fractures, carbonate formations</td>
<td></td>
</tr>
</tbody>
</table>

Further, for simplicity of description, only a simple proppant fluid comprising a base fluid (e.g., gel), water and proppant is described, but of course any of the usual additives can be included therein, such as anti-corrosive agents, anti-scaling agents, friction reducers, acids, salts, anti-bacterial agents, wetting agents, buffers, and the like. Typical additives are shown in Table 2. These can be added to the fluid mixed with proppant, added to the fracture slurry, added to the base fluid, or added at any other convenient point during mixing, injection or downhole, as appropriate.

### TABLE 2

<table>
<thead>
<tr>
<th>Type of Additive</th>
<th>Function Performed</th>
<th>Typical Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biocide</td>
<td>Kills bacteria</td>
<td>Glutaraldehyde carbonate</td>
</tr>
<tr>
<td>Breaker</td>
<td>Reduces fluid viscosity</td>
<td>Acid, oxidizer, enzyme breaker</td>
</tr>
<tr>
<td>Buffer</td>
<td>Controls the pH</td>
<td>Sodium bicarbonate, formic acid</td>
</tr>
<tr>
<td>Clay stabilizer</td>
<td>Prevents clay swelling</td>
<td>KCl, NaCl, KCl substitutes</td>
</tr>
<tr>
<td>Diverting agent</td>
<td>Diverts flow of fluid</td>
<td>Ball sealers, rock salt, flake boric acid</td>
</tr>
<tr>
<td>Fluid loss additive</td>
<td>Improves fluid efficiently</td>
<td>Diesel, particulates, fine sand</td>
</tr>
<tr>
<td>Friction reducer</td>
<td>Reduces the friction</td>
<td>Anionic copolymer</td>
</tr>
<tr>
<td>Iron Controller</td>
<td>Keeps iron in solution</td>
<td>Acetic and citric acid</td>
</tr>
<tr>
<td>Surfactant</td>
<td>Lowers surface tension</td>
<td>Fluorocarbon, Nonionic</td>
</tr>
<tr>
<td>Gel stabilizer</td>
<td>Reduces thermal degradation</td>
<td>MBOH, sodium thiosulfate</td>
</tr>
</tbody>
</table>

By “clean fluid” what is meant is a fluid that does not contain proppant. Typically, the clean fluid is water, preferable one that has been treated to remove excess contaminants and hydrocarbon products (if produced water).

The use of the word “a” or “an” when used in conjunction with the term “comprising” in the claims or the specification means one or more than one, unless the context dictates otherwise.

The term “about” means the stated value plus or minus the margin of error of measurement or plus or minus 10% if no method of measurement is indicated.

The use of the term “of” in the claims is used to mean “and/or” unless explicitly indicated to refer to alternatives only or if the alternatives are mutually exclusive.

The terms “comprise”, “have”, “include” and “contain” (and their variants) are open-ended linking verbs and allow the addition of other elements when used in a claim.

The phrase “consisting of” is closed, and excludes all additional elements.

The phrase “consisting essentially of” excludes additional material elements, but allows the inclusions of non-material elements that do not substantially change the nature of the invention, such as instructions for use, buffers, and the like.

The following abbreviations are used herein:

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPA</td>
<td>proppant added</td>
</tr>
<tr>
<td>HPG</td>
<td>(hydroxypropyl) guar</td>
</tr>
</tbody>
</table>

### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1: General illustration of induced hydraulic fracturing in a shale oil field.

Fig. 2: Oilfield material delivery mechanism used to introduce an oilfield material into a high-pressure fluid flow to a well bore. From US20100243255.

Fig. 3: Low-pressure direct proppant injection concept diagram according to one embodiment.
FIG. 4: Schematic of a three-stage method to continuously produce proppant slurry wherein the lines are simplified, so that only those lines in use are shown.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings that show, by way of illustration, specific embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention. It is to be understood that the various embodiments of the invention, although different, are not necessarily mutually exclusive. For example, a particular feature, structure, or characteristic described herein in connection with one embodiment may be implemented within other embodiments without departing from the spirit and scope of the invention. In addition, it is to be understood that the location or arrangement of individual elements within each disclosed embodiment may be modified without departing from the spirit and scope of the invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined only by the appended claims, appropriately interpreted, along with the full range of equivalents to which the claims are entitled. In the drawings, like numerals refer to the same or similar functionality throughout the several views.

