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(54) **Title**: PROPPANT ADDITION SYSTEM AND RELATED METHODS

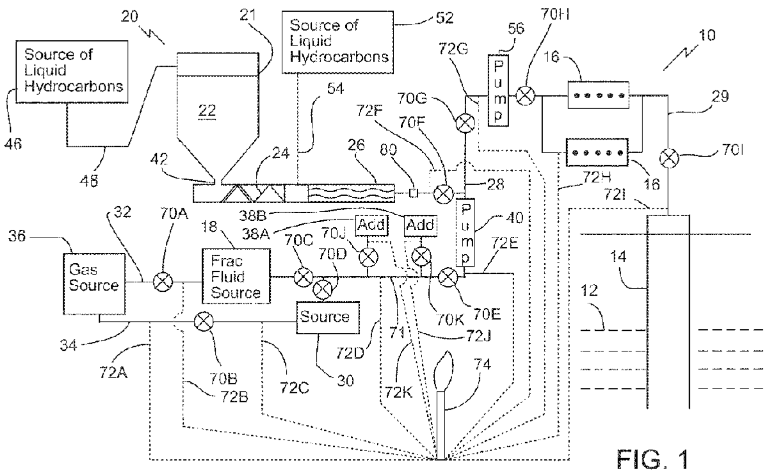

FIG. 1

(57) **Abstract**: An apparatus and related method for fracturing a formation penetrated by a well is disclosed comprising a frac pressure pump, a frac fluid source, and a proppant supply source. The frac pressure pump is connected to the well. The frac fluid source is connected to supply a stream of frac fluid to the frac pressure pump. The proppant supply source has a proppant receiver, a positive displacement pump, and at least an inlet into the proppant supply source. The at least an inlet is connected to one or more liquid hydrocarbon sources to supply liquid hydrocarbons to proppant in the proppant supply source.The positive displacement pump is connected to pump proppant into the stream of frac fluid before the frac pressure pump. Fluid lines connecting the frac pressure pump, the well, and the frac fluid source have isolation valves spaced so that the volume of fluid containable between any set of neighboring isolation valves is less than or equal to 500 L. A proppant supply source may be connected to pump proppant through a linear valve control into a stream of frac fluid.

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PROPPANT ADDITION SYSTEM AND RELATED METHODS

TECHNICAL FIELD

[001] This document relates to proppant addition systems and methods, and particularly to low or atmospheric pressure proppant addition systems and methods.

BACKGROUND

[002] In the conventional fracturing of wells, producing formations, new wells or low producing wells that have been taken out of production, a formation can be fractured to attempt to achieve higher production rates. Proppant and frac fluid are mixed in a blender and then pumped into a well that penetrates an oil or gas bearing formation. High pressure is applied to the well, the formation fractures and proppant carried by the fracturing fluid flows into the fractures. The proppant in the fractures holds the fractures open after pressure is relaxed and production is resumed. Various fluids have been disclosed for use as the fracturing fluid, including various mixtures of hydrocarbons, liquefied petroleum gas, nitrogen, and carbon dioxide.

[003] Proppant addition can be added into a pressurized stream of frac fluid, for example liquefied petroleum gas, directly by having the proppant addition tank itself contained under pressure. Proppant addition systems into LPG, such as those disclosed in WO/2007/098606, often use centrifugal pumps to dynamically seal the proppant from the volatile stream of frac fluid. However, a pressure vessel is still required, as the dynamic seal is only present whilst the centrifugal pump is in operation. Systems have been proposed to avoid the use of a pressure contained proppant tank, for example by sending a stream of proppant blended with frac oils, and a stream of liquefied petroleum gas as (LPG) to separate frac pressure pumps, after which the two streams are combined at pressure and then used to frac a well. This system requires the use and coordination of multiple sets of frac pressure pumps, which are expensive and costly to operate. The outlet pressures from the two sets of frac pressure pumps must be balanced correctly, which makes the pumping difficult to control. It also requires that the mixture of proppant be mixed with substantial amounts of low vapor

pressure frac oils, which may seriously reduce the positive effects of the LPG frac fluid, namely easy clean up and recovery from the well.

SUMMARY

[004] An apparatus for fracturing a formation penetrated by a well is disclosed comprising a frac pressure pump, a frac fluid source, and a proppant supply source. The frac pressure pump is connected to the well. The frac fluid source is connected to supply a stream of frac fluid to the frac pressure pump. The proppant supply source has a proppant receiver, a positive displacement pump, and at least an inlet into the proppant supply source. The at least an inlet is connected to one or more liquid hydrocarbon sources to supply liquid hydrocarbons to proppant in the proppant supply source. The positive displacement pump is connected to pump proppant into the stream of frac fluid before the frac pressure pump.

[005] A method is also disclosed. Proppant and liquid hydrocarbons are supplied into a proppant supply source to create a mixture of proppant and liquid hydrocarbons. The mixture of proppant and liquid hydrocarbons is pumped from the proppant supply source into a stream of frac fluid using a positive displacement pump. The stream of frac fluid containing the mixture of proppant and liquid hydrocarbons is then pumped to a frac pressure pump connected to a well.

[006] An apparatus for fracturing a formation penetrated by a well is also disclosed, the apparatus comprising a frac pressure pump, a frac fluid source, and fluid lines. The frac pressure pump is connected to the well. The frac fluid source is connected to supply a stream of frac fluid to the frac pressure pump. The fluid lines connect the frac pressure pump, the well, and the frac fluid source, the fluid lines having isolation valves spaced so that the volume of fluid containable between any set of neighboring isolation valves is less than 8900 L.

[007] An apparatus for fracturing a formation penetrated by a well is also disclosed, the apparatus comprising: a frac pressure pump connected to the well; a frac fluid source

connected to supply a stream of frac fluid comprising liquefied petroleum gas to the frac pressure pump; a pump connected to the stream of frac fluid for retaining the liquefied petroleum gas in the liquid state and for ensuring that the stream of frac fluid is provided to the the frac pressure pump at or above a required input pressure; and a proppant supply source connected to supply proppant into the stream of frac fluid before the pump.

[008] A method is also disclosed comprising: supplying proppant from a proppant supply source into a stream of frac fluid; supplying the stream of frac fluid containing proppant through a pump to retain the liquefied petroleum gas in the liquid state and to provide the stream of frac fluid containing proppant at or above a required input pressure of the frac pressure pump; and supplying the stream of frac fluid containing the proppant from the pump to a frac pressure pump connected to a well.

[009] An apparatus for fracturing a formation penetrated by a well, the apparatus comprising: a frac fluid source connected to supply a stream of frac fluid to a well; and a proppant supply source connected to pump proppant through a linear valve control into the stream of frac fluid.

[0010] These and other aspects of the device and method are set out in the claims, which are incorporated here by reference.

BRIEF DESCRIPTION OF THE FIGURES

[0011] Embodiments will now be described with reference to the figures, in which like reference characters denote like elements, by way of example, and in which:

[0012] Fig. 1 is a schematic illustrating an apparatus for fracturing a formation penetrated by a well.

[0013] Fig. 2 is a side elevation view, in section, of an embodiment of a proppant supply source that may be used in the system of Fig. 1.

[0014] Fig. 3 is a schematic illustrating a further apparatus for fracturing a formation penetrated by a well.

[0015] Fig. 4 is a flow diagram illustrating a method of supplying frac fluid to a well.

[0016] Fig. 5 is a flow diagram illlustrating a further method of supplying frac fluid to a well.

DETAILED DESCRIPTION

[0017] Immaterial modifications may be made to the embodiments described here without departing from what is covered by the claims.

