



(51) International Patent Classification:

C09K 8/62 (2006.01) *B62B 1/18* (2006.01)
E21B 43/26 (2006.01) *E21B 36/00* (2006.01)
E21B 43/267 (2006.01)

(21) International Application Number:

PCT/US2013/075583

(22) International Filing Date:

17 December 2013 (17.12.2013)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

13/724,907 21 December 2012 (21.12.2012) US

(71) Applicant: PRAXAIR TECHNOLOGY, INC. [US/US];
39 Old Ridgebury Road, Danbury, CT 06810 (US).(72) Inventors: KELLY, Richard, M.; 4161 Tonawanda Creek
Road, East Amherst, NY 14051 (US). DEGENSTEIN,
Nick, Joseph; 58 Sausalito Drive, East Amherst, NY
14051 (US). NEU, Bernard, Thomas; 10 Fernott Drive,
Lancaster, NY 14386 (US).(74) Agents: SCHWARTZ, Iurie A. et al.; Praxair, Inc., 39
Old Ridgebury Road, Danbury, CT 06810 (US).(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,
BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM,
DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,

HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR,
KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME,
MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,
OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,
SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM,
TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM,
ZW.

(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ,
UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,
TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK,
EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,
MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

Published:

- with international search report (Art. 21(3))
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

(54) Title: SYSTEM AND APPARATUS FOR CREATING A LIQUID CARBON DIOXIDE FRACTURING FLUID

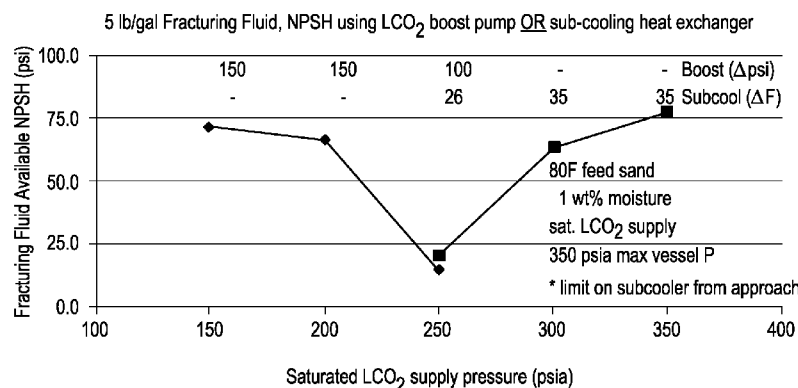


FIG. 1

(57) Abstract: A method, system, and apparatus required for creating a mixture of dry proppant and liquid carbon dioxide (LCO₂) for fracturing oil and gas formations is presented. The operation includes making a mixture of dry proppant and liquid carbon dioxide (LCO₂) for use in a fracturing operation by supplying dry proppant that is pressurized to between 75 and 600 psia with a gas; further supplying a stream of sub-cooled LCO₂ having a pressure substantially equal to that of the pressurized dry proppant; and adding dry, pressurized proppant to the stream of sub-cooled LCO₂, thereby forming a mixed LCO₂ and proppant fracturing slurry.

System and Apparatus for Creating a Liquid Carbon Dioxide Fracturing Fluid

Field of Invention

[0001] The present disclosure comprises a system and apparatus for forming a proppant and carbon dioxide fracturing fluid that can be delivered in a semi-continuous or continuous manner for the fracture treatment of oil and gas reservoirs.

Background of the Invention

[0002] The use of carbon dioxide for enhanced production of oil and gas from reservoirs is well known. Usage of liquid carbon dioxide (LCO₂) in fracture treatment of oil and gas formations has certain advantages in water sensitive and low pressure formations including a significant reduction of water volume and promotion of water flowback, (retrieval of water/fluid used in fracture treatment) which minimizes formation damage caused by water. LCO₂ used in fracturing treatments is typically added to a high pressure stream of water and proppant (typically sand) at the well-head. Combining water with proppant and adding a separate pressurized LCO₂ stream is the most conventional method of forming a CO₂-energized fracture fluid. This is due, in large part, because it is simpler to mix proppant with water at atmospheric pressure, than it is to add proppant to liquid carbon dioxide at a pressure above the triple point of carbon dioxide, (i.e., greater than 75.1 psia).

[0003] Equipment is available and can be used for small fracture treatments to deliver about 100 percent LCO₂ and essentially dry proppant. In this case, “small” fracture treatments are considered to be those up to about 20 tons of proppant on a per batch basis. This equipment is designed for the delivery of a dry proppant and LCO₂ combination and typically delivers the mixture from a relatively small pressurized batch tank. Additional quantities of LCO₂ are added to dilute the proppant concentration of the fracturing slurry stored in the tank to

the appropriate level required for fracture treatment. Once the small batch of LCO₂ and proppant is exhausted, the fracture treatment must either be completed or stopped because it is not possible to quickly empty and refill these existing relatively “small” batch vessels.

[0004] Therefore, a need has been established to develop a portable LCO₂ and proppant blender system that possesses higher proppant capacity for much larger fracture treatments. One example includes the need for supplying this type of proppant for fracturing long-reach, multi-stage, horizontally drilled formations. Because millions of pounds of proppant may be required for large fracture treatments, a single blender, or multiple blenders must be capable of delivering proppant and LCO₂ in a continuous or semi-continuous manner. There also exists a continuing need for an efficient, portable LCO₂ and proppant blender that can be used for small fracture treatments.

[0005] Earlier efforts, for example, as described in U.S. Pat. Number 4,374,545, provides for a simple batch process where proppant is cooled to LCO₂ temperatures by direct contact with LCO₂ yielding a batch tank of proppant and LCO₂ fracturing slurry. As the proppant slurry is delivered from this batch tank, LCO₂ is added to maintain a relatively high LCO₂ level in the tank. Using this slurry batch approach to achieve a much larger continuous or semi-continuous injection method is problematic, both because of the long delay and wasted carbon dioxide when the slurry vessel must be “blown down” (i.e., depressurized) to add more proppant. Other systems utilizing LPG (liquefied petroleum gas - such as described in U.S. Patent Numbers 4,407,825 and 7,735,551) blend dry proppant with flowing LPG at close to ambient temperature. LPG is higher boiling and it is not necessary to precool the proppant and there is no possibility of vaporizing the LPG fluid as dry proppant is added to it.

[0006] In order to achieve the established need for a semi-continuous or continuous fracturing operation using a mixture of LCO₂ and dry proppant, the system requires subcooling LCO₂ (using booster pumping and/or using a subcooling heat exchanger(s) and/or pressurizing the headspace in the supply LCO₂ tanks). The subcooling must be managed in such a way so that warm dry

proppant can be added to the flowing LCO₂ stream without vaporizing a portion of the LCO₂ and so that the slurry fracture fluid is available with the appropriate level of net positive suction head (NPSH) required for safe and reliable operation of the high pressure frac pumps. A method for metering dry proppant is also required which is provided by the use of an auger, control valve, eductor, or some other appropriate method of metering proppant. The present invention described below addresses the design of the system, and associated equipment that meets this need.

Summary of the Invention

[0007] The present invention describes a system, and apparatus for mixing LCO₂ and dry proppant to provide a fracturing slurry in an uninterrupted continuous, semi-continuous process, for fracturing treatment of oil and gas formations. More specifically, the use of a novel design including the following steps is provided: a system for loading dry proppant into at least one dry proppant storage vessel with one or more conveying means; pressurizing the proppant storage vessel(s) to between 75 and 600 psia with a gas, thereby pressurizing the proppant storage vessel(s) and ensuring the proppant remains dry; supplying a stream of sub-cooled LCO₂ having a pressure less than or equal to the pressurized proppant storage vessel(s); and adding dry proppant from the pressurized proppant storage vessel(s) to the stream of sub-cooled LCO₂, thereby forming a mixed LCO₂ and proppant fracturing fluid.