It should also be noted that in the development of any such actual embodiment, numerous decisions specific to circumstance must be made to achieve the developer's specific goals, such as compliance with system-related or business-related constraints, which may vary from one implementation to another. Moreover, it will be appreciated that such a development effort might be complex and time-consuming but would nevertheless be a routine undertaking for those of ordinary skill in the art having the benefit of this disclosure.

This work improves the methodology and systems described in US20100243255, expressly incorporated by reference. US20100243255 described an apparatus and method for injecting a particulate (proppant) slurry into a high-pressure line downstream from the high-pressure pumping units for reservoir fracturing purposes. The method utilized a two-stage process, wherein the particulate solids are introduced into a pressure vessel isolated from the high-pressure line in the first stage, and providing a high-pressure flow into the isolated vessel in the second stage. The end result is a homogeneous flow of slurry into the high-pressure line. The operating stages can be varied to create intermittent flow of slurry or continuous flow. However, wear on the proppant blender is exacerbated by the high-pressure injection conditions.

The presently disclosed method and apparatuses improve upon US20100243255.

In particular, the proppant fluid is introduced upstream from the pumping units under low-pressure conditions. By changing the pressure conditions, a new blender system can be used, resulting in less wear. However, the wear on the pumping unit is still present.

FIG. 2, adapted from US20100243255, is a schematic illustration of one approach for dealing with overflow of fluid resulting from the introduction of proppant into the pressure vessel 203. This figure shows a cross-section of an embodiment of the oilfield material delivery subassembly during a recharging operation. In the embodiment of FIG. 2 the subassembly 285 contains a perforated pipe 251 connecting the pressure vessel 203 to the reservoir 201.

As discussed herein above, the pressure vessel 203 goes through two major operational stages, referred to herein as Stage 1: refill and Stage 2: release. In Stage 1: a low-pressure recharging phase in which oilfield material 275 is introduced into the pressure vessel 203 via gravity from the supply reservoir 201, via actuator 216 which opens (lowers) valve 217, wherein metering gate valve 207 controls the amounts delivered via valve 217.

In Stage 2: after the pressure vessel 203 has been charged with oilfield material 275, the pressure vessel 203 is, by operation of the valves on inlets and outlets thereto, transitioned into a high-pressure phase in which the contents of the pressure vessel 203 is released into the pressure vessel discharge line 229 that in turn connects to the fluid line 270 through the exit port 213 that is controlled by a check valve 215.

FIG. 2 illustrates the recharging phase. During the recharging phase, the oilfield material 275 enters the pressure vessel 203 from the supply reservoir 201 and flows to the lower portion of the pressure vessel 203 by operation of gravity and mixes with fluid 253, which is supplied from a high-pressure line 211 and controlled by a high-pressure valve 210, to form a slurry 277. This oilfield material 275 displaces some of the fluid present in the pressure vessel 203. The overflow caused by the displaced fluid exits the pressure vessel 203 through the overflow outlet 221 that is optionally controlled by valve 219. In this embodiment of subassembly 285, the overflow fluid also exits the pressure vessel 203 through the oilfield material inlet aperture 205 into the perforated pipe 251. The overflow fluid may then exit the pipe through the perforations.

Because the presently disclosed method introduces a slurry mixture under low-pressure conditions upstream from the pumping units, the blender subassembly unit described above can be replaced with a system with comparable functionality but lower wear. Furthermore, multiple tanks can be utilized to avoid disruptions of proppant flow.

FIG. 3 shows one embodiment of the system 300 described herein, wherein proppant hoppers 301, 302 and 303 are arranged over tanks 311, 312, and 313 respectively. Clean water line 320 and displacement pump 335 brings clean water to each of tanks 311, 312, and 313 via branches 321, 322, and 323. The clean water line 320 also has an optional branch (past valve 324) through dilution pump 330, thus adding diluent to high concentration proppant carrier fluid line 340 if needed.

Clean water mixes in tanks 311, 312, and 313 with proppant from hoppers 301, 302 and 303, and proppant slurry exits through a slurry line 344 via branches 341, 342 and 343 from the respective tanks to the proppant carrier fluid line 340 and from there the final fracturing fluid (labeled "final slurry") is delivered to the well, off to the right.

Overflow line 350 allows clean fluid in an upstream tank to feed into a downstream tank, thus allowing space in the upstream tank for proppant to be added thereto. Thus, branches 351, 352, and 353 allow used fluid to combine with the clean water to fill or displace a given tank.