[0018] Proppant may be required to be supplied into a stream of fluid, for example a stream of frac fluid. In some cases it is desirable to supply the proppant as a mixture of proppant and liquid. This wets the proppant, allowing it to be more easily transferred from the proppant supply source and into the stream of frac fluid. In cases where the proppant is being supplied into a high pressure stream of fluid such as liquefied petroleum gas, the proppant supply source may need to be under positive pressure. The liquid in the mixture of proppant and liquid can then act as a liquid seal to prevent gas breakthrough from the proppant supply source into the frac fluid. In some cases the proppant supply source must be under positive pressure when the liquid itself in the proppant has a high vapor pressure, such as when liquefied petroleum gas is added to the proppant. LPG will vaporize at atmospheric pressure creating a hazardous situation.

[0019] Referring to Fig. 1, an apparatus 10 for fracturing a formation 12 penetrated by a well 14 is illustrated. Apparatus 10 comprises a frac fluid source 18 and a proppant supply source 20. Apparatus 10 may also comprise a frac pressure pump 16 connected to the well 14.

[0020] A frac fluid source 18 is connected to supply a stream of frac fluid to the frac pressure pump 16, through line 28 for example. In some embodiments the stream of frac fluid is volatile, for example if frac fluid source 18 comprises LPG. For cost effectiveness, the LPG may be predominantly propane or butane or a propane and butane mix. The frac fluid may also contain minor amounts of pentane and higher hydrocarbons. In some embodiments, the frac fluid comprises liquefied gas, such as LPG or CO_2. Referring to Fig. 1, liquefied CO_2 may be supplied to the stream of frac fluid via source 30. In some embodiments, source 30 may supply other frac fluids, such as lower vapor pressure hydrocarbons. Gas, such as inert gas, may be supplied to each of tanks 18, 30, via lines 32, 34 from gas source 36 as needed. Inert gas may be required to maintain liquefying or drive pressure on the LPG contained in tank 18. Various additives can be introduced into the stream of frac fluid, such as gelling agents, breakers, and activators for example, via additive sources 38A-38B. Additives may be added to the stream before or after the introduction of proppant. A pump 40 may be provided in order to provide the pumping pressure required to move the stream of frac fluid through line 28.

[0021] Proppant supply source 20 is connected to supply proppant into the stream of frac fluid, and is illustrated in Fig. 1 as having a proppant receiver 21, a positive displacement pump 26, and at least an inlet into the proppant supply source 20 (shown for example as inlet 48). The at least an inlet is connected to one or more liquid hydrocarbon sources, for example source 46, to supply liquid hydrocarbons to proppant in the proppant supply source 20. Proppant supply source 20 is illustrated as containing a mixture of proppant and liquid hydrocarbons (shown as mixture 22). The liquid hydrocarbons may comprise hydrocarbons having six or more carbons. In some embodiments, the proppant receiver 21 has an auger 24 for supplying at least proppant, and preferably a mixture of proppant and liquid hydrocarbons, to pump 26. Referring to Fig. 1, the proppant receiver 21 may comprise an outlet 42 for supplying the mixture of proppant and liquid hydrocarbons to the auger 24. Referring to Fig. 2, in other embodiments the auger 24 is located at least partially inside the proppant receiver 21, for example along the base of receiver 21. This way, proppant may be easily channeled from receiver 21 to pump 26. The proppant supply source 20 may be at or below atmospheric pressure, for example if proppant supply source 20 is open to the atmosphere. In Fig. 2, the proppant receiver 21 may be an open topped 100 tonne hopper, which makes for easy addition of proppant into proppant receiver 21.

[0022] Referring to Fig. 1, the positive displacement pump 26 is connected to pump proppant, for example a mixture of proppant and liquid hydrocarbons, into the stream of frac fluid before the frac pressure pump(s) 16. In some embodiments, pump 26 is connected to pump the mixture of proppant and liquid hydrocarbons from the auger 24 into the stream of frac fluid. Positive displacement pumps cause a fluid to move by trapping a fixed amount of it and then displacing the trapped volume into a discharge zone, for example line 28. Positive displacement pumps are advantageous because they provide a pressure seal between the inlet and the outlet. Thus, a mixture of wetted proppant may be added at atmospheric pressure to a pressurized stream of frac fluid. This is advantageous over the use of a centrifugal pump in that, should the pump fail, the pressure seal is maintained. Thus, there is no requirement that the proppant supply source 20 be contained under pressure. Further, positive displacement pumps are advantageous because they are capable of providing relatively stable flow rates regardless of varying pressures in the outlet stream. Thus, a positive displacement pump allows a user more control over the amount of proppant added to the frac stream, and hence more control over the frac itself.

[0023] Pump 26 may be a progressive cavity pump. Progressive cavity pumps are used downhole as sand pumps, and are advantageous because they are capable of moving fluid containing large quantities of solids. A progressive cavity pump is also known as a progressing cavity pump, eccentric screw pump or even just a cavity pump. Names can vary from industry to industry and even regionally, including, Moyno™ pump, Mohno pump, Nemo pump, and Seepex™ pump. This type of pump transfers fluid by means of the progress, through the pump, of a sequence of cavities as its rotor is turned in relation to a stator. This leads to the volumetric flow rate being proportional to the rotation rate and to low levels of shearing being applied to the pumped fluid. Hence these pumps have application in fluid metering and pumping of viscous or shear sensitive materials. In some embodiments, positive displacement pump 26 may be another type of pump, for example a screw pump or lobe pump.

[0024] Referring to Fig. 2, apparatus 10 (shown in detail in Fig. 1) may further comprise a pressure seal between the proppant receiver 21 and the positive displacement pump 26. Referring to Fig. 2, in some embodiments the pressure seal (illustrated as pressure seal 57) may simply be created by the positive displacement pump. In other embodiments, a pressure seal 55 may be in place for example after auger 24, pressure seal 55 allowing fluids to pass into pump 26.

[0025] Referring to Fig. 1, a first inlet 48 of the at least an inlet may be connected into the proppant supply source 20 before the pressure seal. The first inlet may be at least one inlet. Referring to Figs. 1 and 2, liquid hydrocarbons can be supplied to proppant in proppant supply source 20 from a variety of locations. Referring to Fig. 1, liquid hydrocarbons are supplied into proppant receiver 21. Referring to Fig. 2, liquid hydrocarbons may be supplied through first inlets 48 and 49 into the proppant receiver 21 and auger 24, respectively. The first inlet has its liquid hydrocarbons supplied by a liquid hydrocarbon source 46 of the one or more liquid hydrocarbon sources. In some embodiments, each of first inlets 48 and 49 may have different liquid sources. The liquid hydrocarbon source 46 connected to supply the first inlet may comprise hydrocarbons having six or more carbons. Suitable liquid hydrocarbons added to the proppant supply source 20 from the one or more liquid hydrocarbon sources may include hydrocarbons having between eight and ten carbons, or for example eleven to fourteen carbons. It may be advantageous to use hydrocarbons with the least number of carbons possible that are non-volatile, for example when the frac fluid comprises LPG. Non-volatile hydrocarbons have at least one of a low vapor pressure and a high boiling point. The liquid hydrocarbons may have a vapor pressure of less than 200 mm Hg at room temperature, for example a vapor pressure of less than 15 mm Hg at room temperature. Because higher weight hydrocarbons, for example C6-C20 are harder to remove from the formation in contrast to LPG, an amount of liquid hydrocarbons sufficient to only wet the proppant may be added to minimize the liquid hydrocarbons supplied into the stream of frac fluid. Wetted may refer to only enough liquid hydrocarbon to saturate the pores of the proppant contained within vessel 20. Because sand has around 30% porosity an exemplary load of 15 tonnes (15000 kg) of sand would contain 3 m^3 of liquid hydrocarbons, or 200 L per tonne of sand. However, the low vapor pressure means that the liquid hydrocarbon and proppant mixture does not have to be contained within a pressure vessel, particularly when the hydrocarbons have seven or more carbons. For hydrocarbons having five or six carbons, addition of the hydrocarbons under sealed conditions is desirable.