[0008] The system uses LCO₂ obtained from at least one LCO₂ storage tank. In addition, there is also provided a control system for controlling the flow of dry proppant from pressurized proppant storage vessel(s) by allowing the flow of the dry proppant through a metering device into the sub-cooled LCO₂ stream; and mixing or blending the dry proppant with the sub-cooled LCO₂ stream to a desired level of proppant loading within the sub-cooled LCO₂. The loading is typically in the range of 0.1 to 10 lbs of dry proppant to each gallon of sub-cooled LCO₂. This mixing or blending is used to form the fracturing fluid, and is

preferably preformed on a continuous (uninterrupted) basis during the fracturing operation for well injection.

Brief Description of the Drawings

[0009] The above and other aspects, features, and advantages of the present invention will be more apparent from the following drawings, wherein:

[0010] Fig. 1 illustrates the effect of using a booster pump or sub-cooling a 5 lb/gallon proppant/liquid carbon dioxide fracturing fluid on required NPSH (Net Pressure Suction Head) for optimizing saturated liquid carbon dioxide well injection.

[0011] Fig. 2 illustrates the effect of using the combination of a booster pump and sub-cooling for a 5 lb/gallon proppant/liquid carbon dioxide fracturing fluid on required NPSH (Net Positive Suction Head) for optimizing saturated liquid carbon dioxide well injection.

[0012] Fig. 3 is a schematic depiction of the dry blender concept to provide mixing, and injecting the mixture of dry proppant and LCO₂ for fracturing a geological formation.

[0013] Fig. 4 is a schematic depiction of the overall system and method of the present invention for improving the semi-continuous or continuous supply of a mixture of dry proppant and LCO₂ for fracturing of oil and gas formations.

[0014] Fig. 5 is a further illustration of certain aspects of the process flow diagram shown in Fig. 2 without the provision of further sub-cooling after the slurry mixing point.

Detailed Description of the Invention

[0015] The present invention involves a system and apparatus for providing a continuous or semi-continuous supply of fracturing fluid, where the flow and method of controlling the flow uses a metering device (such as an auger) to add proppant into a LCO₂ stream. The proppant is warm and dry, in that is desired to use ambient temperature proppant that contains no free water. Ambient

temperatures may vary from approximately 0 to 100 degrees Fahrenheit, depending on the geographic location and time of year, and the temperature range may be even more extreme depending on the location of the drilling rig. "Warm" is used herein as a relative term, where the proppant is warm compared to the liquid carbon dioxide to which it will be added. In alternative embodiments, the proppant may be pre-cooled to some extent, such that its temperature is less than ambient temperature. It is desired that the proppant is dry and substantially devoid of liquid in order to maintain free flowing characteristics when conveyed through the system. For the present invention, the use of an auger that is capable of metering dry proppant to a mixing point for addition to LCO₂ wherein the loading of the dry proppant per gallon of LCO₂ is in the range of at least 0.1 to 10 lbs per gallon is desired. An even more preferable range is 0.1 to 4 lbs/gallon. Generally it is preferred that the pressurized proppant is added to the liquid carbon dioxide at substantially the same pressure. If an auger is used, the LCO₂ stream should preferably be about 0 to 2 psi less than the upstream proppant pressure to prevent the LCO₂ from passing into the proppant vessel. If, however, an eductor is employed, the LCO₂ stream should be preferably about 5 to 10 psi greater than the upstream proppant pressure, because an eductor will operate by pulling in the proppant against an existing pressure gradient.

[0016] The dry proppant loading in the LCO₂ and the flow rate of the combined stream are normally measured by use of a nuclear densitometer, a magnetic flow meter, a coriolis meter or other suitable measurement devices. The addition of the metered dry proppant with a sub-cooled LCO₂ stream provides the desired proppant loading for the fracturing operation and this mixture is referred herein as the "fracturing fluid". Any gaseous carbon dioxide entrained within the proppant is normally recondensed in the sub-cooled LCO₂. Using the aforementioned mixing technique, carbon dioxide vapor is only formed in the sub-cooling heat exchanger and not when the dry warm proppant mixes with the cold LCO₂. In addition, no LCO₂ remains in the proppant vessel when the proppant vessel is "blown down" to atmospheric pressure where it is to be recharged with proppant. The present invention also includes directing the flow of primarily

liquid fracturing fluid from the metering/mixing or blending device through the appropriate piping and manifolding such that it reaches the high pressure frac pumps in the desired liquid state. A combination of the sub-cooling methods can be used depending on feed LCO₂ conditions to ensure an appropriate level of NPSH (Net Pressure Suction Head) at the high pressure fracturing pumps. It is also part of the present invention to supply and maintain the LCO₂ fracturing fluid to the high pressure fracturing pumps to approximately 50 psi NPSH or at least a pressure sufficiently above saturation conditions for normal, safe, and reliable operation of these high pressure pumps. Feeding of vapor or provision of a low NPSH, risks vapor lock or cavitation effects which negatively affect performance and can damage the pumps.

[0017] LCO₂ can be supplied from the storage tanks at a variety of pressures, and the pressure of the LCO₂ supply tanks will normally change substantially over the course of the fracturing operation, for example by up to 100 psi or more. Since the pressure of the LCO₂ is constantly changing, the pressure of the proppant vessel needs to be accurately controlled in real time.

[0018] Different methods of providing and controlling pressure above the saturation point for carbon dioxide are preferable dependent on the different LCO₂ supply conditions. For example, it has been determined that the booster pump approach is very effective when starting with a relatively low pressure LCO₂ supply. High LCO₂ supply pressures typically cannot be boosted due to equipment design pressure limitations. Sub-cooling the LCO₂ in a heat exchanger is very effective when high pressure LCO₂ is available and the LCO₂ is close to the saturation conditions. For many moderate LCO₂ supply pressures, both a booster pump and a sub-cooling heat exchanger are often necessary to achieve high proppant loadings while supplying the proppant slurry mix to the high pressure frac pumpers with sufficient NPSH or pressure above the saturation pressure. Another approach for controlling the LCO₂ supply pressure is to pressurize the LCO₂ tanks with vapor in the tank head space. This approach is similar to pumping, but instead requires supplying pressurized vapor to the head space of each tank.

[0019] Figure 1 illustrates the NPSH effect of the booster pump approach at low LCO₂ supply pressures and the effect of the sub-cooling heat exchanger on higher pressure feed LCO₂. In both cases the feed LCO₂ is in the saturated condition. With low pressure LCO₂ supply (e.g., less than 250 psia), it is possible to use a booster pump to raise the pressure of the saturated LCO₂ by at least 100 psi, if the blender vessel is rated for 350 psi (a typical value). If the LCO₂ is supplied at 350 psia, as would normally be the case at the beginning of a summer season fracturing operation, a booster pump would not be sufficient to generate the required NPSH for a blender vessel rated at 350 psi. In this scenario, high pressure feed LCO₂ utilizes a sub-cooling heat exchanger to lower the temperature of the feed LCO₂ from about 10 degrees Fahrenheit to about -20 degrees Fahrenheit. The cooling action of the sub-cooling heat exchanger concurrently generates NPSH in the LCO₂ stream. The data points in Plot A below demonstrate that with a LCO₂ supply pressure of 250 psi neither booster pumping or the subcooling heat exchanger alone are sufficient for generating the required NPSH.

[0020] LCO₂ sub-cooling can be achieved by passing a portion of the LCO₂ through a pressure reducing valve such that a portion of the LCO₂ stream evaporates or ‘flashes’ forming a lower temperature as well as lower pressure LCO₂ stream. This lower pressure CO₂ stream is typically pressurized to about 125 psia, and is used in the sub-cooling heat exchanger to reduce the temperature of the main, higher pressure LCO₂ stream. As the higher pressure LCO₂ stream is cooled in this sub-cooling heat exchanger the lower pressure CO₂ stream evaporates and the vaporized and/or warmed portion of the low pressure stream is vented, as needed, to maintain the pressure of the low pressure stream at, for example, near 125 psia.

