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System to optimize centrifugal pumps and manifolding in variable rate slurry pumping applications

Abstract

A method includes providing a total flow rate of a proppant slurry by utilizing a slurry pump to provide a concentrated slurry flow rate of a concentrated slurry, utilizing a clean fluid pump to provide a clean pump flow rate of a clean fluid, and combining the clean pump flow rate of the clean fluid with the concentrated slurry flow rate of the concentrated slurry to provide the total pump flow rate of the proppant slurry. The clean fluid is substantially proppant free, the concentrated slurry has a higher concentration of the proppant than the proppant slurry, the total flow rate of the proppant slurry is greater than a maximum slurry pump flow rate of a preferred operating range (POR) of the slurry pump, and the concentrated slurry flow rate is less than or equal to the maximum slurry pump flow rate.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS
(1) None.
STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT
(2) Not applicable.
BACKGROUND
(3) Subterranean hydraulic fracturing is conducted to increase or “stimulate” production from a hydrocarbon well. To conduct a fracturing process, high pressure is used to pump special fracturing fluids, including some that contain propping agents (“proppants”) down-hole and into a hydrocarbon formation to split or “fracture” the rock formation along veins or planes extending from the well-bore. Once the desired fracture is formed, the fluid flow is reversed and the liquid portion of the fracturing fluid is removed. The proppants are intentionally left behind to stop the fracture from closing onto itself due to the weight and stresses within the formation. The proppants thus literally “prop-apart”, or support the fracture to stay open, yet remain highly permeable to hydrocarbon fluid flow since they form a packed bed of particles with interstitial void space connectivity. Sand is one example of a commonly-used proppant. The newly-created-and-propped fracture or fractures can thus serve as new formation drainage area and new flow conduits from the formation to the well, providing for an increased fluid flow rate, and hence increased production of hydrocarbons. Two or more wells clustered together can be stimulated simultaneously with the same fracturing equipment.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) For a more complete understanding of the present disclosure, reference is now made to the following brief description, taken in connection with the accompanying drawings and detailed description, wherein like reference numerals represent like parts.

(2) FIG. **1** is a representative plot of typical vibration characteristics, in relation to head pressure and rate output, of industrial centrifugal pumps;
(3) FIG. **2**A is an example slurry pump curve, depicting best efficiency point (BEP), a preferred operating range (POR), and a desired operating range for an example slurry pump suitable for use in the system and method of this disclosure;
(4) FIG. **2**B is the example slurry pump curve of FIG. **2**A showing the extended operating range that can be provided via a blending system and method of this disclosure;
(5) FIG. **3**A is a schematic of a blending system, according to embodiments of this disclosure;
(6) FIG. **3**B is a schematic of another blending system, according to embodiments of this disclosure;
(7) FIG. **4** is a schematic of a slurry blender according to embodiments of this disclosure;
(8) FIG. **5** is a representative graph of performance as a function of time during an example proppant slurry blending operation, according to embodiments of this disclosure;
(9) FIG. **6** is a schematic of a hydraulic fracturing system, according to embodiments of this disclosure; and
(10) FIG. **7** is a block diagram of a computer system according to embodiments of the disclosure.

DETAILED DESCRIPTION

(11) It should be understood at the outset that although illustrative implementations of one or more embodiments are illustrated below, the disclosed systems and methods may be implemented using any number of techniques, whether currently known or not yet in existence. The disclosure should in no way be limited to the illustrative implementations, drawings, and techniques illustrated below, but may be modified within the scope of the appended claims along with their full scope of equivalents.

(12) Throughout this disclosure, a reference numeral followed by an alphabetical character refers to a specific instance of an element and the reference numeral alone refers to the element generically or collectively. Thus, as an example (not shown in the drawings), widget “1a” refers to an instance of a widget class, which may be referred to collectively as widgets “1” and any one of which may be referred to generically as a widget “1”. For example, reference to a slurry blender **40** can, in instances, include slurry blender **40**A, slurry blender **40**B, or a combination thereof.

(13) Stimulation operations can present a wide range of slurry pumping needs. For example, the slurry pump (e.g., on a blending trailer) may need to operate from 20 bpm to 80 bpm for different job conditions. By nature of their design, centrifugal slurry pumps typically have a narrow preferred operating range for increased efficiency and reduced wear, which operating range can be narrower for more abrasive slurries. It is generally not practical to select individual pumps and manifolds (e.g., of different sizes, metallurgy, etc.) for each disparate operating condition. Accordingly, equipment is conventionally often operated outside of a range that is desirable for best longevity of the equipment (e.g., the centrifugal pump(s) utilized for pumping proppant slurries).

(14) Increasing life of slurry pumps can be effected by limiting pump operating range to the POR, which conventionally mandates a different pump when a desired operating range is beyond the POR of the slurry pump being utilized. The different pump could have an improved metallurgy, or differing internal pump geometry/size, etc. However, metallurgy changes can result in a higher initial cost of the pump. Geometry changes to the slurry pump to reduce wear may also come with concomitant undesirable results, such as reducing pump rate or head pressure and/or increasing pump weight and cost.

(15) FIG. **1** is a representative plot of typical vibration characteristics of example, industrial centrifugal pumps. A given pump may have an allowable operating range in view of, for example, an allowable vibration limit. It may be preferable and recommended to operate the pump within a preferred operating range (POR) having a lower POR vibration limit (e.g., not exceeding the vibration limit). FIG. **2**A depicts pump curves, including head pressure (psig) and efficiency as a

function of the capacity for an example slurry centrifugal pump. As depicted in FIG. **2**A, the slurry pump can have a best efficiency point (BEP) flow rate (also referred to herein simply as a “BEP”). The preferred operating range (POR) for a pump (e.g., which provides a range from a “minimum POR flow rate” to a “maximum POR flow rate”) pumping a given slurry can be from a minimum recommended percentage of the BEP flow rate to a maximum recommended percentage of the BEP flow rate. The POR can depend on the characteristics (e.g., abrasiveness) of the given slurry being pumped. For example, TABLE 1 depicts an example wear service class designation for various slurries. A wear service class 1 can include light slurry class for mildly abrasive slurries; a wear service class 2 can include medium slurry class for abrasive slurries, a wear service class 3 can include heavy slurry class for highly abrasive slurries, and a wear service class 4 can include very heavy slurry class for extremely abrasive slurries. Proppant slurries can generally be abrasive, highly abrasive, or extremely abrasive, depending on the composition of the slurry (concentration and type of proppant, acidity, etc.).