[0026] Referring to Fig. 2, apparatus 10 may further comprise a second inlet 54 of the at least an inlet connected to supply liquid hydrocarbons into the proppant supply source 20 after the pressure seal, for example seals after at least one of 55 and 57. Liquid may be supplied through inlet 54 from liquid hydrocarbon source 52 of the one or more liquid hydrocarbon sources. Suitable liquids include hydrocarbons having six or more carbons, and other frac oils. Other liquids may be present as desired, for example alcohols. In some embodiments, the liquid hydrocarbon source 52 connected to supply the second inlet 54 comprises liquefied petroleum gas, including, for example, propane, butane or pentane or mixtures thereof. This way, the proppant may be wetted with liquefied petroleum gas prior to being supplied into the stream of frac fluid. In other embodiments, other high vapor pressure liquids may be added via second inlet 54. It should be understood that at least one of inlets 48, 49, and 54 may be present. The inlet 54 is illustrated as being connected directly into pump 26, although this is not required.

[0027] Referring to Fig. 1, the pressure applied by the frac pressure pump 16 may be a pressure suitable for fracturing the formation 12. An example frac pressure pump is a diesel Quintuplex™ pump with water cooled turbines, or an electrically powered Triplex(tm) piston pump, but any suitable pump may be used. As illustrated, more than one pumping device may be used as the pump 16.

[0028] Referring to Fig. 1, in some embodiments the apparatus 10 comprises a pump, such as a boost pump 56, which is connected to the stream of frac fluid for retaining liquefied petroleum gas in the liquid state and for ensuring that the stream of frac fluid is provided to the the frac pressure pump 16 at or above a required input pressure of the frac pressure pump 16. Boost pump 56 may also aid in pumping the stream of frac fluid in high ambient temperatures, for example those seen in Texas in the daytime in summer. Boost pump 56 may be positioned at any point along line 28 and provides extra pressure, for example 300 psi, in order to retain the LPG or other liquefied gas in the liquid state in the stream of frac fluid. The stream of frac fluid may then pass into a blender (not shown) where other chemicals may be added to the stream of frac fluid, and then on to the frac pressure pumps. Proppant supply source 20 may be connected to supply proppant into the stream of frac fluid before the pump 56. Pump 56 may be a centrifugal pump. In some embodiments one or more frac chemicals, such as gelling agent, may be added at the pump 56. This may be done by adding gelling agent into the eye (not shown) of pump 56 if pump 56 is a centrifugal pump.

[0029] Referring to Fig. 3, an exemplary system is illustrated where proppant supply source 20 is provided. Liquid hydrocarbons are supplied to proppant receiver 21 from liquid hydrocarbon source 46 and inlet 48. The proppant receiver 21 may be a rotary tub, and supplies a mixture of proppant and liquid hydrocarbons to positive displacement pumps 26A, 26B through line 60. At least one pump 26, in this case two, is connected to pump the mixture of proppant and liquid hydrocarbons supplied from the proppant receiver 21 into the stream of frac fluid in line 28. Line 60 feeds lines 60A, 60B into pumps 26A, 26B, respectively. A circulation pump 62 may be provided on inlet 48 to ensure that the frac fluid, for example heavy frac oils are pumped to proppant receiver 21.

Referring to Fig. 1, proppant supply source 20 may be connected to pump proppant through a linear valve control 80, for example a globe valve, into the stream of frac fluid. The proppant supply source 20 may comprise a centrifugal pump (not shown) before the linear valve control 80. In an example of such an embodiment, a centrifugal pump, API spec, mixes and then pumps slurry through the globe valve, which is set between 0 - 100% flow. This way, the centrifugal pump may be kept at head pressure all the time, while control of the flux of proppant into the frac fluid stream is controlled with the linear valve control 80. Linear valve controls allow easy and quantifiable rate control of the flow of proppant through control 80 depending on how open the control 80 is. For example, the globe valve may allow

10 m^3/min of flow when open 100%, and 5 m^3/min at 50% open. In addition, the control 80 may fail to zero when the main safety valve is operated. Rate control may otherwise be difficult with a pump such as a centrifugal pump and may only be achieved by increasing or decreasing the speed of the pump. One or more electrical or pressure transducers may be used for control of linear valve control 80.

[0030] Referring to Fig. 4, an exemplary method is illustrated. Referring to Fig. 1, in stage 100 (shown in Fig. 4), proppant and liquid hydrocarbons are supplied into a proppant supply source 20 to create a mixture of proppant and liquid hydrocarbons. The liquid hydrocarbons may comprise hydrocarbons having six or more carbons. Auger 24 may be provided to allow a thick, highly solids laden mixture to be channeled from receiver 21 to pump 26 without requiring pressurization. In stage 102 (shown in Fig. 4) the mixture of proppant and liquid hydrocarbons is pumped from the proppant supply source 20 into the stream of frac fluid in line 28 using positive displacement pump 26. In stage 104 (shown in Fig. 4) the stream of frac fluid containing the mixture of proppant and liquid hydrocarbons is supplied to frac pressure pump(s) 16 connected to well 14.

[0031] Referring to Fig. 5, a further exemplary method is illustrated. Referring to Fig. 1, in stage 106 (shown in Fig. 5), proppant is supplied from proppant supply source 20 into a stream of frac fluid located for example in line 28. In a stage 108, the stream of frac fluid containing proppant is supplied through pump 56 to retain the liquefied petroleum gas in the liquid state and to provide the stream of frac fluid containing proppant at or above a required input pressure of the frac pressure pump 16. In a stage 110 (shown in Fig. 5), the stream of frac fluid containing the proppant is supplied from the pump 56 to frac pressure pump 16 connected to well 14.

[0032] In some embodiments of the methods described herein, no breaker is added to the stream of frac fluid. Reduction of the pressure on the frac fluid in the well 14 may be sufficient to break the gel naturally or the gel may break simply by the passage of time during the frac. The methods herein may also comprise supplying gas, for example through source 30, to the stream of frac fluid upstream or downstream of the pump 56. This may be advantageous, for example when CO2 is added to the stream of frac fluid immediately before or after pump 56. The embodiments of each method may and apparatus may be used in other embodiments disclosed herein.

[0033] Table 1 below illustrates various slurry rates required to create a stream of frac fluid with specific a wellhead density. The exemplary data is constructed using sand (Regular density 2650 kg/m^3) contained as a mixture of proppant and liquid hydrocarbons having 1325 kg of sand and 500 L of liquid hydrocarbons per m^3 of mixture in proppant supply source 20. Wellhead flow rate indicates the flow rate of the frac fluid slurry pumped down the well. Wellhead density indicates the density in kg of sand per m^3 of frac fluid sent down the well. The third column refers to the amount of sand required to be added to the frac fluid, and the fourth column indicates the amount of sand required to be added to the frac fluid each minute, both in order to achieve the desired wellhead density.