[0021] If the booster pump and sub-cooling processes are used in combination, then it is possible to generate an appropriate pressure above the saturation pressure such that the fracturing fluid can be supplied directly to the high pressure frac pumps at constant NPSH values. Figure 2 shows that it is possible to use this combination approach to achieve 75 psi (NPSH) above the

saturation pressure, resulting in a fracturing fluid that is sufficiently sub-cooled and either semi-continuously or continuously delivered in an uninterrupted manner to the high pressure frac pump.

[0022] As mentioned above, at relatively low LCO₂ supply pressures (e.g., less than about 250 psia), a high booster pump pressure rise and relatively low amount of sub-cooling are needed. In contrast, at high LCO₂ supply pressures (e.g. above 250 psia), a lower booster pump pressure rise and a high amount of sub-cooling are needed. At a saturated LCO₂ supply pressure of about 250 psia, substantial amounts of both boost pumping and sub-cooling via a heat exchanger are required.

[0023] Table 1 below provides the data obtained for the use of the combination of the booster pump and sub-cooling obtained with a heat exchanger to enhance the use of the carbon dioxide fracturing fluid performance. Details for the case of using a 5 lb proppant per gallon flow rate of LCO₂ are presented.

Table 1 Booster Pump and Sub-Cooling Combination Conditions and Data Obtained Using a 5 lb/gallon Proppant/Liquid Carbon Dioxide Fracturing Fluid for Optimizing Saturated Liquid Carbon Dioxide Well Injection 5 lb/gallon Fracturing Fluid							
LCO₂ tank conditions							
Sat pressure	psia	125	150	200	250	300	350
Sat temperature	F	-46.4047	-37.7138	-23.1652	-11.1187	-0.74241	8.429268
Sand conditions							
Inlet temp	F	80	80	80	80	80	80
Moisture level	wt%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
Moisture/sand cooling	btu/btu	0.126	0.133	0.133	0.140	0.145	0.146
Boost Pump							
Pressure rise	psi	150	155	105	80	50	0
Subcooler							
Subcooling degrees	dF	0	0	-15	-20	-26	-35
Vaporized/Total CO ₂	--	0.000	0.000	0.056	0.076	0.099	0.130
Vaporizer pressure	psia	125	125	125	125	125	125
Vaporizer temp	F	-46.4	-46.4	-46.4	-46.4	-46.4	-46.4
Vaporizer min approach	dF	0.9	9.7	9.0	15.9	20.1	19.8
Subcooled feed temp	F	-45.5	-36.7	-37.4	-30.5	-26.3	-26.6
Fracturing Fluid							
Fracturing Fluid Loading	lb/gal	5	5	5	5	5	5
Fracturing Fluid temp	F	-23.2	-15.8	-15.7	-10.1	-6.0	-5.7
Fracturing Fluid press	psia	275	305	305	330	350	350
Fracturing Fluid sat. overpressure	psi	75.1	75.3	75.2	75.3	75.9	74.8
Fracturing Fluid subcooling	F	17.4	16.0	16.0	15.0	14.4	14.1

[0024] In addition to the booster pump and sub-cooling heat exchanger combination, described in Figure 1, Figure 2, and Table 1, another possible method to manage the LCO₂ supply sub-cooling system is to supply CO₂ vapor or some other gas, (e.g. nitrogen gas), to the headspace of the LCO₂ supply tanks. Using this method, it is also possible to provide the aforementioned boost in pressure.

[0025] As fracturing proceeds and LCO₂ is drained from the storage vessels, the pressure of the LCO₂ contained within the vessel will decrease, and the temperature will decrease if no headspace pressurizing method is used. This headspace pressurizing method ensures that the LCO₂ supply pressure is maintained at a relatively fixed pressure of, for example, about 350 psia throughout the duration of the fracturing treatment. If this method is chosen, only a subcooling heat exchanger and either no booster pump or alternatively a very small booster pump is required to maintain the appropriate NPSH of the slurry over time as the LCO₂ is drained from the LCO₂ supply tanks. This method ensures and provides for the proper delivery of fracturing fluid with appropriate NPSH (sub-cooled slurry) to the high pressure frac pumps. In summary, the use of the headspace pressurizing method can help to decrease or eliminate the natural progression of pressure decreasing and temperature decreasing, as LCO₂ is withdrawn from the supply tanks. This makes control of the system easier and/or helps to maintain an appropriate NPSH of the fracturing slurry supplied to the high pressure frac pumps.

[0026] In addition to the booster pump and sub-cooling heat exchanger approaches described above, other methods are useful to help achieve an appropriate proppant slurry with greater than the saturation pressure exerted upon the carbon dioxide to keep the system in an optimal liquid phase.

[0027] An alternative step to the embodiments regarding the invention as already presented includes: using pre-cooled proppant in pressurized proppant vessels by passing LCO₂ or cold carbon dioxide vapor through the bed of proppant prior to full pressurization. This alternative method also allows for the utilization of cold nitrogen vapor in lieu of, or together with, carbon dioxide. In

order to pre-cool the proppant and/or proppant mixture, indirect cooling of the proppant with a suitable refrigerant using heat transfer coils embedded in the pressure vessel and/or indirectly cooling the proppant during proppant loading by passing the proppant through a heat exchanger cooled by a suitable refrigerant is also viable. Cold carbon dioxide vapor can be obtained from “boil-off” from portable carbon dioxide storage units or from “flashed” carbon dioxide used to sub-cool the LCO₂ stream. Included with these additional processes is the ability to apply increased pressure to the head space of the storage tanks as well as using booster pumps to properly maintain the stream of mixed proppant fracturing fluid. This methodology allows for the addition of more pressure to ensure greater than the saturation point is reached for carbon dioxide prior to entering the high pressure fracture pumps.

[0028] An alternative method for sub-cooling the LCO₂ in a heat exchanger is to flash the saturated high pressure LCO₂ to a lower pressure, causing a portion of LCO₂ to boil-off and the remaining portion to form a lower pressure saturated LCO₂ stream. This can be achieved by throttling the high pressure saturated LCO₂ across a valve or expansion device, and then passing the two-phase product through a phase separator to remove the vapor phase carbon dioxide from the resulting lower pressure saturated LCO₂. It can also be achieved in the LCO₂ storage vessels, by lowering the pressure in the headspace of the vessels, venting carbon dioxide vapor and creating a lower pressure saturated LCO₂ in the storage vessels. When LCO₂ is sub-cooled in such a manner, it is then pumped to a higher pressure by the booster pumps to create the desired pressure above saturation.

[0029] In addition, it is possible to use continuous addition of proppant to the proppant vessel when these vessels are in a pressurized state with the use of lock-hoppers, or other similar equipment, for introducing proppant to a pressurized system. To achieve the desired pressurization it is necessary to quickly refill the lock-hopper vessels with new proppant. This is normally achieved by rapidly conveying proppant using equipment such as inclined belt or other conveyors systems including pneumatic conveyers, buckets, augers, etc. In achieving a

continuous system, changing the proppant type as required by the geological formation at a specific point in time during the fracturing process, as determined by the frac design, can be required. Drying of proppant in the storage vessel to aid solids flow and prevent freezing may be required and can be achieved, for example, by flowing dry gas (could be carbon dioxide or nitrogen or any mixture of dry gases – including air - available at the well site) through the proppant bed. It is also possible to thicken (increase viscosity) or otherwise modify the rheological properties of the LCO₂ stream to facilitate higher proppant loadings and transport of the proppant through downstream equipment, leading eventually into the well bore and the associated oil and gas formation.