(16) TABLE-US-00001 TABLE 1 Example Wear Service Classes Wear Service Class Slurry Class Equivalent Duty Class 1 Light Mildly Abrasive 2 Medium Abrasive 3 Heavy Highly Abrasive 4 Very Heavy Extremely Abrasive

(17) TABLE 2 depicts an example preferred operating range (POR) for each wear service class for an example slurry pump such as the pump of FIG. **2**A and FIG. **2**B. For a given slurry pump, the POR for a slurry of a given wear service class may be estimated and/or provided/recommended by a manufacturer.

(18) TABLE-US-00002 TABLE 2 Example Preferred Operating Ranges Based on Service Class Service Class Operating Limits 1 2 3 4 Preferred Operating 30-125% 40-120% 50-105% 60-100% Range (POR) (% of BEP Flow Rate)

(19) Operating within the POR can minimize pump wear (e.g., erosion) during pumping of the slurry. For a service class 4 slurry of Table 2, the example POR of the slurry pump of Table 2 has a POR of from 60 to 100% of the BEP flow rate. Accordingly, as depicted in FIG. **2**A, the preferred operating range within which slurry pump erosion can be minimized when pumping the given slurry in wear class 4 is from a minimum POR flow rate of 36 barrels per minute (bpm) to a maximum POR flow rate of 60 bpm, a range of just 24 (i.e., 60-36) bpm. This range can be much less than a desired range of operation. For example, in the example of FIG. **2**A, an example desired/needed blender operation range can be from 20 bpm to 80 bpm, a 60 (i.e., 80-20) bpm range.

(20) To enable maintenance of slurry pumps and associated header/manifold in a narrower operating range and close to the most desirable operating condition (e.g., within the POR), the slurry pump rate can be augmented by a clean fluid pump, as detailed herein, to increase a total system slurry production flow rate. Centrifugal pumps that are pumping clean fluid (e.g., a fluid comprising no or little proppant) are able to operate through a much wider operating flow rate range without exposure to abrasive wear. By operating a clean pump in parallel with a slurry pump, as disclosed herein, and metering the clean fluid stream into the slurry stream downstream of the slurry pump (e.g., to avoid increasing the total flow through the slurry pump that may exceed the POR), the slurry pump can be operated closer to (or at) its best efficiency point (BEP) and within the preferred operating range (POR). The combined (e.g., diluted) total slurry rate provided by the blender system can thus be higher than achievable by the slurry pump alone (when the slurry pump is operated within its POR), thus providing a desired amount of proppant slurry, while enabling a reduction in the wear on the slurry pump by keeping it within its desired percentage of the BEP flow rate.

(21) For example, FIG. **2**B is the example slurry pump curve of FIG. **2**A showing the extended operating range that can be provided via a blending system and method of this disclosure. As depicted in FIG. **2**B, although the POR is still between 36 and 60 bpm, the use of the clean fluid pump in addition to the slurry pump to provide the total slurry flow rate enables an extended

operating range of, for example, 36 bpm to 100 bpm, while maintaining operation of the slurry pump in the POR, and thus minimizing erosion thereof. In the example of FIG. **2**B, when augmenting the slurry pump with the clean pump in parallel, as per this disclosure, the blending unit slurry discharge rate range was increased from 24 bpm to 64 bpm, while maintaining the slurry pump operation within its desired preferred operating range to minimize wear.

(22) As detailed further hereinbelow, a blender/blending system of this disclosure can comprise a slurry pump (e.g., with associated flowmeter and pressure transducer), a clean pump (e.g., with associated flowmeter, and pressure transducer), a proportional valve to throttle addition of a clean flow stream to the slurry, and a control system to monitor (e.g., flowrates and pressures) and control (e.g., speed of centrifugal pumps and position of the proportional valve of) the blending system. The blender slurry pump can maintain a desired pressure to fracturing pumps (e.g., Quintuplex pumps or other high pressure fracturing pumps). Once the slurry pump rate enters the POR and/or approaches the maximum percentage BEP flow rate, additional slurry rate can be augmented by adding clean fluid (e.g., from a clean fluid centrifugal pump) to the slurry stream (e.g., downstream of the slurry pump). This can allow for a total higher slurry rate to be provided; that is, the total slurry rate can be greater than the maximum POR flow rate which is the maximum available slurry rate that can be achieved with the slurry pump alone while maintaining the slurry pump operation within the POR thereof.

(23) To maintain a proper clean fluid to concentrated slurry ratio, the control system can be configured to monitor the combined slurry and clean rates and control the proportion of clean rate (e.g., across a proportional valve) into the slurry stream. To ensure that the clean fluid enters the slurry stream, the proportion of clean fluid being added can be maintained at a higher discharge pressure (e.g., at least 10 psi or more higher) than the slurry pump discharge. This can be desirable, as flowing slurry across, for example, a proportional valve into the clean stream could undesirably erode the proportional valve.

(24) A slurry blender (or "blending unit" or "blending system") of this disclosure will now be described with reference to FIG. **3**A, which is a schematic of a blending system IA, according to embodiments of this disclosure, configured for providing a total flow rate of a proppant slurry; FIG. **3**B, which is a schematic of another blending system IB, according to embodiments of this disclosure, configured for providing a total flow rate of a proppant slurry; and FIG. **4**, which is a schematic of a slurry blender **40**A suitable for use in blending system IA of FIG. **3**A, according to embodiments of this disclosure.

(25) A blending system of this disclosure can comprise: a slurry pump **50**A operable to provide a concentrated slurry **45** in a concentrated slurry line **43**, wherein the concentrated slurry **45** has a higher concentration of a proppant **18** than the proppant slurry **47**; a clean fluid pump **50**B operable to provide a clean fluid **44** in a clean fluid line **42**, wherein the clean fluid is substantially proppant-free; and a control system (or "controller") **60** (described hereinbelow with reference to FIG. **4**). The controller **60** can be configured to monitor a concentrated slurry flow rate Q.sub.CS of the concentrated slurry **45** in the concentrated slurry line **43** and a clean fluid flow rate Q.sub.CF of the clean fluid **44** in the clean fluid line **42**, and control (e.g., a speed of) the concentrated slurry pump **50**A and (e.g., a speed of) the clean fluid pump **50**B, such that combination of the concentrated slurry **45** and the clean fluid **44** provides the proppant slurry **47** having the (e.g., desired/selected) total flow rate Q.sub.TS. The total flow rate Q.sub.TS of the proppant slurry **47** can be greater than a maximum slurry pump flow rate of a preferred operating range (POR) of the slurry pump **50**A (i.e., the maximum POR flow rate of the slurry pump **50**A), while the concentrated slurry flow rate Q.sub.CS can be less than or equal to the maximum slurry pump flow rate of the POR, (e.g., the slurry pump flow rate can be above the BEP and/or within the POR of the slurry pump can be maintained above the minimum rate of the POR and below the maximum rate of the POR)). The concentrated slurry **45** in slurry line **43** can be produced in a mixer **70** via combination of proppant **18** with water/dilution fluid (e.g., introduced, for example, from water inlet line **21**A via low