Recycle line 360 allows for excess clean fluid to be emptied from a tank before proppant has been added and recycled as makeup water in e.g. slurry stream, fluid injection stream and the like. Thus, branches 361, 362, and 363 allow for clean fluid to be displaced from each tank and pumped into
other fluid streams. For example, the displaced fluid from Tank 1 311 flows through branch 361 and is pumped by the displacement pump 335 back to Tank 2 312 through branch 352 while the valves on branches 351, 353 are closed. Ideally, displaced fluid from a first tank will be used to form part of the clean fluid needed to displace the proppant slurry from a second tank. The partially drained first tank will then have free space available for accepting proppant without excess fluid overflow.

The tank filling and emptying operations occur sequentially, as expressed in steps described in Table 2, wherein at step 1, tank 311 is full of a proppant/water slurry, already exiting via the slurry line 341 to combine with the proppant carrier to make the final proppant fluid. At the same time, tank 312 is full of water having just been cleaned, and tank 313 is partially full of water, allowing ingress of proppant into tank 313 at this time. By utilizing the multi-tank design and sequential operations, a continuous flow of proppant is possible.

**TABLE 3**

<table>
<thead>
<tr>
<th>Beginning Status</th>
<th>Action</th>
<th>Beginning Status</th>
<th>Action</th>
<th>Beginning Status</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank 311</td>
<td></td>
<td>Tank 312</td>
<td></td>
<td>Tank 313</td>
<td></td>
</tr>
<tr>
<td>1 Full of proppant slurry</td>
<td>Displacing into line</td>
<td>Full of water</td>
<td>Pumping into Tank 311</td>
<td>40% Full of water</td>
<td>Filling with proppant</td>
</tr>
<tr>
<td>2 Full of water</td>
<td>Pumping into Tank 313</td>
<td>40% Full of water</td>
<td>Filling with proppant slurry</td>
<td>Full of water</td>
<td>Filling with proppant</td>
</tr>
<tr>
<td>3 40% Full of water</td>
<td>Filling with proppant slurry</td>
<td>Full of proppant slurry</td>
<td>Displacing into line</td>
<td>Full of water</td>
<td>Pumping into Tank 2</td>
</tr>
</tbody>
</table>

In more detail, FIG. 4 shows a schematic of the three stages that each tank 411, 412, and 413 undergo. In stage 1, the proppant slurry in the first tank 411 is displaced via branch 441 and combined with proppant slurry from other tanks in proppant slurry line 444. The proppant slurry line 444 then combines with a concentrated proppant carrier in line 440 to form the final proppant fluid for injection. The clean fluid necessary to displace the slurry and remove all proppant from the tank 411 partially comprises clean fluid from a second tank in the system and from the clean fluid source 420.

Once the proppant slurry is completely displaced from the tank 411, the tank 411 will be full of clean fluid, such as water, in Stage 2. During Stage 2 approximately 40-60% by tank volume of the clean fluid in the tank 411 will be displaced or emptied through the recycle line 461 for use in displacing the proppant slurry from a third tank. Though not shown in FIG. 4, the displaced clean fluid may also be used as makeup flow for the low-pressure proppant slurry line 444.

This removal of clean fluid frees up space within the tank 411 for accepting proppant without potential fluid overflow. Thus, in Stage 3, the proppant from the hopper 401 will be gravity drained into the tank 411 to form a proppant slurry.

Stages 1-3 are performed by for all tanks within a system simultaneously, but in a staggered fashion. As such, the number of tanks used in the system is preferably multiples of three. However, it is possible to modify the system for any number of tanks, provided there are at least 3 tanks. For instance, in a four-tank system, two tanks can undergo stage 1 while the remaining two tanks undergo stage 2 and 3.

FIG. 4 also shows the optional dilution line 430 wherein clean fluid 420 is introduced into the concentrated proppant carrier fluid line 440. This is shown for clarity only and is not a requirement in the three stage operation.

The proppant slurry is combined with the concentrated proppant carrier fluid to form a final proppant fluid, the carrier fluid serving to carry the proppant more effectively than a thin fluid could. This final proppant fluid can be introduced under low-pressure conditions into a direct injection system upstream from the pumping units. The high-pressure pump assembly is configured to deliver the fluid mixture therein to a downstream component at an injection pressure, wherein the injection pressure is greater than the fracture fluid blending pressure.