[0034] Table 1: Exemplary Slurry Rates

Wellhead flow rate (m^3/min)	Wellhead Density (kg sand/m^3 of slurry)	Kg of Sand added per m^3 of frac fluid	kg of sand/ minute needed	Slurry rate leaving Proppant Tank (m^3/min)
0	0	0	0	0
3	100	96.4	289.2	0.218264151
3	200	186	558	0.421132075
3	300	269.5	808.5	0.610188679
3	400	347.5	1042.5	0.786792453
3	600	420.6	1261.8	0.952301887
3	800	614.5	1843.5	1.391320755
3	1000	726	2178	1.643773585

[0035] LPG may include a variety of petroleum and natural gases existing in a liquid state at ambient temperatures and moderate pressures. In some cases, LPG refers to a mixture of such fluids. These mixes are generally more affordable and easier to obtain than any one individual LPG, since they are hard to separate and purify individually. Unlike conventional hydrocarbon based fracturing fluids, common LPGs are tightly fractionated products resulting in a high degree of purity and very predictable performance. Exemplary LPGs used in this document include ethane, propane, butane, pentane, and various mixes thereof. Further examples include HD-5 propane, commercial butane, i-butane, i-pentane, n-pentane, and n-butane. The LPG mixture may be controlled to gain the desired hydraulic fracturing and clean-up performance.

[0036] LPGs tend to produce excellent fracturing fluids. LPG is readily available, cost effective and is easily and safely handled on surface as a liquid under moderate pressure. LPG is completely compatible with formations and formation fluids, is highly soluble in formation hydrocarbons and eliminates phase trapping - resulting in increased well production. LPG may be readily and predictably viscosified to generate a fluid capable of efficient fracture creation and excellent proppant transport. After fracturing, LPG may be recovered very rapidly, allowing savings on clean up costs.

[0037] Referring to Fig. 1, an apparatus 10 is illustrated for fracturing a formation 12 penetrated by a well 14, the apparatus 10 comprising a frac pressure pump 16, and a frac fluid source 18. Frac pressure pump 16 is connected to the well 14, and frac fluid source 18 is connected to supply a stream of frac fluid to the frac pressure pump 16. Fluid lines, for example lines 28 and 29 connecting the frac pressure pump 16, the well 14, and the frac fluid source 18 are present. The fluid lines have isolation valves, for example isolation valves 70C, 70E, 70G, 70H, and 70I spaced so that the volume of fluid containable between any set of neighboring isolation valves is less than8900 L, for example less than or equal to 1000 L, or 500 L. The volume is chosen to reduce the risk of an unconfined vapor cloud explosion, which is known to potentially occur upon escape of a minimum vapor mass of 4536 kg (~8900 L of LPG). Thus, the lower the volume the lower the risk of explosion in the event of a leak. Such an explosion may occur when a leak occurs with a large release rate of vapor (~15 kg/ s or more) and a significant delay before ignition (~greater than 30 s) (Barry, T. F., "Application of Fire and Explosion Risk Assessment to an LPG Bulk Storage Facility," Fire Hazard and Fire Risk Assessment, ASTM STP 1150, Marcelo M. Hirschler, Ed., American

Society for Testing and Materials, Philadelphia, 1992, pp. 183-206. [2] Lees, F. P., Loss Prevention in the Process Industries, Butterworths, London, 1980).The isolation valves may be remotely controlled by a controller, and activated in the event of for example a leak, an emergency, after pressure testing, or at any suitable stage during the frac procedure. Referring to Fig. 1, apparatus 10 may include other components, such as proppant supply source 20, additive source 38A-B, gas source 36, source 30, pump 40, pump 56, and any other component required. The isolation valves 70A-K compartmentalize the apparatus 10 to define segments of the system that can contain the maximum amount of fluid. For example, valves 70C, 70D, 70J, 70K, and 70E define a segment 71 of line 28 that can be isolated. The isolation valves may be spaced so that each of the frac pressure pump 16, the well 12, the frac fluid source 18, and any other component of the system if desired, may be independently isolated from one another. Vents 72A-K may be spaced in between each set of neighboring isolation valves, in order to provide an outlet for venting the fluid contained in between the isolation valves should a particular segment of the system be isolated. As illustrated, the vents may be connected to vent any fluid present, for example to a flare 74, isolation vessel (not shown), or sales line (not shown). At least some of the vents may be connected to a manifold (not shown) prior to flaring. In some embodiments, a pop tank (not shown) is provided prior to the flare stack 74.

[0038] This system provides added safety to frac apparatus 10, especially when the frac fluid source comprises liquefied petroleum gas, since the entire system can be isolated into small segments should one or more components in the system fail. Thus, if for example a leak is detected, the isolation valves may be activated in order to reduce the total amount of frac fluid leaked to the environment to the volume contained in the segment where the leak occured. Also, should a leak occur in one or more segment and catch fire, the amount of frac fluid available as fuel to the fire can also be reduced by isolating the one or more segments. After a segment is isolated it may be safely vented, in order to clear away any hazardous fluid contained within the fluid lines.

[0039] In some embodiments, a source of fluid, for example source 30, is connected to the stream of frac fluid, the fluid having a lower flash point than liquefied petroleum gas. Examples of such fluid include one or more of inert gas, CO2, methanol, and water. Source 30 may be used for purging system components with fluid having a lower flash point than liquefied petroleum gas. Purging may be carried out before and after a frac, in order to clear the lines and components of frac fluid. Fluid in the lines may be purged to a waste tank, or in the case of some gases through flare stack 74.

[0040] It should be understood that the figures illustrated exemplary systems, and various valving, tubing, connections, and other devices may be necessary in order to properly operate the system.

[0041] In some embodiments proppant supply source 20 may use a centrifugal pump to pump proppant supplied to the centrifugal pump from a screw pump (not shown). Proppant, for example dry sand, may be added to the eye of the centrifugal pump.

[0042] In the claims, the word “comprising” is used in its inclusive sense and does not exclude other elements being present. The indefinite article “a” before a claim feature does not exclude more than one of the feature being present. Each one of the individual features described here may be used in one or more embodiments and is not, by virtue only of being described here, to be construed as essential to all embodiments as defined by the claims.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. An apparatus for fracturing a formation penetrated by a well, the apparatus comprising:

a frac pressure pump connected to the well;

a frac fluid source connected to supply a stream of frac fluid to the frac pressure pump;

a proppant supply source having a proppant receiver, a positive displacement pump, and at least an inlet into the proppant supply source, the at least an inlet being connected to one or more liquid hydrocarbon sources to supply liquid hydrocarbons to proppant in the proppant supply source, the positive displacement pump being connected to pump proppant into the stream of frac fluid before the frac pressure pump.

2. The apparatus of claim 1 in which the stream of frac fluid comprises liquefied petroleum gas.

3. The apparatus of claim 1 - 2 in which the proppant supply source is at atmospheric pressure.

4. The apparatus of claim 1 - 3 in which the positive displacement pump is a progressive cavity pump.

5. The apparatus of any one of claim 1 - 4 in which the proppant receiver has an auger for supplying at least proppant to the positive displacement pump.

6. The apparatus of any one of claim 1 - 5 further comprising a pressure seal between the proppant receiver and the positive displacement pump.

7. The apparatus of claim 6 in which a first inlet of the at least an inlet is connected into the proppant supply source before the pressure seal.

8. The apparatus of claim 7 in which a liquid hydrocarbon source connected to supply the first inlet comprises hydrocarbons having six or more carbons.

9. The apparatus of any one of claim 6 - 8 in which a second inlet of the at least an inlet is connected into the proppant supply source after the pressure seal.

10. The apparatus of claim 9 in which a liquid hydrocarbon source connected to supply the second inlet comprises liquefied petroleum gas.

11. The apparatus of claim 1 - 10 in which the one or more liquid hydrocarbon sources comprise hydrocarbons having between eight and ten carbons.

12. The apparatus of claim 1 - 11 in which the one or more liquid hydrocarbon sources comprise hydrocarbons having a vapor pressure of less than 200 mm Hg.

13. A method comprising:

supplying proppant and liquid hydrocarbons into a proppant supply source to create a mixture of proppant and liquid hydrocarbons;

pumping the mixture of proppant and liquid hydrocarbons from the proppant supply source into a stream of frac fluid using a positive displacement pump; and

supplying the stream of frac fluid containing the mixture of proppant and liquid hydrocarbons to a frac pressure pump connected to a well.