pressure boost pump **20**, water line **21**A, and/or flow meter FM**3**)).
(26) A flow meter FM**1** can be positioned on the concentrated slurry flow line **43** and a flow meter FM**2** can be positioned on clean fluid line **42**, and for providing the concentrated slurry flow rate Q.sub.CS of the concentrated fluid **45** and the clean fluid flow rate Q.sub.CF of the clean fluid **44**, respectively, to controller **60**.
(27) In embodiments, such as the embodiment of FIG. **3**A, the slurry pump **50**A and the clean fluid pump **50**B can be positioned on a (e.g., same or different) mobile blender apparatus, for example to provide slurry blender **40**A. In such embodiments, slurry blender **40**A can be positioned, for example, on a blender trailer or one or more skid(s)). In other embodiments, such as depicted in the embodiment of FIG. **3**B, a slurry blender **40**B can comprise the concentrated slurry blender **50**A, and the clean fluid blender **50**B can be separate, for example, can be provided by a clean boost pump (CBT) **30** or clean boost apparatus **35**, disparate from slurry blender **40**B. An output of slurry blender **40**A can comprise the proppant slurry **47**, while an output of slurry blender **40**B can comprise the concentrated slurry **45** (e.g., when the concentrated slurry **45** is combined with the clean fluid **44** after exit of the concentrated slurry **45**) or can comprise the proppant slurry **47** (e.g., when the concentrated slurry **45** is combined with the clean fluid **44** within (e.g., a blender header **46** of) slurry blender **40**B (as indicated by dashed line **44** in FIG. **3**B)).
(28) As depicted in the embodiment of FIG. **3**A, in embodiments, water from water source **10** can be introduced via water suction lines **11**A to a low pressure boost **20** (e.g., and water line **21**) to a dilution fluid inlet line **41** of the slurry blender **40**A/**40**B. One or more clean boost pump(s) **30** can be configured to introduce water/dilution fluid **36** from water source **10** to a (e.g., clean) manifold **80** (e.g., a manifold trailer configured to introduce proppant slurry **47** to one or more high pressure pumps **122** (described hereinbelow with reference to FIG. **6**). As noted hereinabove, mixer **70** can receive proppant **18** to produce the concentrated slurry **45**. Water from water source **10** can be introduced via water suction lines **11**B and a clean boost pump **30** via clean boost line **36** and/or a valve V**1** to manifold trailer **80** and/or via clean line **36** to one or more clean hydraulic fracturing pumps **122** (FIG. **6** hereinbelow). Valve V**1** can typically be closed to isolate the slurry **45** from clean fluid **44**, and the slurry and clean fluids can be combined after the high pressure pumps **122**.
(29) With reference back to the embodiment of FIG. **3**A, slurry blender **40**A/blending system IA can further include a blender header or low pressure manifold **46** (also referred to herein as a “slurry blender discharge manifold **46**”) fluidly connected to the concentrated slurry line **43** and the clean fluid line **42**. As depicted in FIG. **3**A, the concentrated slurry line **43** can be fluidly connected with a dirty/slurry side **46**A of the blender header **46**, and the clean fluid line **42** can be fluidly connected with another/clean side **46**B of the blender header **46**. In the embodiment of FIG. **3**A, blender header **46** further comprises one or more outlets **48** for extracting the proppant slurry **47** therefrom.
(30) With reference to the embodiment of FIG. **3**B, which depicts a blender system IB where the clean flow rate can be provided from a separate unit from the concentrated slurry **45** flow, slurry blender **40**B comprise discharge header **46** having one or more outlets **48** from which concentrated slurry **45** can be removed from slurry blender **40**B. In such embodiments, as detailed further hereinbelow with reference to FIG. **4**, slurry blender **40**B can comprise a clean fluid flow meter FM**2**, a proportional valve **49** (also referred to herein as an actuated valve or a dilution valve **49**) and associated feedback to controller **60**, and can also comprise clean fluid pump **50**B. In embodiments, clean boost pump **30** acts as clean fluid pump **50**B. In the embodiment of FIG. **3**B, clean boost apparatus **35** can receive water from one or more clean boost pumps **30**, and provide clean boost fluid in line **31** exiting therefrom. A portion of the clean boost fluid (e.g., clean fluid **44** for combination with the concentrated slurry **45**) can be provided from clean boost apparatus **35**, while a portion of clean boost **36** can be introduced to a manifold **124** (FIG. **6**) (e.g., a clean manifold **124** or a clean side of a manifold **124**) of manifold trailer **80**. The concentrated slurry **45** and the clean fluid **44** boost utilized to provide the proppant slurry **47** can be combined with the

concentrated slurry **45** downstream from discharge header **46**, within discharge header **46** (as depicted by dotted line **44**), prior to introduction into manifold **124** of manifold trailer **80**, or within a manifold **124** of manifold trailer **80**. In such embodiments, the one or more outlets **48** of discharge header **46** can be for the removal of proppant slurry **47** from the slurry blender **40**B. The clean boost **36** can be introduced to a same or a different manifold **124** or manifold trailer **50** than the concentrated slurry **45**, the proppant slurry **47**, or the clean fluid **44**. A flow meter FM**4** can be positioned on clean boost line **31** upstream of separation of water in line **36** therefrom, as depicted in FIG. **3**B. A portion of the water from water source **10** can thus be introduced via water suction lines **11**B and a clean boost pump **30** via clean boost line **36** and/or a valve V**1** to manifold trailer **80** and/or via clean line **36** to one or more clean hydraulic fracturing pumps **122** (FIG. **6** hereinbelow). As noted hereinabove with reference to FIG. **3**A, concentrated slurry **45** in slurry line **43** can be produced in a mixer **70** via combination of proppant **18** with water/dilution fluid (e.g., introduced, for example, from water inlet line **11**A via low pressure boost pump **20**, water line **21**A, and/or flow meter FM**3**)).