[0030] Figure 3 is a high level process flow diagram showing the basic elements of the invention. Here, LCO₂ is supplied from the site storage supply [101]. This LCO₂ is typically saturated and supplied at a pressure of between about 150 and 350 psia. The majority of the feed LCO₂ [102] is routed to one or more booster pumps [104] to raise the pressure above saturation and essentially generate sub-cooling in the LCO₂ liquid stream [105]. The liquid stream [105] is further sub-cooled, in this instance, by physically cooling the stream via indirect heat exchange in the heat exchange unit [106] with a separate CO₂ stream [107] that is provided at a lower pressure. A “slipstream” [103] of the original supply of LCO₂ [101] is used for sub-cooling and the pressure of the slipstream is reduced to lower the boiling temperature of the stream [107]. As the main LCO₂ stream [105] is cooled, generating the sub-cooled LCO₂ stream [109], the low pressure CO₂ stream [107] is vaporized and warmed, yielding stream [108], which is typically vented to atmosphere. The sub-cooled LCO₂ stream [109] is then combined with the pressurized, metered proppant stream [111] at the blending point [110] to form a mixed LCO₂ and proppant slurry, which becomes the fracturing fluid [112]. The metered, pressurized proppant stream [111] is dry and at a temperature that is typically much warmer than the sub-cooled LCO₂ stream. Metering of the proppant stream supplied to the blending point [111] is accomplished using an appropriate metering device [113]. The proppant is supplied from the proppant storage vessel [114]. Depending on the type of

metering device [113] selected (e.g. auger, eductor, valve, etc), the metering device [113] and blending point [110] could be provided for in a single unit. The amount of sub-cooling of the LCO₂ stream [109] is managed such that the fracturing slurry stream [112] remains sub-cooled with about 50 psi of NPSH available after addition of the proppant stream [111]. The fracture fluid stream [112] is at least semi-continuously supplied to the high pressure frac pumps which in turn supplies the well head with a further pressurized stream of dry proppant and CO₂ fluid (i.e., fracturing fluid).

[0031] Figure 4 is a schematic detailing a complete process flow diagram that illustrates one embodiment of the systematic operation of the present invention. Specifically, an external source of gas pressure [1] is used to pressurize the head space of the liquid carbon dioxide (LCO₂) storage vessels [2] creating a pressure that is above the saturation pressure of the LCO₂ within the LCO₂ tanks. The LCO₂ then flows out of any one or more of numerous storage vessels [2a], [2b], and [2c] into a low pressure collection header [3]. The collection header [3] feeds one or more booster pumps [4] which may be arranged in a series and/or parallel arrangement depending on the flow or pressure required and the capacity and pressure capability of each pump. The high pressure feed carbon dioxide header [5] feeds the sub-cooling heat exchanger [11] pressurized gas supply vaporizer [23] and a fluid stream that is primarily a liquid stream [26], which can be used to cool and/or pressurize the now pressurized proppant storage vessel(s) [20a] and [20b].

[0032] The sub-cooling heat exchanger [11] cools high pressure feed LCO₂. The pressure of the low pressure boiling carbon dioxide must be kept above a minimum of about 75 psia to ensure no solid carbon dioxide is formed (as at these pressures and temperatures, the carbon dioxide is close to its triple point). Typically, the boiling low temperature LCO₂ stream will be kept at a pressure of about 125 psia. The stream of cold vapor carbon dioxide [12] is then vented to a stack arrangement, and/or sent to some other manifold for pressurization of another unit, and/or to cool and/or dry proppant.

[0033] Sub-cooled high pressure LCO₂ then proceeds to the proppant mixing point [22a] and/or [22b] (which could be arranged in series or parallel), for mixing the sub-cooled LCO₂ with proppant in the range of 0.1 to more than 10 lbs of proppant/gallon LCO₂. The LCO₂ booster pump [4] and sub-cooling heat exchanger [11] are operated in such a way as to keep the LCO₂ and proppant slurry (proppant) sub-cooled at the proppant mixing points [22a] and [22b]. In one preferred embodiment, a pressure of at least 50 psi above the saturation pressure of carbon dioxide is maintained in the fracturing slurry after the proppant has been mixed with the LCO₂. As pressure is correlated with temperature, this process results in a fracturing slurry temperature with at least a 50 psi “safety margin” before the fracturing slurry will begin to boil. Feeding of vapor or provision of a lower NPSH risks vapor lock or cavitation effects which negatively affect performance and can damage the pumps.

[0034] A parallel slipstream of pure LCO₂ [28] can be provided that optionally bypasses at least one of the proppant mixing points, [22a] and [22b]. For example, this could be useful during the stages of the fracturing operation where no proppant is required (commonly referred to as pad or the padding stage). This bypass stream [28] can also be used to help control the final proppant loading, for example. In the case where the LCO₂ and proppant fracturing fluid does not have enough sub-cooling, or when the proppant slurry is not sub-cooled and contains some vapor, an additional sub-cooling heat exchanger [13] and/or a slurry booster pump [27] is utilized to increase the pressure above the saturation pressure for carbon dioxide within the flowing fracturing fluid stream.

[0035] The fracturing slurry continues to be conveyed into the low pressure slurry manifold [51], and onward to the high pressure frac pumps, [52a], [52b], and [52c], that are arranged in parallel. Three such pumps are described here, however there may be any number used in order to meet the required capacity. The high pressure frac pumps [52a], [52b], [52c], feed the high pressure slurry manifold, [53] which in turn, feeds a wellhead [61]. Additives can be added at multiple locations depending on the purpose and type of chemical required for

addition. These chemical additives often function to serve as viscosity control agents which can increase or decrease the viscosity of the fracturing fluid, as required during operation. As shown in Fig. 2, chemicals [8] can be added to the high pressure feed LCO₂ manifold [5], and to the inlet of the slurry booster pump [27]. High pressure chemical addition also can occur by use of a holding tank [54], that is normally at ambient temperature and pressure. The tank contains these chemicals to allow for flow to a high pressure fracture pump [55] disposed in parallel to the slurry frac pumps, [52a], [52b], and [52c], before mixing with the fracturing slurry in the high pressure slurry manifold [53]. Dry proppant is supplied from the proppant delivery transports or from portable proppant storage units, [31a], [31b], and [31c], to a proppant transport system [32] which moves the proppant vertically and/or horizontally to ensure proppant delivery to the top of the lock-hoppers [25a], [25b], [25c], and [25d] and/or to the top of the pressurized proppant storage vessels [20a], [20b]. In the embodiment shown, the proppant is delivered to the top of the lock-hoppers [25a], [25b], [25c] and, [25d]. One or more of the lock-hoppers [25a], [25b], [25c], and [25d] are employed to pre-pressurize or further pressurize the proppant storage vessel [20a], [20b]. More than one pressurized proppant storage vessel(s) can be used to enable the delivery of multiple proppant types during a fracture treatment during which proppant delivery is continuous or at least semi-continuous.

[0036] During operation, proppant is delivered to the lock-hopper [25] and the lock-hopper proppant feed valves are closed. The lock-hopper unit is pressurized via the CO₂ stream flowing within the pressure line [29] and the pressure control system [24]. When the pressure is sufficiently close to the pressure of the pressurized proppant storage vessel [20] the bottom lock-hopper valve is opened and the lock-hopper contents are transferred to the pressurized proppant storage vessel, [20]. The lock-hoppers [25] are also used to pressurize and deliver proppant when the pressurized proppant storage vessel [20] is not delivering proppant. Alternatively, the lock-hoppers [25] can be used while proppant is being metered out of the pressurized proppant and storage vessel [20] in order to better utilize the equipment and to reduce cycle and proppant filling time. One

mode of continuous operation allows for the pressurized proppant storage vessel [20a] or [20b] to deliver proppant to the metering device [21a], with a lock hopper [25a] adding pressurized proppant to a proppant storage vessel [20a] while lock hopper [25b] is being refilled with proppant and repressurized. When lockhopper [25a] is empty, it is 'blown down' of pressure, refilled with proppant and repressurized while lockhopper [25b] is adding pressurized proppant to the storage vessel [20a]. Additionally, depending on the size of the hoppers [25] compared to the size of the proppant storage vessel(s) [20], and the frequency with which each can be filled and emptied, there may be any number of lockhoppers employed.