Although only a few exemplary embodiments have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the example embodiments without materially departing from this invention. Accordingly, all such modifications are intended to be included within the scope of this disclosure as defined in the following claims. In the claims, means-plus-function clauses are intended to cover the structures described herein as performing the recited function and not only structural equivalents, but also equivalent structures. Thus, although a nail and a screw may not be structural equivalents in that a nail employs a cylindrical surface to secure wooden parts together, whereas a screw employs a helical surface, in the environment of fastening wooden parts, a nail and a screw may be equivalent structures. It is the express intention of the applicant not to invoke 35 U.S.C. §112, paragraph 6 for any limitations of any of the claims herein, except for those in which the claim expressly uses the words 'means for' together with an associated function.

The following are incorporated by reference herein in their entireties for all purposes.

**[0106]** US20100243225
**[0107]** U.S. Pat. No. 7,044,220
**[0108]** U.S. Pat. No. 7,281,581
**[0109]** U.S. Pat. No. 7,325,608
**[0110]** U.S. Pat. No. 8,061,424
**[0111]** U.S. Pat. No. 6,776,235
**[0112]** US20080135242
**[0113]** US20080128131

1. An apparatus for preparing a proppant fluid for injection into a reservoir, comprising:
   a) a first vessel, a second vessel and a third vessel, wherein each vessel has a hopper containing particulates above the vessel, such that the particulates can gravity feed into the vessel;
b) a clean fluid line in fluid communication with each vessel, the clean fluid line transporting a clean fluid from a source to each vessel;
c) a concentrated proppant carrier fluid line in fluid communication with each vessel, the concentrated proppant carrier fluid line transporting a concentrated proppant carrier fluid;
d) a recycle fluid line in communication with each vessel, the recycle fluid line transporting a clean fluid from the vessel to form a make-up flow for the clean fluid line; and
e) a displaced proppant slurry line in fluid communication with each vessel, wherein the proppant slurry line feeds into the concentrated proppant carrier fluid line to form a proppant slurry for introduction into a hydrocarbon-containing reservoir.

2. The method of claim 1, further comprising a dilution line having a dilution pump that connects the clean fluid line and the concentrated proppant carrier fluid line such that the clean fluid dilute the concentrated proppant carrier fluid before the proppant carrier fluid combines with the proppant slurry line.

3. The apparatus of claim 1, further comprising a makeup fluid line connecting the recycle fluid line to the displaced proppant slurry line.

4. The apparatus of claim 1, wherein the particulates are sand.

5. The apparatus of claim 1, wherein the clean fluid is treated water.

6. The apparatus of claim 1, wherein the number of the vessels is a multiple of three.

7. A method of preparing a proppant fluid for injection into a reservoir using the apparatus in claim 1, comprising:
a) filling the first vessel with a clean fluid;
b) partially displacing the clean fluid from the first vessel, wherein the displaced clean fluid serves as a make-up flow for the clean fluid into a subsequent vessel;
c) adding particulates into the first vessel to refill the first vessel without creating fluid overflow;
d) mixing the particulates and clean fluid in the first vessel to form a proppant slurry;
e) displacing the proppant slurry and flushing the first vessel with a fluid mixture, wherein the fluid mixture comprises clean fluid and displaced clean fluid from another vessel, combining the displaced proppant slurry with the concentrated proppant carrier fluid to form the proppant fluid for injection into a reservoir;
g) repeating steps a)-f) in the second vessel and the third vessel sequentially; and
h) introducing the proppant fluid into a low pressure side of a direct proppant injection system.

8. The method of claim 7, further comprising using the clean fluid to dilute the concentrated proppant carrier fluid before combination with the displaced proppant slurry.

9. The method of claim 7, further comprising using the displaced clean fluid to dilute the displaced proppant slurry.

10. The method of claim 7, wherein the particulates are sand.

11. The method of claim 7, wherein the clean fluid is treated water.

12. A method of fracturing a reservoir, comprising:
a) injecting a first fluid into a reservoir at an injection pressure high enough to fracture the reservoir forming fractures;
b) continuously combining a proppant slurry with a proppant carrier to make a proppant fluid, wherein the proppant slurry is continuously made in at least three tanks in staggered phases such that one tank is being washed with water partially obtained from a previously washed tank, a second tank is partially full of wash water and is receiving proppant, and a third tank is dispensing proppant slurry; and
c) injecting the proppant fluid into the reservoir to prop open the fractures.

13. The method of claim 12, further comprising adding one or more additives to the proppant slurry or the proppant carrier or the proppant fluid.

14. The method of claim 13, wherein the proppant carrier is in the form of a gel, emulsion, foam, micelle, or viscoelastic surfactant.