(31) Controller **60** can be further configured to monitor a concentrated slurry pressure P.sub.CS of the concentrated slurry **45** in the concentrated slurry line **43** and a clean fluid pressure P.sub.CF of the clean fluid **44** in the clean fluid line **42**, and control (e.g., a position of) a proportional valve **49** between the clean side **46**B of the blender header **46** and the dirty side **46**A of the blender header **46** to ensure that (e.g., only) clean fluid **44** (and not concentrated slurry **45**) passes through the proportional valve **49**. This can help ensure long life of the proportional valve **49**. If the concentrated slurry flow rate is Q.sub.CS and the clean fluid flow rate is Q.sub.CF, the total slurry flow rate of proppant slurry Q.sub.TS provided by the system can be depicted as Q.sub.TS=Q.sub.CS+Q.sub.CF. For example, if the concentrated slurry flow rate Q.sub.CS is 60 bpm and the clean fluid flow rate (e.g., the “clean boost” provided by the clean fluid centrifugal pump **50**B) Q.sub.CF is 40, then the combined flow rate of the proppant slurry **47** is 100 bpm. With reference to the example slurry pump **50**A of FIG. **2**A and FIG. **2**B, such a slurry pump having a maximum POR of 60 bpm, the clean boost provided by the clean fluid pump **50**B enables a total proppant slurry flow rate of 100 bpm, while still operating the slurry pump **50**A within the POR.

(32) The controller can control operation (e.g., of slurry blender **40**A) such that the clean fluid pressure of the clean fluid **44** in the clean fluid line **42** is at least 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, or 20 psi (or at least 15, 20, 25, 30, or 35%) greater than the concentrated slurry pressure of the concentrated slurry **45** in the concentrated slurry line **43** (e.g., such that only clean fluid **44** passes through the proportional valve **49**). The controller **60** can thus have a rate control function to slave the clean rate Q.sub.CF to the concentrated slurry rate Q.sub.CS.

(33) In embodiments, such as the embodiment of FIG. **3**A, slurry pump **50**A, clean pump **50**B, and the blender header **46** are positioned on a (e.g., same) apparatus (e.g., a mobile unit, trailer or skid(s)).

(34) As noted hereinabove, the blending system of this disclosure can include a flow meter FM**1** on the concentrated slurry line **43**, a flow meter FM**2** on the clean fluid line **42**, a pressure transducer T**1** (FIG. **4**) on the concentrated slurry line **43**, and a pressure transducer T**2** (FIG. **4**) on the clean fluid line **42**. The controller **60** can be in communication with the flow meter FM**1**, the flow meter FM**2**, the transducer T**1**, and/or the transducer T**2**, and can receive concentrated slurry flow rate Q.sub.CS information from the flow meter FM**1** on the concentrated slurry line **43**, clean fluid flow rate Q.sub.CF information from the flow meter FM**2** on the clean fluid line **42**, concentrated slurry pressure P.sub.CS information from the pressure transducer T**1** on the concentrated slurry line **43**, and clean fluid pressure P.sub.CF information from the transducer T**2** on the clean fluid line **42** to control operation of the slurry blender **40**A/blending system IA/IB.

(35) The system can further include a manifold **124** (e.g., of a manifold trailer **50** downstream from the blender **40**A/**40**B) configured to feed the proppant slurry **47** to one or more (e.g., “dirty”) hydraulic fracturing pumps **122**. As mentioned hereinabove, the manifold **124** can be configured to

receive: (a) the concentrated slurry **45** and the clean fluid **44**, or (b) the proppant slurry **47** (e.g., from the blender **40**A/**40**B, the slurry pump **50**A, the clean pump **50**B, and/or clean boost apparatus **35**).

(36) FIG. **5** is a representative graph of performance as a function of time during an example proppant slurry blending operation utilizing the pump described in FIG. **1**, FIG. **2**A and FIG. **2**B. For this example operation, the concentrated slurry pump rate Q.sub.CS was established at 60 bpm, the pump BEP flow rate. At this point, the total slurry rate Q.sub.TS from the unit was 60 bpm, as shown by the "selected dirty rate" Q.sub.TS line. To increase the total slurry rate Q.sub.TS, the clean fluid rate Q.sub.CF of clean fluid **44** ("clean discharge pump rate" Q.sub.CF line in FIG. **5**) was metered into the slurry pump **50**A discharge stream comprising the concentrated slurry **45** at various rate steps ("Dilution Valve **49** Conc SetP" line in FIG. **5**) until the total slurry rate Q.sub.TS from the unit was 100 bpm, while maintaining the slurry pump **50**A at its BEP, 60 bpm. As the dilution/proportional valve **49** is opened ("Dilution Valve **49** % Open" in FIG. **5**) via the various rate steps ("Dilution Valve **49** Conc SetP" line in FIG. **5**), additional clean fluid **44** (e.g., Q.sub.CF line in FIG. **5**) is combined with the concentrated slurry **45** (e.g., Q.sub.CS line in FIG. **5**) to provide the total proppant slurry **47** (e.g., Q.sub.TS in FIG. **5**). Operation in this manner can be utilized to increase the capability of the unit blending unit/system, minimize slurry pump **50**A wear, and can potentially allow for decreasing the size of the slurry pump **50**A in applications requiring less total slurry rate Q.sub.TS.

(37) Reference will now be made to FIG. **6**, which is a block diagram of a hydraulic fracturing system **100** treating one well **130**, the hydraulic fracturing system **100** comprising a blending system IA/IB of this disclosure. In embodiments, the blending system comprises a slurry blender **40**A or slurry blender **40**B, as described hereinabove.

(38) In embodiments, the proppant slurry **47** provided as described hereinabove with reference to FIG. **3**A, FIG. **3**B, and/or FIG. **4**, can be introduced into a fracturing manifold **124** fluidly connected with one or more (e.g., high pressure) fracturing pumps **122** configured to introduce a fracturing fluid (e.g., a "dirty" fluid comprising proppant) **123** into a (e.g., first) well **130**. Although not depicted in the embodiment of FIG. **6**, the proppant slurry **47** can be combined with clean fluid (e.g., from a clean manifold **124**) prior to introduction into well **130** and/or the proppant slurry **47** can be introduced into more than one manifold **124** for introduction into a plurality of wells **130**. Furthermore, the proppant slurry **47** or a treatment fluid **123** comprising or consisting essentially of same can be introduced to more than one well **130**, in embodiments.