[0037] Proppant is metered from the pressurized proppant storage vessel [20] through the metering device [21a] and [21b]. The metering device consists of a variable speed auger, a control valve, an eductor, or some combination thereof. The metering device [21] delivers a proppant into the sub-cooled LCO₂ stream to form the fracturing slurry and provides operation even if upset conditions allow some LCO₂ to get back into the pressurized proppant storage vessel [20] or in case the pressurized proppant storage vessel [20] is intentionally operated with both proppant and LCO₂. The pressure level in the pressurized proppant storage vessel(s) [20a] and [20b] is controlled by a pressure control device [24], which can be as simple as a valve for pressure regulation. The metered dry proppant is combined with the flowing LCO₂ at mixing points [22a] and [22b]. In the case of an eductor, the metering devices [21] and mixing points [22] are essentially combined because the flow of solids is determined by the volume of liquid flowing through the eductor. It is critical to be able to control and closely maintain the pressure of the system. Gaseous carbon dioxide will flow with the dry proppant into the sub-cooled LCO₂ stream, since it will fill the void space between proppant particles. The positive pressure differential between the proppant storage vessel and sub-cooled LCO₂ stream will cause additional gaseous carbon dioxide to flow through the proppant particles. As the gaseous carbon dioxide flows into the sub-cooled LCO₂ stream, the liquid and gas will mix and cause the gaseous carbon dioxide to condense into liquid form.

[0038] In some installations, it might be necessary to pre-cool or dry the proppant in the pressurized proppant storage vessels [20] by the addition of cold vapor and/or LCO₂. This pre-cooling or drying can be achieved using stream [26] or by using the cold vapor from the sub-cooling heat exchanger [12] and/or [14]. The flow of gas or liquid used for this purpose can be introduced to the top, bottom and/or middle sections of the pressurized proppant storage vessel [20]. This cooling of the proppant (typically sand), can also take place as the sand is being used, for example with LCO₂ in stream [26] can be administered to the bottom of the proppant storage vessel [20] as the sand is being withdrawn from the vessel. In this way the withdrawn sand is being partially cooled before it is mixed with the main stream of LCO₂ to reduce the size of the subcooling heat exchanger [11]. The vapor that is created can be used to pressurize the proppant storage vessel [20] and also to reduce the size of the vaporizer [23] that is required to maintain pressure in the proppant supply vessel [20].

[0039] Any vent gas or blow-down from the pressurized proppant vessel [20], or from the lock-hoppers [25] is collected in a common vent manifold [42], subsequently vented and/or otherwise utilized for additional operations, such as recycle, as necessary. Operation [41] will most likely consist of a vent stack but this gaseous or vapor based carbon dioxide stream can also be used for other purposes. For example, the vented carbon dioxide can be used for further drying of proppant, or for pressurizing the carbon dioxide system that can in turn be used to pressurize the liquid carbon dioxide supply vessels, etc. Furthermore, in the case of a smaller fracturing process that can be completed with one batch of the proppant/proppant mixture (nominally 80 tons or less), there is no need for the addition of proppant to the pressurized proppant vessel (not shown) and the use of lock-hoppers (not shown).

[0040] Figure 5 indicates that for some fracturing installations, it might be necessary to pre-cool the dry proppant in the pressurized proppant storage vessels [20] with the addition of cold vapor and/or LCO₂. This pre-cooling or drying can be achieved using the fluid stream [26] or by using the cold vapor from the sub-cooling heat exchanger [12] and/or [14]. The flow used for this purpose can be

introduced to the top, bottom, and/or middle sections of the pressurized proppant storage vessel [20]. Any vent gas or blow-down from the pressurized proppant vessel [20], or from the lock-hoppers [25] is collected in a common vent manifold [42], subsequently vented, or otherwise utilized in the overall operation [41]. Furthermore, in the case of a smaller fracturing operation that can be completed with 80 tons or less of the proppant/proppant mixture, there is no need for the addition of proppant to the pressurized proppant vessel and the use of the lock-hoppers.

[0041] While the invention herein disclosed has been described by means of specific embodiments and processes or control techniques associated therewith, numerous modifications and variations can be made thereto by those skilled in the art without departing from the scope of the invention as set forth in the claims or sacrificing all of its features and advantages. Various modifications and changes may be made with respect to the foregoing detailed description. Certain embodiments of the invention as will become apparent to those skilled in the art without departing from the spirit of the present disclosure.

What is claimed is:

1. A system for making a fracturing fluid comprising a mixture of dry proppant and liquid carbon dioxide (LCO₂) for use in a fracturing operation, comprising:

loading dry proppant into at least one dry proppant storage vessel with one or more conveying means;

pressurizing said proppant storage vessel(s) to between 75 and 600 psia with a gas, thereby pressurizing said proppant storage vessel(s) and ensuring said proppant remains dry;

supplying a stream of sub-cooled LCO₂ having a pressure substantially equal to the pressurized proppant storage vessel(s); and

adding dry proppant from the pressurized proppant storage vessel(s) to the stream of sub-cooled LCO₂, thereby forming a mixed LCO₂ and proppant fracturing fluid.

2. The system of claim 1, wherein dry proppant is fed into said proppant storage vessel from at least one lock hopper, allowing for loading of fresh dry proppant into said proppant storage vessel before the first charge of dry proppant has been emptied.

3. The system of claim 1, wherein said fracturing fluid is delivered to at least one high pressure pump to further raise the pressure of said fracturing fluid prior to supply to an injection well to carry out the fracturing operation.

4. The system of claim 1, further providing a control system for controlling the flow of dry proppant from pressurized proppant storage vessel(s) by allowing the flow of said dry proppant through a metering device into said sub-cooled LCO₂ stream; and

adding said proppant to said sub-cooled LCO₂ stream to obtain a desired level of proppant loading within said sub-cooled LCO₂ that is in the range of 0.1 to 10 lbs of dry proppant to each gallon of sub-cooled LCO₂ thereby forming said fracturing fluid.

5. The system of claim 1, wherein said fracturing fluid is provided on a continuous basis for fracturing during well injection.

6. The system of claim 1, wherein said fracturing fluid is provided on a semi-continuous basis for fracturing during well injection.

7. The system of claim 1, wherein said fracturing fluid is provided on a batch basis for fracturing during well injection.

8. The system of claim 1, wherein said LCO₂ is combined with one or more liquefied gases selected from the group consisting of nitrogen, methane, ethane, propane, butane, and liquefied petroleum gas.

9. The system of claim 1, wherein chemical additives are added to said fracturing fluid such that these additives act as viscosity control agents of said fracturing fluid.

10. An apparatus employed in a fracturing operation, comprising: at least one pressurized proppant storage vessel containing proppant and a gas, said vessel connected to a metering device for adding proppant into a sub-cooled LCO₂ stream and;

a sub-cooler for ensuring that the liquid carbon dioxide (LCO₂) is in a sub-cooled liquid state and/or a booster pump(s) for increasing the pressure of the LCO₂ stream above its saturation point and conveying the LCO₂ to a mixing point, wherein proppant is metered into the LCO₂ to form a fracturing fluid.

11. The apparatus of claim 10, wherein said fracturing fluid is delivered to at least one high pressure pump to further increase the pressure of the fracturing fluid prior to supply to an injection well to carry out the fracturing operation.

12. The apparatus of claim 10, wherein said sub-cooler provides a sub-cooled feed stream of LCO₂ coupled with a device that monitors and/or controls pressure of at least one or more LCO₂ storage tank(s) and simultaneously measures and controls the pressure and temperature of said sub-cooled LCO₂ stream.