14. The method of claim 13 in which the proppant supply source has an auger for supplying at least proppant from a proppant receiver of the proppant supply source to the positive displacement pump.

15. The method of claim 14 in which the stream of frac fluid comprises liquefied petroleum gas.

16. The method of any one of claim 13 - 15 in which the proppant supply source is at atmospheric pressure.

17. The method of any one of claim 13 - 16 in which the positive displacement pump is a progressive cavity pump.

18. The method of any one of claim 13 - 17 in which the liquid hydrocarbons comprise hydrocarbons having between eight and ten carbons.

19. An apparatus for fracturing a formation penetrated by a well, the apparatus comprising:

a frac pressure pump connected to the well;

a frac fluid source connected to supply a stream of frac fluid to the frac pressure pump;

fluid lines connecting the frac pressure pump, the well, and the frac fluid source, the fluid lines having isolation valves spaced so that the volume of fluid containable between any set of neighboring isolation valves is less than 8900 L.

20. The apparatus of claim 19, in which the isolation valves are spaced so that each of the frac pressure pump, the well, and the frac fluid source may be independently isolated from one another.

21. The apparatus of any one of claim 19 - 20 further comprising vents spaced in between each set of neighboring isolation valves.

22. The apparatus of claim 21 in which the vents are connected to vent fluid to a flare.

23. The apparatus of any one of claim 19 - 22 in which the frac fluid source comprises liquefied petroleum gas.

24. The apparatus of any one of claim 19 - 23 in which the volume of fluid containable between any set of neighboring isolation valves is less than 1000 L.

25. The apparatus of claim 24 in which the volume of fluid containable between any set of neighboring isolation valves is less than 500 L.

26. An apparatus for fracturing a formation penetrated by a well, the apparatus comprising:

a frac pressure pump connected to the well;

a frac fluid source connected to supply a stream of frac fluid comprising liquefied petroleum gas to the frac pressure pump;

a pump connected to the stream of frac fluid for retaining the liquefied petroleum gas in the liquid state and for ensuring that the stream of frac fluid is provided to the the frac pressure pump at or above a required input pressure; and

a proppant supply source connected to supply proppant into the stream of frac fluid before the pump.

27. The apparatus of claim 26 in which the proppant supply source comprises a proppant receiver, a positive displacement pump, and at least an inlet into the proppant supply source, the at least an inlet being connected to one or more liquid hydrocarbon sources to supply liquid hydrocarbons to proppant in the proppant supply source, the positive displacement pump being connected to pump proppant into the stream of frac fluid before the pump.

28. The apparatus of any one of claim 26-27 further comprising a source of fluid connected to the stream of frac fluid, the fluid having a lower flash point than liquefied petroleum gas.

29. The apparatus of claim 28 in which the fluid comprises one or more of inert gas, CO_2, methanol, and water.

30. The apparatus of any one of claim 26 - 29 in which a gelling agent is added at the pump.

31. The apparatus of any one of claim 26 - 30 in which the pump is a centrifugal pump.

32. A method comprising:

supplying proppant from a proppant supply source into a stream of frac fluid;

supplying the stream of frac fluid containing proppant through a pump to retain the liquefied petroleum gas in the liquid state and to provide the stream of frac fluid containing proppant at or above a required input pressure of the frac pressure pump; and

supplying the stream of frac fluid containing the proppant from the pump to a frac pressure pump connected to a well.

33. The method of claim 32 further comprising adding a gelling agent at the pump.

34. The method of any one of claim 32 - 33 in which no breaker is added to the stream of frac fluid.

35. The method of any one of claim 32 - 34 further comprising purging system components with fluid having a lower flash point than liquefied petroleum gas.

36. The method of claim 35 in which the fluid comprises one or more of inert gas, CO_2, methanol, and water.

37. The method of any one of claim 32 - 36 further comprising supplying gas to the stream of frac fluid upstream or downstream of the pump.

38. An apparatus for fracturing a formation penetrated by a well, the apparatus comprising:

a frac fluid source connected to supply a stream of frac fluid to a well; and

a proppant supply source connected to pump proppant through a linear valve control into the stream of frac fluid.

39. The apparatus of claim 38 in which the linear flow valve control comprises a globe valve.

40 The apparatus of any one of claim 38 - 39 in which the proppant supply source comprises a centrifugal pump before the linear valve control.

AMENDED CLAIMS
received by the International Bureau on 11 May 2010

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. An apparatus for fracturing a formation penetrated by a well, the apparatus comprising:
a frac pressure pump connected to the well;
a frac fluid source connected to supply a stream of frac fluid to the frac pressure pump;
a proppant supply source having a proppant receiver, a positive displacement pump, and at least an inlet into the proppant supply source, the at least an inlet being connected to one or more liquid sources to supply liquid to proppant in the proppant supply source, the positive displacement pump being connected to pump proppant into the stream of frac fluid before the frac pressure pump.

2. The apparatus of claim 1 in which the liquid is a hydrocarbon.

3. The apparatus of claim 2 in which the liquid comprises liquefied petroleum gas.

4. The apparatus of any one of claim 1 - 3 in which the stream of frac fluid comprises liquefied petroleum gas.

5. The apparatus of claim 1 - 4 in which the proppant supply source is at atmospheric pressure.

6. The apparatus of claim 1 - 5 in which the positive displacement pump is a progressive cavity pump.

7. The apparatus of any one of claim 1 - 6 in which the proppant receiver has an auger for supplying at least proppant to the positive displacement pump.

8. The apparatus of any one of claim 1 - 7 further comprising a pressure seal between the proppant receiver and the positive displacement pump.

AMENDED SHEET (ARTICLE 19)

9. The apparatus of claim 8 in which a first inlet of the at least an inlet is connected into the proppant supply source before the pressure seal.

10. The apparatus of claim 9 in which a liquid source of the one or more liquid sources connected to supply the first inlet comprises liquid hydrocarbons having six or more carbons.

11. The apparatus of any one of claim 8 - 10 in which a second inlet of the at least an inlet is connected into the proppant supply source after the pressure seal.

12. The apparatus of claim 11 in which a liquid source of the one or more liquid sources connected to supply the second inlet comprises liquefied petroleum gas.

13. The apparatus of claim 1 - 12 in which the one or more liquid sources comprise hydrocarbons having between eight and ten carbons.

14. The apparatus of claim 1 - 13 in which the one or more liquid sources comprise butane.

15. The apparatus of any one of claim 1-14 further comprising a source of fluid connected to the stream of frac fluid, the fluid having a lower flash point than liquefied petroleum gas.

16. The apparatus of claim 15 in which the fluid comprises one or more of inert gas, CO2, methanol, and water.

17. A method comprising:

supplying proppant and a liquid into a proppant supply source to create a mixture of proppant and liquid;

pumping the mixture of proppant and liquid from the proppant supply source into a stream of frac fluid using a positive displacement pump; and supplying the stream of frac fluid containing the mixture of proppant and liquid to a frac pressure pump connected to a well.

18. The method of claim 17 in which the liquid is a hydrocarbon.

19. The method of claim 18 in which the liquid comprises liquefied petroleum gas.

20. The method of any one of claim 17-19 in which the proppant supply source has an auger for supplying at least proppant from a proppant receiver of the proppant supply source to the positive displacement pump.

21. The method of any one of claim 17-20 in which the stream of frac fluid comprises liquefied petroleum gas.

22. The method of any one of claim 17 - 21 in which the proppant supply source is at atmospheric pressure.

23. The method of any one of claim 17 - 22 in which the positive displacement pump is a progressive cavity pump.

24. The method of any one of claim 17 - 23 in which the liquid comprises hydrocarbons having between eight and ten carbons.