(39) FIG. **6** depicts the proppant slurry **47** (and/or clean fluid in clean line **36**) being introduced into a manifold **124**, wherein low pressure lines **126** introduce the fluid into the high pressure fracturing pumps **122**, and high pressure fluid is returned via high pressure lines **128** to line **123** for introduction into the well **130** for treatment. As depicted, the pumping capacity of the fracturing fleet can be divided into a dirty fluid group **250** and a clean fluid group **260**.

(40) Frac pumps **122** can be high pressure (e.g., positive displacement) pumps, while slurry pump **50**A, clean fluid pump **50**B/clean boost pump **30** can be low pressure (e.g., centrifugal) pumps.

(41) The hydraulic fracturing system **100** of FIG. **6** can be utilized to pump hydraulic fracturing fluids **123** into a wellbore **130**, is illustrated. As depicted, a plurality of hydraulic fracturing pumps **122** (also referred to as "frac pump" or high horsepower pumps) can be connected in parallel to a fracturing manifold **124** (also referred to as a "missile") to provide fracturing fluids **123** to the treatment well **130** (also referred to as the wellhead). The fracturing fluids (e.g., pumped into well(s) **130** via line **123**) are typically a blend of friction reducer and water, e.g., slick water, and proppant, although any fracturing or treatment fluid comprising proppant can be introduced into one or more wells **130** according to this disclosure.

(42) The blending system IA/IB is in fluid communication with the manifold **124** so that the fracturing treatment is pumped into the manifold **124** for distribution to the frac pumps **122**, via (e.g., low pressure) supply line **126**. The fracturing fluids are returned to the manifold **124** from the

frac pumps **122**, via high pressure line **128**, to be pumped into the treatment well **130** that is in fluid communication with the manifold **124**. Although fracturing fluids typically contain a proppant, a portion of the pumping sequence may include a fracturing fluid without proppant (sometimes referred to as a pad fluid or a flush fluid herein). Although fracturing fluids typically include a gelled fluid, the fracturing fluid may be blended without a gelling chemical. Alternatively, the fracturing fluids can be blended with an acid to produce an acid fracturing fluid, for example, pumped as part of a spearhead or acid stage that clears debris that may be present in the wellbore and/or fractures to help clear the way for fracturing fluid to access the fractures and surrounding formation.

(43) A control van **110** can be communicatively coupled (e.g., via a wired or wireless network) to any of the frac units wherein the term "frac units" may refer to any of the plurality of frac pumps **122**, a manifold **124**, a blending system IA/IB, etc. The managing application **136** executing on a computer (e.g., server) **132** within the control van **110** can establish unit level control over the frac units communicated via the network. Unit level control can include sending instructions to the frac units and/or receiving equipment data from the frac units. For example, the managing application **136** within the control van **110** can establish a pump rate of 25 bpm with the plurality of frac pumps **122** while receiving pressure and rate of pump crank revolutions from sensors on the frac pumps **122**. The control van **110** can comprise controller **60** described above for controlling operation of blending system IA/IB, or they can be separate controllers. In embodiments, control van or controller **110** can include controller **60** controlling blending system IA/IB.

(44) Although the managing application **136** is described as executing on a computer **132**, it is understood that the computer **132** can be a computer system, for example computer system **380** in FIG. **10**, or any form of a computer system such as a server, a workstation, a desktop computer, a laptop computer, a tablet computer, a smartphone, or any other type of computing device. The computer **132** (e.g., computer system) can include one or more processors, memory, input devices, and output devices, as described in more detail further hereinafter. Although the control van **110** is described as having the managing application **136** executing on a computer **132**, it is understood that the control van **110** can have 2, 3, 4, or any number of computers **132** (e.g., computer systems) with 2, 3, 4, or any number of managing applications **136** executing on the computers **132**.

(45) A method of this disclosure can comprise: (operating a blender IA/IB/slurry blender **40**A to provide) providing a total flow rate Q.sub.TS of a proppant slurry **47** by: utilizing a slurry pump **50**A to provide a concentrated slurry flow rate Q.sub.CS of a concentrated slurry **45**, wherein the concentrated slurry **45** has a higher concentration of a proppant **18** than the proppant slurry **47**, wherein the total flow rate of the proppant slurry Q.sub.TS is greater than a maximum slurry pump flow rate of a preferred operating range (POR) of the slurry pump (e.g., is greater than the maximum POR flow rate of the slurry pump **50**A), and wherein the concentrated slurry flow rate Q.sub.CS is less than or equal to the maximum slurry pump flow rate (e.g., the maximum POR flow rate); and utilizing a clean fluid pump **50**B (e.g., to augment the concentrated slurry pump rate Q.sub.CS) to provide a clean pump flow rate Q.sub.CF of a clean fluid **44**, wherein the clean fluid **44** is substantially proppant-free; and combining the clean pump **50**B flow rate Q.sub.CF of the clean fluid **44** with the concentrated slurry flow rate Q.sub.CS of the concentrated slurry **45** to provide the total pump flow rate Q.sub.TS of the proppant slurry **47**.

(46) The method can further comprise determining the maximum slurry pump flow rate (e.g., the maximum POR flow rate) by: determining a wear service class of the concentrated slurry **45**; finding or estimating a best efficiency point (BEP) flow rate of the slurry pump **50**A being utilized to provide the concentrated slurry **45**; finding or estimating, as a percentage of the BEP flow rate, a (e.g., manufacturer recommended) preferred operating range (POR) of the slurry pump **50**A being utilized to pump the concentrated slurry **45** in the wear service class, from a minimum recommended percentage of the BEP flow rate to a maximum recommended percentage of the BEP flow rate; and calculating the maximum pump slurry flow rate (e.g., the maximum POR flow rate)