13. The apparatus of claim 10, wherein said device includes a flow meter and a densitometer that measures the flow rate and density of said fracturing fluid.

14. The apparatus of claim 10, wherein the gas added to said proppant storage tank is substantially a dry gas.

15. The apparatus of claim 10, wherein said pressurized storage vessel includes at least one lock hopper for loading and unloading proppant.

16. The apparatus of claim 10, wherein said fracturing fluid is provided on a continuous basis for fracturing during well injection.

17. The apparatus of claim 16, wherein said fracturing fluid is provided on a semi- continuous basis for fracturing during well injection.

18. The apparatus of claim 16, wherein said fracturing fluid is provided on a batch basis for fracturing during well injection.

19. The apparatus of claim 10, wherein the sub-cooling of the feed stream of LCO₂ is provided by any one of at least one heat exchanger, a head space pressurization unit, or by flashing LCO₂ followed by increasing the pressure using a booster pump.

20. The apparatus of claim 10, wherein said booster pump(s) are required to boost insufficient pressure supplied from said LCO₂ storage tanks if said pressure is insufficient for maintaining sub-cooling of LCO₂.

21. The apparatus of claim 10, wherein said metering device is an auger, eductor, and/or proppant flow control valve, ensuring maintaining the proper flow-rate of said fracturing proppant.

22. The apparatus of claim 10, wherein a densitometer and flow meter are also provided to ensure maintaining said flow rate in a manner required to achieve semi-continuous or continuous slurry injection for fracturing of a hydrocarbon well.

23. The apparatus of claim 10, wherein said densitometer is a nuclear-sourced based densitometer.

24. The apparatus of claim 22, wherein said flow meter is a magnetic field or coriolis-based flow meter, wherein said coriolis-based meter measures both density and flow-rate.

25. The apparatus of claim 10, wherein said system is mobile in that it can be moved from one well location to another.

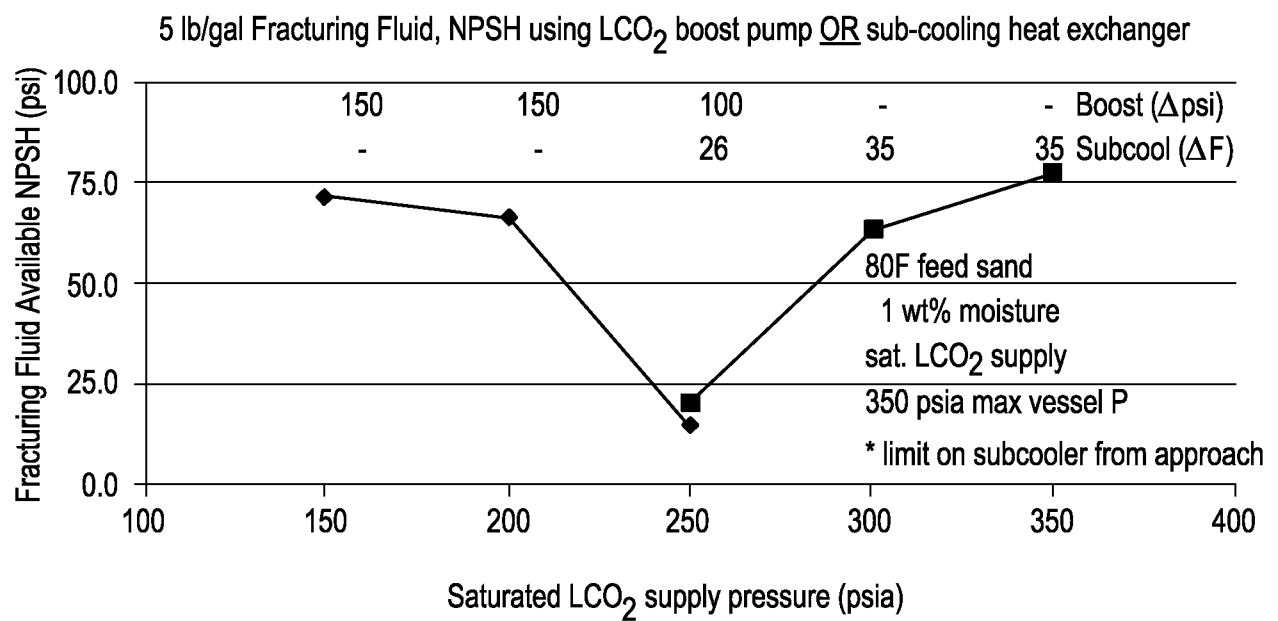
26. A method for controlling a fracturing fluid composition, wherein a dry proppant is being routed and introduced into LCO₂, thereby forming a liquid carbon dioxide proppant fracturing fluid.

27. The method of claim 26, wherein conveying said fracturing fluid to at least one high pressure pump further raises the pressure of said fracturing slurry prior to supplying said slurry to an injection well for completing the fracturing operation.

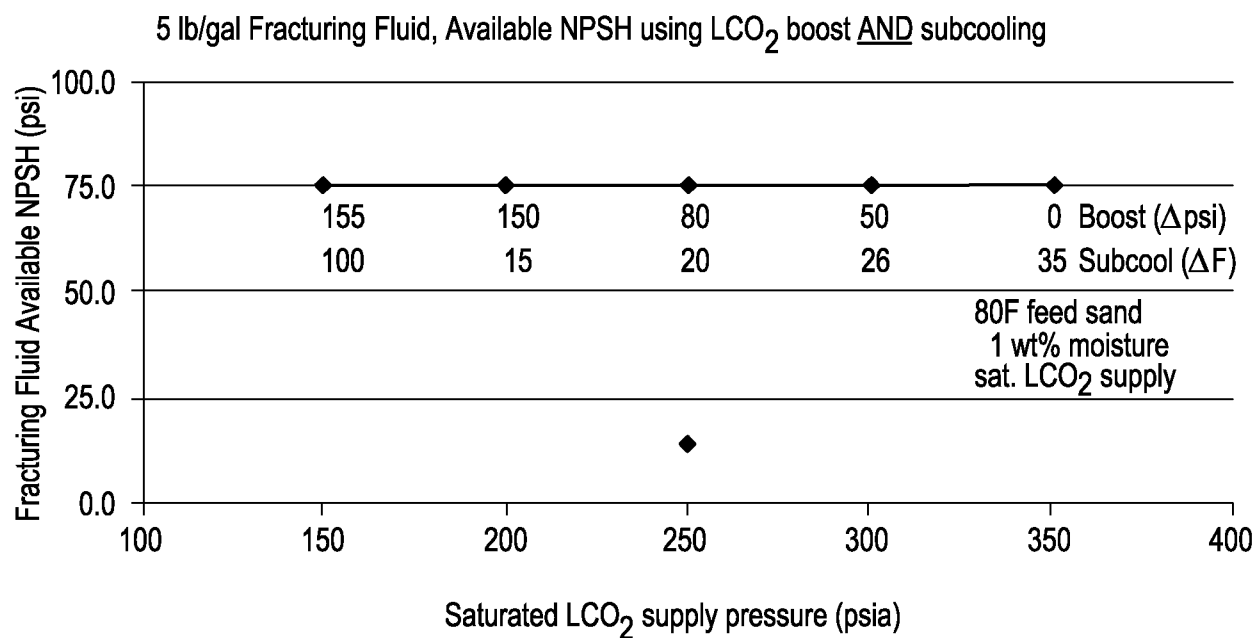
28. The method of claim 26, wherein a feedback loop controller capable of using parameter feedback data obtained from sensing devices for controlling the flow rate and pressure of said dry proppant, or said liquid carbon dioxide, or said or said fracturing fluid, or any combination thereof, is employed.