25. The method of any one of claim 17 - 24 further comprising purging system components with fluid having a lower flash point than liquefied petroleum gas.

26. The method of claim 25 in which the fluid comprises one or more of inert gas, CO2, methanol, and water.

27. The method of any one of claim 17 - 26 further comprising supplying gas to the stream of frac fluid.

28. An apparatus for fracturing a formation penetrated by a well, the apparatus comprising:

a frac fluid source connected to supply a stream of frac fluid to a well; and

a proppant supply source connected to pump proppant through a linear valve control into the stream of frac fluid.

29. The apparatus of claim 28 in which the linear flow valve control comprises a globe valve.

30 The apparatus of any one of claim 28 - 29 in which the proppant supply source comprises a centrifugal pump before the linear valve control.

31. An apparatus for fracturing a formation penetrated by a well, the apparatus comprising:

a frac pressure pump connected to the well;

a frac fluid source connected to supply a stream of frac fluid to the frac pressure pump;

a proppant supply source having a proppant receiver, a positive displacement pump, and at least an inlet into the proppant supply source, the at least an inlet being connected to one or more liquid hydrocarbon sources to supply liquid hydrocarbons to proppant in the proppant supply source, the positive displacement pump being connected to pump proppant into the stream of frac fluid before the frac pressure pump.

32. A method comprising:

supplying proppant and liquid hydrocarbons into a proppant supply source to create a mixture of proppant and liquid hydrocarbons;

pumping the mixture of proppant and liquid hydrocarbons from the proppant supply source into a stream of frac fluid using a positive displacement pump; and

supplying the stream of frac fluid containing the mixture of proppant and liquid hydrocarbons to a frac pressure pump connected to a well.

33. The apparatus of claim 31 together with the limitations of any one of claims 2-16, in which liquid hydrocarbons comprise liquid.

STATEMENT UNDER ARTICLE 19 (1)

STATEMENT UNDER ARTICLE 19(1) EXPLAINING THE AMENDMENTS AND INDICATING ANY IMPACT THAT SUCH AMENDMENTS MIGHT HAVE ON THE DESCRIPTION AND THE DRAWINGS

International Bureau of WIPO
34, chemin des Colombettes
P.O. Box 18, 1211 Geneva 20
Switzerland

Ref: 482-4PCT
Application No.: PCT/CA2009/001871
Title: PROPPANT ADDITION SYSTEM AND RELATED METHODS
Applicant: GASFRAC ENERGY SERVICES INC. et al.

The claims are amended as follows:

New claim no.	Corresponding original claim no.	Remarks
1	1	Amended
2-3	N/A	New
4	2	Amended
5-9	3-7	Unchanged
10	8	Amended
11	9	Unchanged
12-14	10-12	Amended
15-16	28-29	Amended
17	13	Amended
18-19	N/A	New
20-21	14-15	Amended
22-23	16-17	Unchanged
24	18	Amended
25-27	35-37	Amended
	19-27, 30-34	Cancelled
28-30	38-40	Unchanged
31	1	Unchanged

32	13	Unchanged
33	N/A	New

REMARKS

New claims 1 and 13 have been amended to amend "liquid hydrocarbon" to "liquid", as supported by paragraph 18 of the description as filed. Corresponding changes have been made to new claims 10, 12-14, and 24 by necessity. New claims 2-3 and 18-19 are added to clarify the nature of the liquid. New claims 31 and 32 are added to retain the same wording of original claims 1 and 13, respectively. New claim 33 is added to claim the limitations of any of new claims 2-16. New claims 4, and 20-21 are made multiply dependent. The antecedent language in new claims 10 and 12 is clarified. New claim 14 is amended to claim butane. Although original claims 19-37 are cancelled, new claims 15-16 incorporate limitations from cancelled original claims 28-29, and new claims 25-27 incorporate limitations from cancelled original claims 35-27.

The amendments do not go beyond the disclosure as filed.

Respectfully submitted

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Ph. 780-448-0606
Fax 780-433-5719

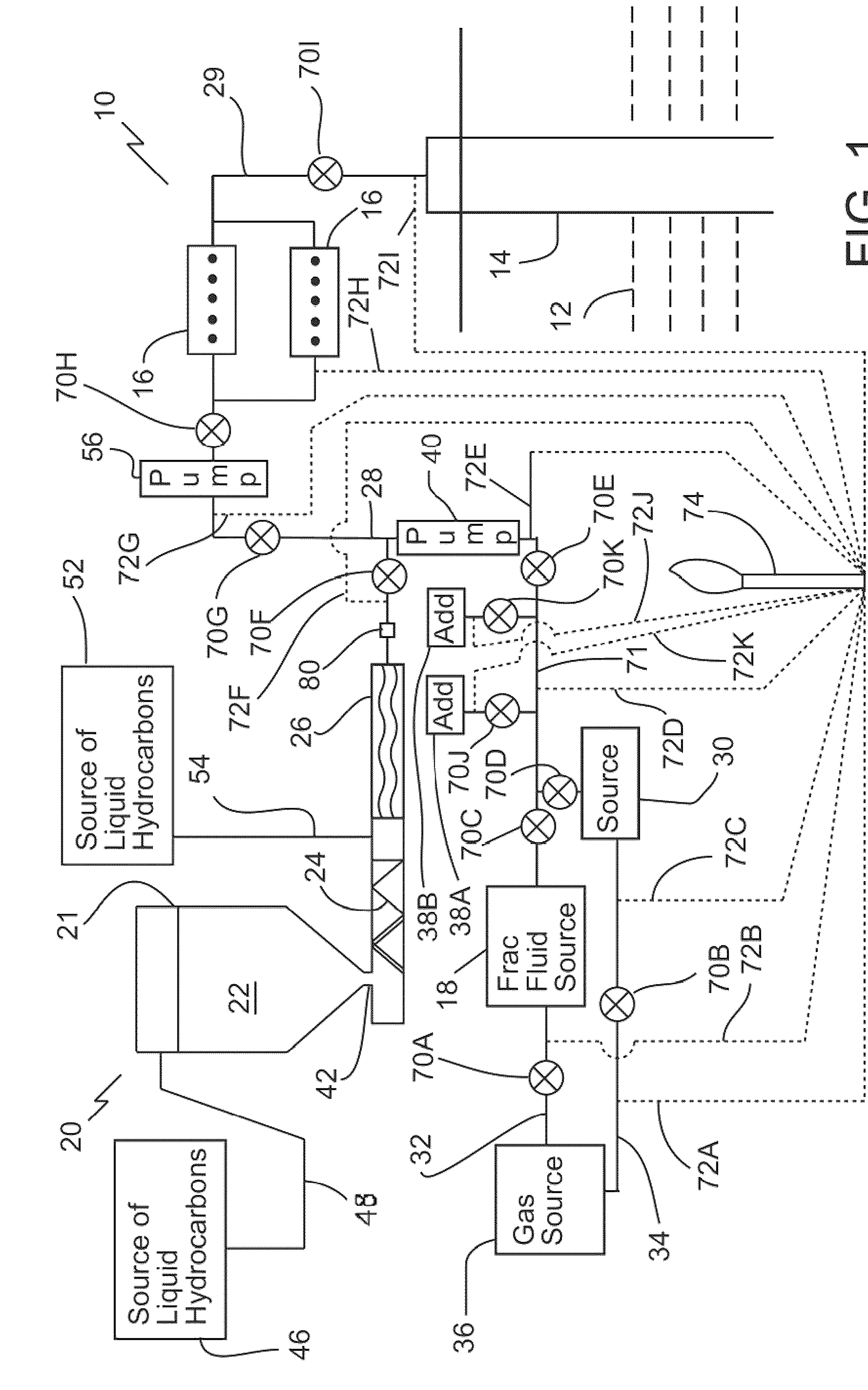
10
29
70I
16
16
14
12
72I
72H
70H
56
Pump
40
Pump
72E
70E
72J
74
28
72G
70G
70F
72F
80
70K
72K
71
Add
Add
38B
38A
70J
70D
70C
72D
30
Source
52
Source of Liquid Hydrocarbons
54
26
24
21
22
18
Frac Fluid Source
72C
70B
72B
42
70A
20
32
Gas Source
34
72A
36
48
Source of Liquid Hydrocarbons
46