by multiplying the maximum recommended percentage of the POR by the BEP flow rate.
(47) The method can further comprise maintaining the concentrated slurry flow rate Q.sub.CS below the maximum slurry pump flow rate Q.sub.TS. In embodiments, for example, the method can comprise maintaining the concentrated slurry flow rate Q.sub.CS just below (e.g., within 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, or 20% of) the maximum slurry pump flow rate Q.sub.TS. The method can further include determining the minimum pump slurry flow rate (e.g., the minimum POR flow rate) by multiplying the minimum recommended percentage of the POR by the BEP flow rate, and maintaining operation of the slurry pump **50**A such that the concentrated slurry flow rate Q.sub.CS discharged therefrom remains at or above (e.g., within 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, or 20% of) the minimum POR flow rate.
(48) Combining the clean pump flow rate Q.sub.CF of the clean fluid **44** with the concentrated slurry flow rate Q.sub.CS of the concentrated slurry **45** to provide the total pump flow rate Q.sub.TS of the proppant slurry **47** can further comprise providing the concentrated slurry **45** and the clean fluid **44** to a blender header **46** and extracting the proppant slurry **47** from (e.g., one or more discharge hoses fluidly connected to) the blender header **46**. As noted hereinabove, the slurry pump **50**A, the clean pump **50**B, and the blender header **46** can be positioned on a (e.g., same or one or more different) mobile blender apparatus (e.g., a blender trailer or skid(s)).
(49) Providing the concentrated slurry **45** and the clean fluid **44** to the blender header **46** can further comprise introducing the clean fluid **44** from a clean side **46**B of the blender header **46** and via a proportional valve **49** to a dirty side **46**A of the blender header **46**. The proportional valve (e.g., “proportional control valve”) **49** can combine the clean fluid **44** as a proportion of the concentrated slurry **45**. For example, the clean fluid **44** can be combined as 10, 20, 30, 40, 50, 60%, or more of the concentrated slurry **45** to provide the proppant slurry **47**. In embodiments, the fluid flow can be limited by the maximum rate of the clean pump and the proppant rate in the slurry.
(50) The method can further comprise maintaining the clean fluid **44** at or above a clean fluid pressure P.sub.CF that is at least 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, or 20 psi (or at least 15, 20, 25, 30, or 35%) greater than a concentrated slurry pressure P.sub.CS of the concentrated slurry **45** (such that only clean fluid **44** passes through the proportional valve **49**).
(51) Providing the concentrated slurry **45** and the clean fluid **44** to the blender header **46** can further comprise providing the concentrated slurry **45** to the blender header **46** from the slurry pump **50**A via a concentrated slurry flow line **43** and providing the clean fluid **44** from the clean fluid pump **50**B (e.g., clean boost apparatus **35**/clean boost pump **30**) to the blender header **46** via a clean fluid flow line **42**. The method can further comprise utilizing a control system **60** to monitor the concentrated slurry flow rate Q.sub.CS in the concentrated slurry line **43** and the clean fluid flow rate Q.sub.CF of the clean fluid **44** in the clean fluid line **42**, the concentrated slurry pressure P.sub.CS and the clean fluid pressure P.sub.CF, and control (e.g., a speed of) the concentrated slurry pump **50**A, (e.g., a speed of) the clean fluid pump **50**B, and (e.g., a position of) the proportional valve **49** to provide the proppant slurry **47** having the total flow rate Q.sub.TS. The slurry pump **50**A and the clean pump **50**B can be positioned on a (e.g., same or different) apparatus (e.g., a mobile blender apparatus (e.g., a blender trailer or skid(s))).
(52) Combining the clean pump flow rate Q.sub.CF of the clean fluid **44** with the concentrated slurry flow rate Q.sub.CS of the concentrated slurry **45** to provide the total pump flow rate Q.sub.TS of the proppant slurry **47** can further comprise providing the concentrated slurry **45** and the clean fluid **44**, separately or in combination as the proppant slurry **47**, to a manifold **124** (e.g., of a manifold trailer **80**) configured to feed the proppant slurry **47** to one or more (e.g., “dirty”) hydraulic fracturing pumps **122**.
(53) The method can further comprise introducing the proppant slurry **47** downhole in a hydraulic fracturing operation.
(54) In embodiments, a method of providing a total flow rate Q.sub.TS of a proppant slurry **47** comprising a proppant **18**, according to this disclosure comprises: determining a maximum (e.g., a

preferred operating) slurry pump **50**A flow rate for minimizing wear (e.g., a maximum POR flow rate) on a slurry pump **50**A pumping a concentrated slurry **45** by: determining a wear service class of the concentrated slurry **45**; finding or estimating a best efficiency point (BEP) flow rate of the slurry pump **50**A being utilized to provide the concentrated slurry **45**; finding or estimating, as a percentage of the BEP, a (e.g., manufacturer recommended) preferred operating range (POR) of the slurry pump **50**A being utilized to pump the concentrated slurry **45** in the wear service class, from a minimum recommended percentage of the BEP flow rate to a maximum recommended percentage of the BEP flow rate; and calculating the maximum pump slurry flow rate (e.g., the maximum POR flow rate) by multiplying the maximum recommended percentage of the POR by the BEP flow rate; and combining a clean pump flow rate Q.sub.CF of a clean fluid **44** from a clean fluid pump **50**B with a concentrated slurry flow rate Q.sub.CS of the concentrated slurry **45** from the slurry pump **50**A to provide the total pump flow rate Q.sub.TS of the proppant slurry **47**, wherein the concentrated slurry **45** has a higher concentration of the proppant **18** than the proppant slurry **47**, wherein the total flow rate Q.sub.TS of the proppant slurry **47** is greater than the maximum slurry pump flow rate (e.g., the maximum POR flow rate) of the slurry pump **50**A, wherein the concentrated slurry flow rate Q.sub.CS is less than the maximum slurry pump flow rate (e.g., the maximum POR flow rate), and wherein the clean fluid **44** is substantially proppant-free.
(55) The method can further comprise maintaining the concentrated slurry flow rate Q.sub.CS (e.g., just) below (e.g., within 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, or 20% of) the maximum slurry pump flow rate (e.g., the maximum POR flow rate).
(56) Combining the clean pump flow rate Q.sub.CF of the clean fluid **44** with the concentrated slurry flow rate Q.sub.CS of the concentrated slurry **45** to provide the total pump flow rate Q.sub.TS of the proppant slurry **47** can further comprise providing the concentrated slurry **45** and the clean fluid **44** to a blender header **46** and extracting the proppant slurry **47** from (e.g., one or more discharge hoses fluidly connected to) the blender header **46**.
(57) Providing the concentrated slurry **45** and the clean fluid **44** to the blender header **46** can further comprise introducing the clean fluid **44** from a clean side **46**B of the blender header **46** and via a proportional valve **49** to a dirty side **46**A of the blender header **46**. Introducing the clean fluid **44** from the clean side **46**B of the blender header **46** and via the proportional valve **49** to the dirty side **46**A of the blender header **46** can further comprise introducing the clean fluid **44** at a clean fluid pressure P.sub.CF that is at least 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, or 20 psi (or at least 15, 20, 25, 30, or 35%) greater than a concentrated slurry pressure P.sub.CS of the concentrated slurry **45** (e.g., such that only clean fluid **44** passes through the proportional valve **49**).
(58) Providing the concentrated slurry **45** and the clean fluid **44** to the blender header **46** can further comprise providing the concentrated slurry **45** to the blender header **46** from the slurry pump **50**A via a concentrated slurry flow line **43** and providing the clean fluid **44** from the clean fluid pump **50**B to the blender header **46** via a clean fluid flow line **42**. The method can further comprise utilizing a control system **60** to monitor the concentrated slurry flow rate Q.sub.CS in the concentrated slurry line **43** and the clean fluid flow rate Q.sub.CF of the clean fluid **44** in the clean fluid line **42**, the concentrated slurry pressure P.sub.CS (e.g., in the concentrated slurry line **43**/concentrated slurry **45** on the dirty side **46**A of the header **46**), and the clean fluid pressure Q.sub.CF (e.g., in the clean fluid line **42**/clean fluid **44** on the clean side **46**B of the blender header **46**), and control (e.g., a speed of) the concentrated slurry pump **50**A, (e.g., a speed of) the clean fluid pump **50**B, and (e.g., a position of) the proportional valve **49** to provide the proppant slurry **47** having the total flow rate Q.sub.TS.
(59) FIG. **7** illustrates a computer system **380** suitable for implementing one or more embodiments disclosed herein, for example implementing one or more computers, servers or the like as disclosed or used herein, including without limitation any aspect of the computing system associated with controller **30** or control van **110** (e.g., computer **132**). The computer system **380** includes a processor **382** (which may be referred to as a central processor unit or CPU) that is in