29. A system for combining metered dry and warm proppant with a sub-cooled LCO₂ stream resulting in a fracturing fluid comprising:
- (i) mixing of said proppant and LCO₂ preventing carbon dioxide vapor from being generated by providing a pressure level of 50 psi NPSH or at least a pressure sufficiently above saturation conditions; and
 - (ii) recondensing any gaseous carbon dioxide entrained within the proppant of said fracturing fluid.
30. A system for making a fracturing fluid comprising a mixture of dry proppant and liquid carbon dioxide (LCO₂) for use in a fracturing operation, comprising:
- supplying dry proppant that is pressurized to between 75 and 600 psia with a gas;
 - providing a stream of sub-cooled LCO₂ having a pressure substantially equal to the pressurized dry proppant; and
 - adding dry, pressurized proppant to the stream of sub-cooled LCO₂, thereby forming a mixed LCO₂ and proppant fracturing fluid.

1/5

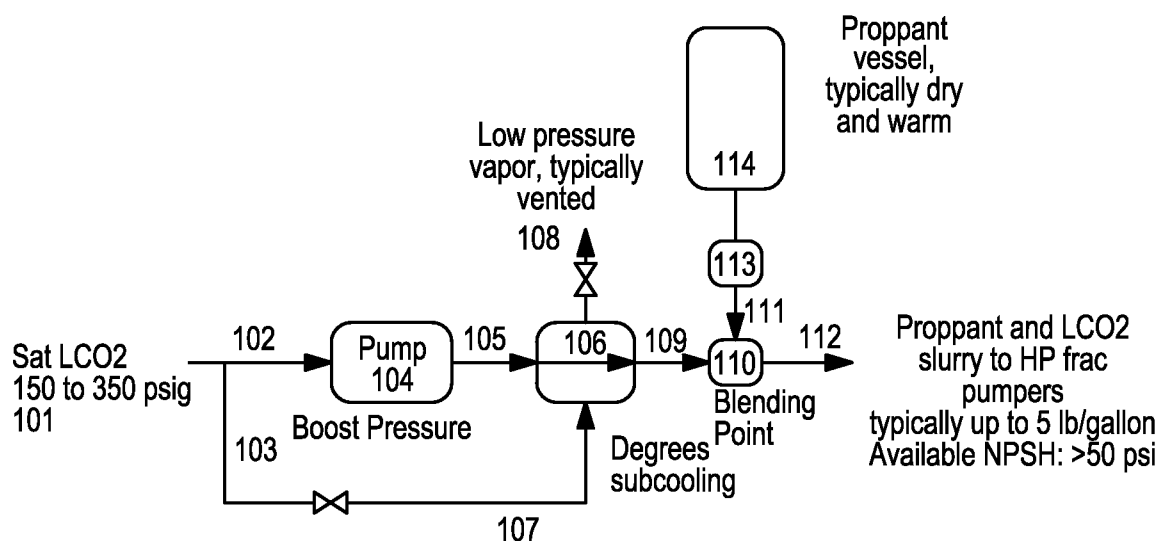
**FIG. 1**

2/5

**FIG. 2**

3/5

Dry Blender Concept:
Boost pump with Subcooling Heat Exchanger

**FIG. 3**

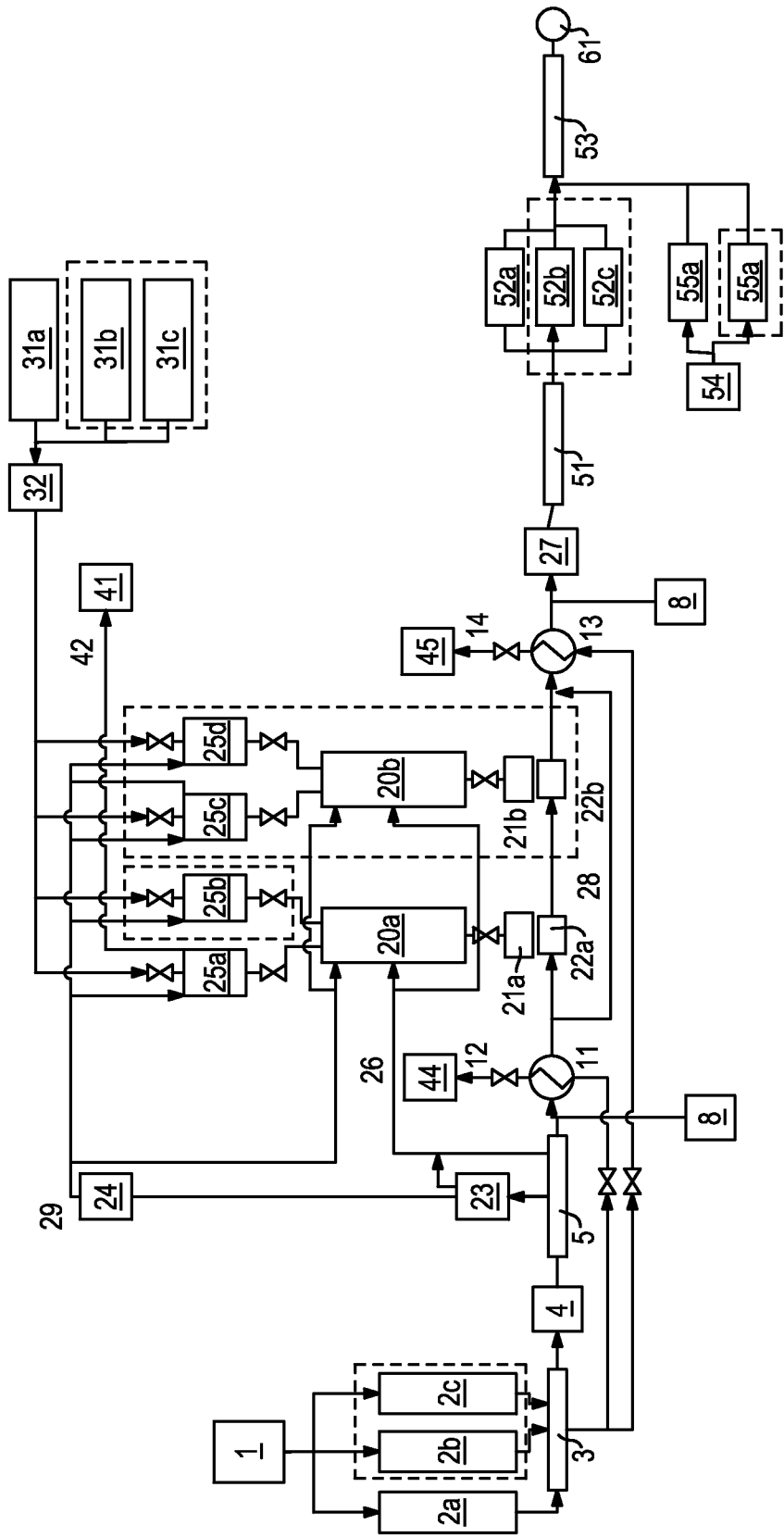


FIG. 4

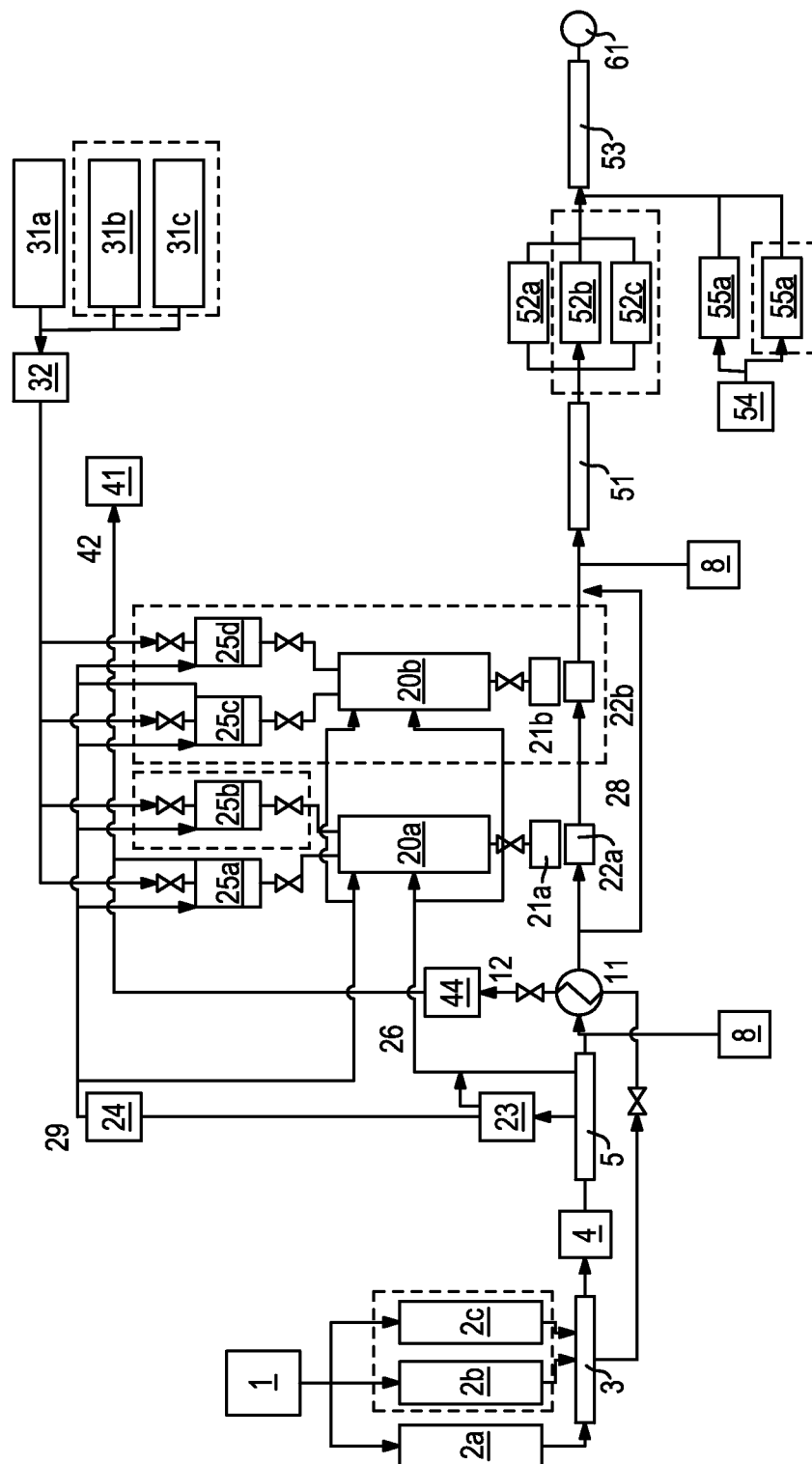


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/075583

A. CLASSIFICATION OF SUBJECT MATTER INV. C09K8/62 E21B43/26 E21B43/267 B62B1/18 E21B36/00 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) C09K E21B B62B		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CA 1 134 258 A1 (CANADIAN FRACMASTER LTD) 26 October 1982 (1982-10-26) claims 1, 2, 6, 8, 18 the whole document -----	1-9, 26-28
X	EP 0 695 852 A2 (CANADIAN FRACMASTER LTD [CA]) 7 February 1996 (1996-02-07) claims 3,12,15 the whole document -----	1-9, 26-28
X	EP 0 711 902 A2 (CANADIAN FRACMASTER LTD [CA]) 15 May 1996 (1996-05-15) claims 5,8,16 the whole document -----	1-9, 26-28
	-/-	
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "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 20 February 2014		Date of mailing of the international search report 03/06/2014
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Straub, Thomas

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2013/075583

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2008/142224 A1 (WILSON DENNIS RAY [US] WILSON DENNIS R [US]) 19 June 2008 (2008-06-19)	26-28
A	claims 27-29,39 the whole document -----	1-9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/075583

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of 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. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims 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. ☐ Claims 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:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an 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 claims 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 claims Nos.:

1-9, 26-28

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.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-9, 26-28