FIG. 1

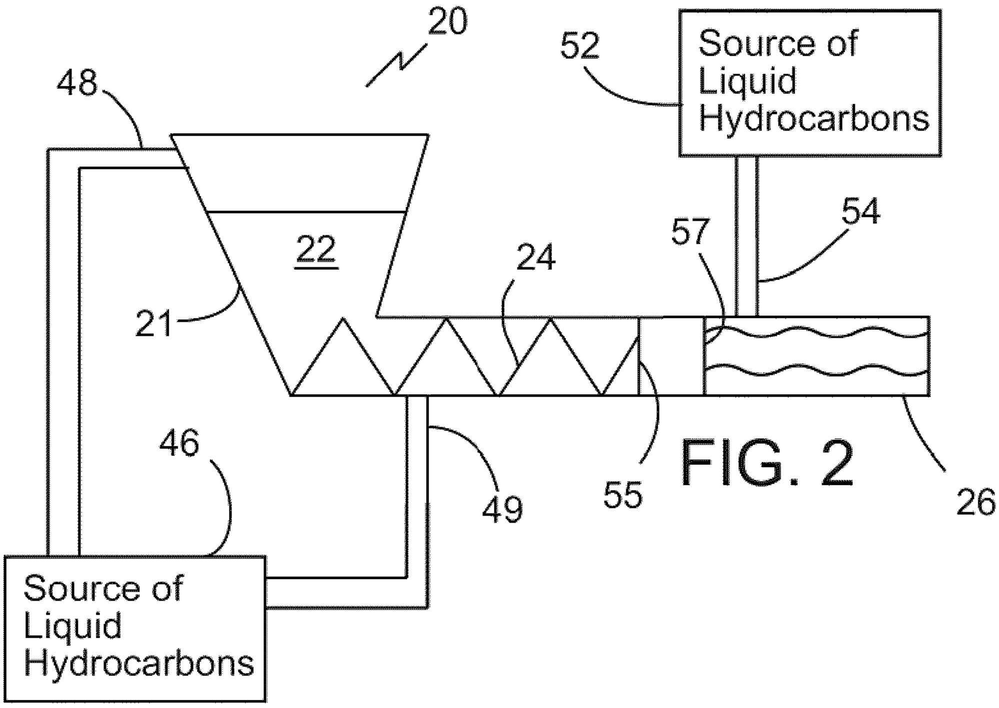
20
52
Source of Liquid Hydrocarbons
48
54
57
22
24
21
46
49
55
26
Source of Liquid Hydrocarbons

FIG. 2

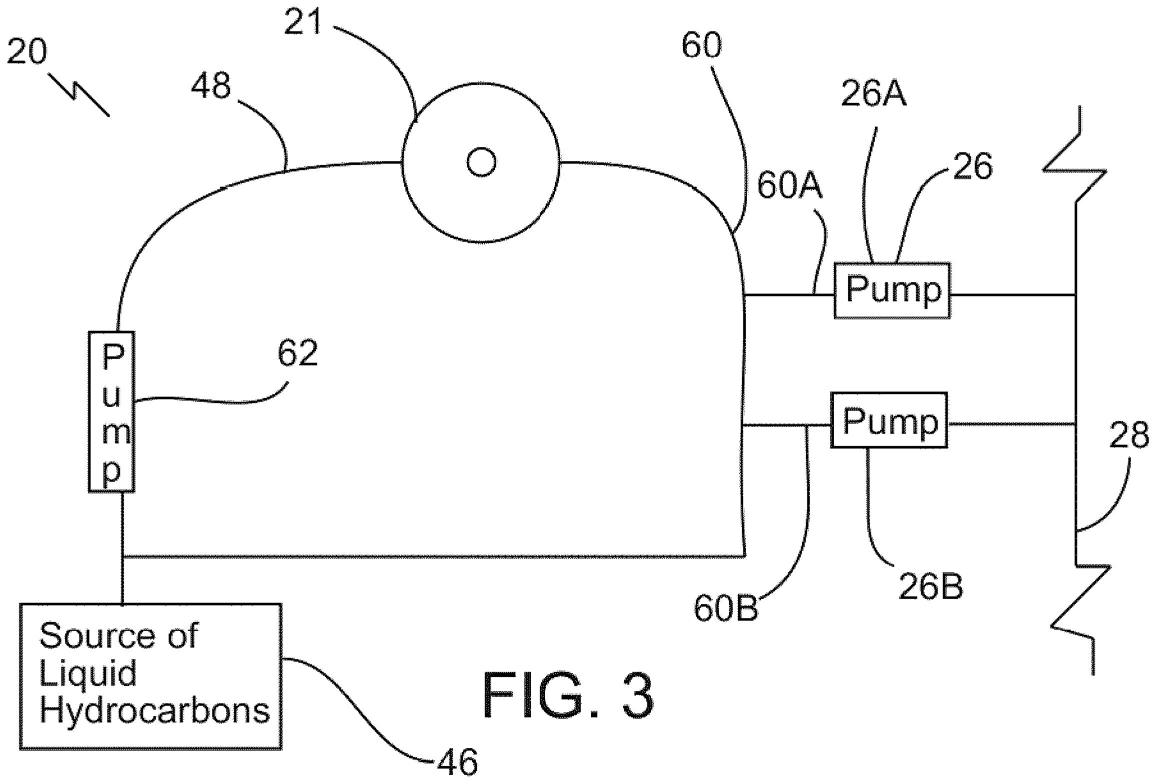
21
20
60
48
26A
26
60A
Pump
62
Pump
28
60B
26B
Source of Liquid Hydrocarbons
46