communication with memory devices including secondary storage **384**, read only memory (ROM) **386**, random access memory (RAM) **388**, input/output (I/O) devices **390**, and network connectivity devices **392**. The processor **382** may be implemented as one or more CPU chips.

(60) It is understood that by programming and/or loading executable instructions onto the computer system **380**, at least one of the CPU **382**, the RAM **388**, and the ROM **386** are changed, transforming the computer system **380** in part into a particular machine or apparatus having the novel functionality taught by the present disclosure. It is fundamental to the electrical engineering and software engineering arts that functionality that can be implemented by loading executable software into a computer can be converted to a hardware implementation by well-known design rules. Decisions between implementing a concept in software versus hardware typically hinge on considerations of stability of the design and numbers of units to be produced rather than any issues involved in translating from the software domain to the hardware domain. Generally, a design that is still subject to frequent change may be preferred to be implemented in software, because re-spinning a hardware implementation is more expensive than re-spinning a software design. Generally, a design that is stable that will be produced in large volume may be preferred to be implemented in hardware, for example in an application specific integrated circuit (ASIC), because for large production runs the hardware implementation may be less expensive than the software implementation. Often a design may be developed and tested in a software form and later transformed, by well-known design rules, to an equivalent hardware implementation in an application specific integrated circuit that hardwires the instructions of the software. In the same manner as a machine controlled by a new ASIC is a particular machine or apparatus, likewise a computer that has been programmed and/or loaded with executable instructions may be viewed as a particular machine or apparatus.

(61) Additionally, after the computer system **380** is turned on or booted, the CPU **382** may execute a computer program or application. For example, the CPU **382** may execute software or firmware stored in the ROM **386** or stored in the RAM **388**. In some cases, on boot and/or when the application is initiated, the CPU **382** may copy the application or portions of the application from the secondary storage **384** to the RAM **388** or to memory space within the CPU **382** itself, and the CPU **382** may then execute instructions that the application is comprised of. In some cases, the CPU **382** may copy the application or portions of the application from memory accessed via the network connectivity devices **392** or via the I/O devices **390** to the RAM **388** or to memory space within the CPU **382**, and the CPU **382** may then execute instructions that the application is comprised of. During execution, an application may load instructions into the CPU **382**, for example load some of the instructions of the application into a cache of the CPU **382**. In some contexts, an application that is executed may be said to configure the CPU **382** to do something, e.g., to configure the CPU **382** to perform the function or functions promoted by the subject application. When the CPU **382** is configured in this way by the application, the CPU **382** becomes a specific purpose computer or a specific purpose machine.

(62) The secondary storage **384** is typically comprised of one or more disk drives or tape drives and is used for non-volatile storage of data and as an over-flow data storage device if RAM **388** is not large enough to hold all working data. Secondary storage **384** may be used to store programs which are loaded into RAM **388** when such programs are selected for execution. The ROM **386** is used to store instructions and perhaps data which are read during program execution. ROM **386** is a non-volatile memory device which typically has a small memory capacity relative to the larger memory capacity of secondary storage **384**. The RAM **388** is used to store volatile data and perhaps to store instructions. Access to both ROM **386** and RAM **388** is typically faster than to secondary storage **384**. The secondary storage **384**, the RAM **388**, and/or the ROM **386** may be referred to in some contexts as computer readable storage media and/or non-transitory computer readable media.

(63) I/O devices **390** may include printers, video monitors, liquid crystal displays (LCDs), touch screen displays, keyboards, keypads, switches, dials, mice, track balls, voice recognizers, card