A system for making a fracturing fluid comprising a mixture of dry proppant and liquid carbon dioxide (LCO₂) for use in a fracturing operation, comprising: loading dry proppant into at least one dry proppant storage vessel with one or more conveying means; pressurizing said proppant storage vessel(s) to between 75 and 600 psia with a gas, thereby pressurizing said proppant storage vessel(s) and ensuring said proppant remains dry; supplying a stream of sub-cooled LCO₂ having a pressure substantially equal to the pressurized proppant storage vessel(s); and adding dry proppant from the pressurized proppant storage vessel(s) to the stream of sub-cooled LCO₂, thereby forming a mixed LCO₂ and proppant fracturing fluid.

A method for controlling a fracturing fluid composition, wherein a dry proppant is being routed and introduced into LCO₂, thereby forming a liquid carbon dioxide proppant fracturing fluid.

2. claims: 10-25

An apparatus employed in a fracturing operation, comprising: at least one pressurized proppant storage vessel containing proppant and a gas, said vessel connected to a metering device for adding proppant into a sub-cooled LCO₂ stream and;

a sub-cooler for ensuring that the liquid carbon dioxide is in a sub-cooled liquid state and/or a booster pump(s) for increasing the pressure of the LCO₂ stream above its saturation point and conveying the LCO₂ to a mixing point, wherein proppant is metered into the LCO₂ to form a fracturing fluid.

3. claim: 29

A system for combining metered dry and warm proppant with a sub-cooled LCO₂ stream resulting in a fracturing fluid comprising: (i) mixing of said proppant and LCO₂ preventing carbon dioxide vapor from being generated by providing a pressure level of 50 psi NPSH or at least a pressure sufficiently above saturation conditions; and (ii) recondensing any gaseous carbon dioxide entrained within the proppant of said fracturing fluid.

4. claim: 30

A system for making a fracturing fluid comprising a mixture of dry proppant and liquid carbon dioxide (LCO₂) for use in a

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

fracturing operation, comprising: supplying dry proppant that is pressurized to between 75 and 600 psia with a gas; providing a stream of sub-cooled LC02 having a pressure substantially equal to the pressurized dry proppant; and adding dry, pressurized proppant to the stream of sub-cooled LC02, thereby forming a mixed LC02 and proppant fracturing fluid.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2013/075583

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
CA 1134258	A1	26-10-1982	AU	550576 B2	27-03-1986
			AU	8789382 A	14-04-1983
			CA	1134258 A1	26-10-1982
			DE	3235845 A1	14-04-1983
			GB	2112835 A	27-07-1983
			NL	8203477 A	18-04-1983
			US	4374545 A	22-02-1983

EP 0695852	A2	07-02-1996	AU	696717 B2	17-09-1998
			AU	2727295 A	15-02-1996
			CA	2129613 C	23-09-1997
			EP	0695852 A2	07-02-1996
			NO	953053 A	06-02-1996
			US	5515920 A	14-05-1996

EP 0711902	A2	15-05-1996	AU	3424895 A	23-05-1996
			CA	2135719 A1	15-05-1996
			CA	2198156 A1	15-05-1996
			EP	0711902 A2	15-05-1996
			NO	954126 A	15-05-1996
			US	5558160 A	24-09-1996
			US	5883053 A	16-03-1999

US 2008142224	A1	19-06-2008	CA	2669403 A1	26-06-2008
			GB	2456448 A	22-07-2009
			RU	2009127702 A	27-01-2011
			US	2008142224 A1	19-06-2008
			US	2008142226 A1	19-06-2008
			WO	2008076952 A2	26-06-2008