FIG. 3

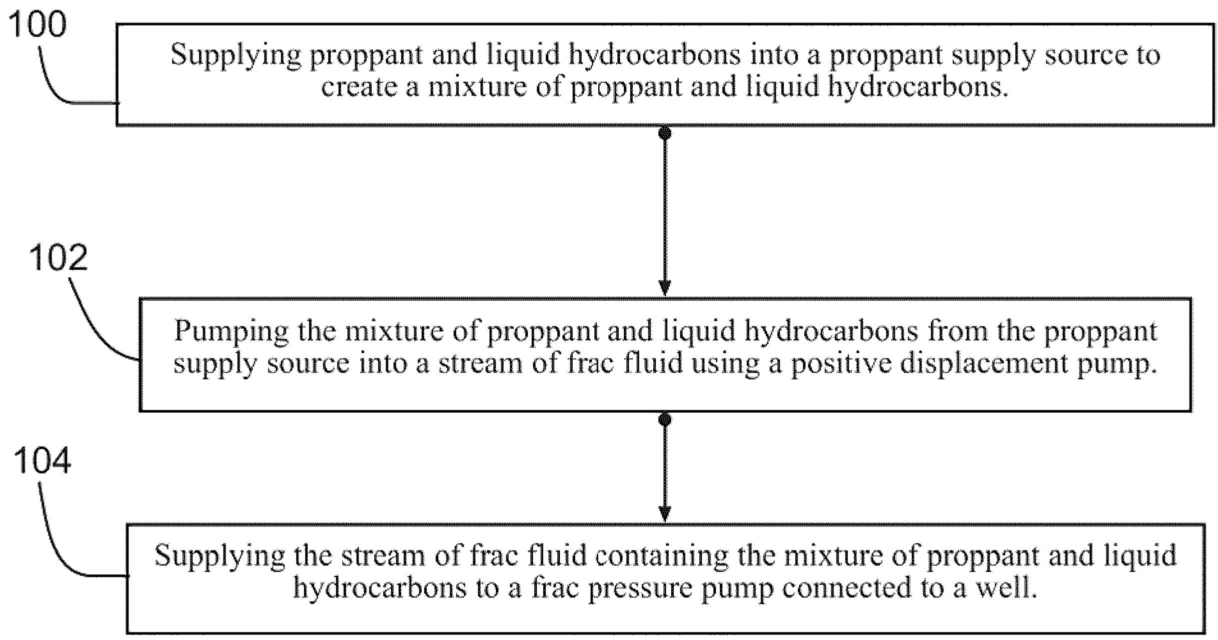
100
Supplying proppant and liquid hydrocarbons into a proppant supply source to create a mixture of proppant and liquid hydrocarbons.
102
Pumping the mixture of proppant and liquid hydrocarbons from the proppant supply source into a stream of frac fluid using a positive displacement pump.
104
Supplying the stream of frac fluid containing the mixture of proppant and liquid hydrocarbons to a frac pressure pump connected to a well.

FIG. 4

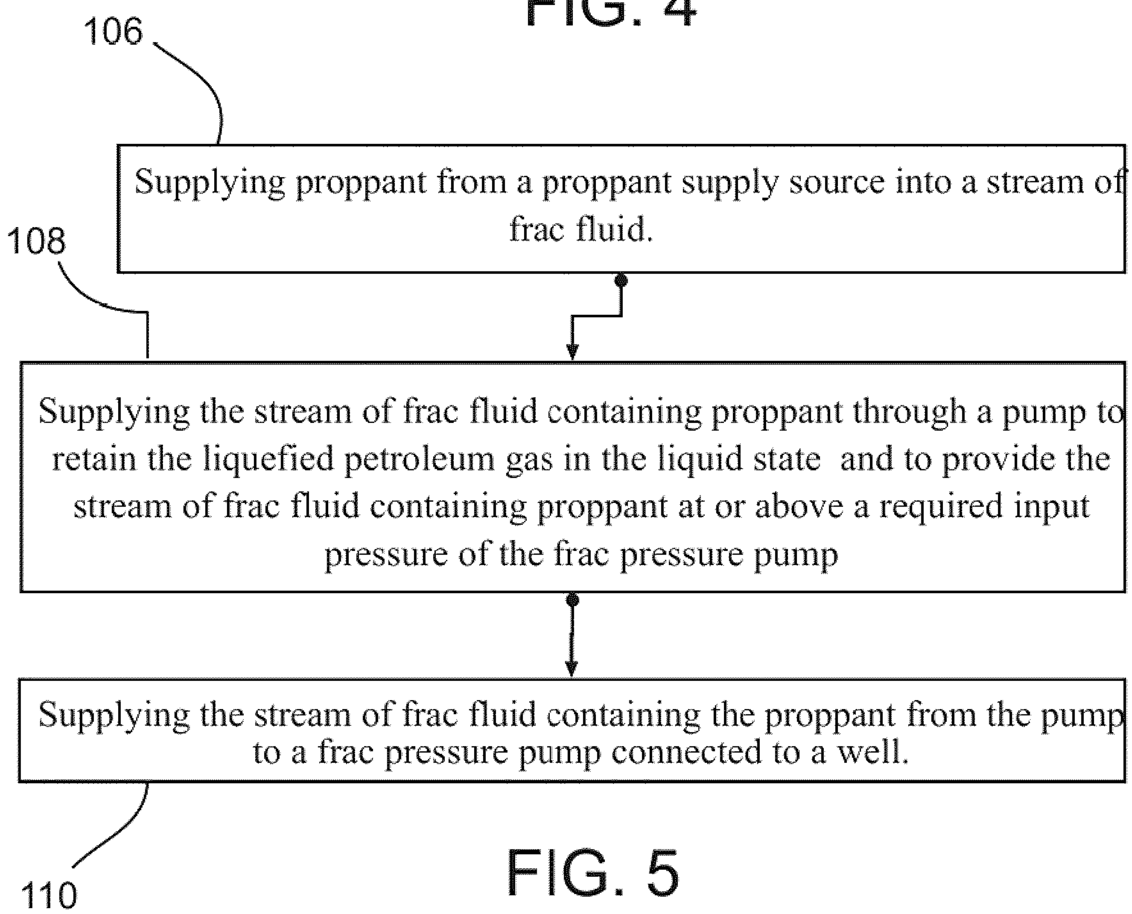
106
Supplying proppant from a proppant supply source into a stream of frac fluid.
108
Supplying the stream of frac fluid containing proppant through a pump to retain the liquefied petroleum gas in the liquid state and to provide the stream of frac fluid containing proppant at or above a required input pressure of the frac pressure pump
Supplying the stream of frac fluid containing the proppant from the pump to a frac pressure pump connected to a well.
110

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2009/001871

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***E21B 43/267*** (2006.01) , ***E21B 33/068*** (2006.01)
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: ***E21B 43/267*** (2006.01) , ***E21B 33/068*** (2006.01)

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

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Epoque (Epodoc); keywords: frac, fracturing, proppant, sand, volume, pump, valve, pressure, line, pipe (variants thereof, singly or in combination, with or without class).

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 20050006089 A1 (JUSTUS, D.M., et al.) 13 January 2005 (13-01-2005) [whole document]	26, 28, 29, 30, 31; 32, 33, 34, 35, 36, 37, 38, & 39
Y	[whole document]	19, 20, 23, 24, & 25
A	US 20060065400 A1 (SMITH, D.R.) 30 March 2006 (30-03-2006)	1 to 40
A	WO 2007098606 A1 (LOREE, D.N., et al.) 7 September 2007 (07-09-2005)	1 to 40
A	US 5899272 A (LOREE, D.N.) 4 May 1999 (04-05-1999)	1 to 40
A	US 4665982 A (BROWN, B.R.) 19 May 1987 (19-05-1987)	1 to 40
A	US 2888988 A (CLARK, W.H.) 2 June 1959 (02-06-1959)	1 to 40

[ ] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents :
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search
4 March 2010 (04-03-2010)

Date of mailing of the international search report
11 March 2010 (11-03-2010)

Name and mailing address of the ISA/CA
Canadian Intellectual Property Office
Place du Portage I, C114 - 1st Floor, Box PCT
50 Victoria Street
Gatineau, Quebec K1A 0C9
Facsimile No.: 001-819-953-2476

Authorized officer
Edward Dabrowski (819) 953-1378

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of the first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons :

1. [ ] Claim Nos. :
   because they relate to subject matter not required to be searched by this Authority, namely :

2. [ ] Claim Nos. :
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically :

3. [ ] Claim Nos. :
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows :

Group A: 1 to 18, and 26 to 38, relate to frac proppant and fluid supply and pump positioning.

Group B: 19 to 25, relate to the importance of valve positioning within a frac fluid and pump system.

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [X] As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claim Nos. :

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim Nos. :

Remark on Protest [ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2009/001871

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
US2005006089A1	13-01-2005	US2005006089A1 US7090017B2	13-01-2005 15-08-2006
US2006065400A1	30-03-2006	CA2499699A1 US2006065400A1	30-03-2006 30-03-2006
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