readers, paper tape readers, or other well-known input devices.
(64) The network connectivity devices **392** may take the form of modems, modem banks, Ethernet cards, universal serial bus (USB) interface cards, serial interfaces, token ring cards, fiber distributed data interface (FDDI) cards, wireless local area network (WLAN) cards, radio transceiver cards, and/or other well-known network devices. The network connectivity devices **392** may provide wired communication links and/or wireless communication links (e.g., a first network connectivity device **392** may provide a wired communication link and a second network connectivity device **392** may provide a wireless communication link). Wired communication links may be provided in accordance with Ethernet (IEEE 802.3), Internet protocol (IP), time division multiplex (TDM), data over cable service interface specification (DOCSIS), wavelength division multiplexing (WDM), and/or the like. In an embodiment, the radio transceiver cards may provide wireless communication links using protocols such as code division multiple access (CDMA), global system for mobile communications (GSM), long-term evolution (LTE), WiFi (IEEE 802.11), Bluetooth, Zigbee, narrowband Internet of things (NB IoT), near field communications (NFC), radio frequency identity (RFID). The radio transceiver cards may promote radio communications using 5G, 5G New Radio, or 5G LTE radio communication protocols. These network connectivity devices **392** may enable the processor **382** to communicate with the Internet or one or more intranets. With such a network connection, it is contemplated that the processor **382** might receive information from the network, or might output information to the network in the course of performing the above-described method steps. Such information, which is often represented as a sequence of instructions to be executed using processor **382**, may be received from and outputted to the network, for example, in the form of a computer data signal embodied in a carrier wave.
(65) Such information, which may include data or instructions to be executed using processor **382** for example, may be received from and outputted to the network, for example, in the form of a computer data baseband signal or signal embodied in a carrier wave. The baseband signal or signal embedded in the carrier wave, or other types of signals currently used or hereafter developed, may be generated according to several methods well-known to one skilled in the art. The baseband signal and/or signal embedded in the carrier wave may be referred to in some contexts as a transitory signal.
(66) The processor **382** executes instructions, codes, computer programs, scripts which it accesses from hard disk, floppy disk, optical disk (these various disk based systems may all be considered secondary storage **384**), flash drive, ROM **386**, RAM **388**, or the network connectivity devices **392**. While only one processor **382** is shown, multiple processors may be present. Thus, while instructions may be discussed as executed by a processor, the instructions may be executed simultaneously, serially, or otherwise executed by one or multiple processors. Instructions, codes, computer programs, scripts, and/or data that may be accessed from the secondary storage **384**, for example, hard drives, floppy disks, optical disks, and/or other device, the ROM **386**, and/or the RAM **388** may be referred to in some contexts as non-transitory instructions and/or non-transitory information.
(67) In an embodiment, the computer system **380** may comprise two or more computers in communication with each other that collaborate to perform a task. For example, but not by way of limitation, an application may be partitioned in such a way as to permit concurrent and/or parallel processing of the instructions of the application. Alternatively, the data processed by the application may be partitioned in such a way as to permit concurrent and/or parallel processing of different portions of a data set by the two or more computers. In an embodiment, virtualization software may be employed by the computer system **380** to provide the functionality of a number of servers that is not directly bound to the number of computers in the computer system **380**. For example, virtualization software may provide twenty virtual servers on four physical computers. In an embodiment, the functionality disclosed above may be provided by executing the application and/or applications in a cloud computing environment. Cloud computing may comprise providing

computing services via a network connection using dynamically scalable computing resources. Cloud computing may be supported, at least in part, by virtualization software. A cloud computing environment may be established by an enterprise and/or may be hired on an as-needed basis from a third party provider. Some cloud computing environments may comprise cloud computing resources owned and operated by the enterprise as well as cloud computing resources hired and/or leased from a third party provider.

(68) In an embodiment, some or all of the functionality disclosed above may be provided as a computer program product. The computer program product may comprise one or more computer readable storage medium having computer usable program code embodied therein to implement the functionality disclosed above. The computer program product may comprise data structures, executable instructions, and other computer usable program code. The computer program product may be embodied in removable computer storage media and/or non-removable computer storage media. The removable computer readable storage medium may comprise, without limitation, a paper tape, a magnetic tape, magnetic disk, an optical disk, a solid state memory chip, for example analog magnetic tape, compact disk read only memory (CD-ROM) disks, floppy disks, jump drives, digital cards, multimedia cards, and others. The computer program product may be suitable for loading, by the computer system **380**, at least portions of the contents of the computer program product to the secondary storage **384**, to the ROM **386**, to the RAM **388**, and/or to other non-volatile memory and volatile memory of the computer system **380**. The processor **382** may process the executable instructions and/or data structures in part by directly accessing the computer program product, for example by reading from a CD-ROM disk inserted into a disk drive peripheral of the computer system **380**. Alternatively, the processor **382** may process the executable instructions and/or data structures by remotely accessing the computer program product, for example by downloading the executable instructions and/or data structures from a remote server through the network connectivity devices **392**. The computer program product may comprise instructions that promote the loading and/or copying of data, data structures, files, and/or executable instructions to the secondary storage **384**, to the ROM **386**, to the RAM **388**, and/or to other non-volatile memory and volatile memory of the computer system **380**.

(69) In some contexts, the secondary storage **384**, the ROM **386**, and the RAM **388** may be referred to as a non-transitory computer readable medium or a computer readable storage media. A dynamic RAM embodiment of the RAM **388**, likewise, may be referred to as a non-transitory computer readable medium in that while the dynamic RAM receives electrical power and is operated in accordance with its design, for example during a period of time during which the computer system **380** is turned on and operational, the dynamic RAM stores information that is written to it. Similarly, the processor **382** may comprise an internal RAM, an internal ROM, a cache memory, and/or other internal non-transitory storage blocks, sections, or components that may be referred to in some contexts as non-transitory computer readable media or computer readable storage media.

(70) The herein disclosed system and method allow for reduced capital costs via the use of smaller slurry pumps **50**A, less slurry pump wear, lower maintenance cost, and/or wider equipment operating ranges. The system and method of this disclosure can provide an increased total proppant slurry **47** discharge rate Q.sub.TS with a slurry pump **50**A operated within the POR, by augmenting a concentrated slurry flow rate Q.sub.CS with a clean fluid discharge rate (or “boost”) Q.sub.CS from a clean fluid pump **50**B.

(71) The herein disclosed system and method can provide for increased operating life and reduced non-productive time (NPT) of frac blending equipment.

(72) While several embodiments have been provided in the present disclosure, it should be understood that the disclosed systems and methods may be embodied in many other specific forms without departing from the spirit or scope of the present disclosure. The present examples are to be considered as illustrative and not restrictive, and the intention is not to be limited to the details given herein. For example, the various elements or components may be combined or integrated in

another system or certain features may be omitted or not implemented.

(73) Also, techniques, systems, subsystems, and methods described and illustrated in the various embodiments as discrete or separate may be combined or integrated with other systems, modules, techniques, or methods without departing from the scope of the present disclosure. Other items shown or discussed as directly coupled or communicating with each other may be indirectly coupled or communicating through some interface, device, or intermediate component, whether electrically, mechanically, or otherwise. Other examples of changes, substitutions, and alterations are ascertainable by one skilled in the art and could be made without departing from the spirit and scope disclosed herein.

ADDITIONAL DISCLOSURE

(74) The following are non-limiting, specific embodiments in accordance with the present disclosure:

(75) In a first embodiment, a method comprises: (e.g., operating a blender to provide) providing a total flow rate of a proppant slurry by: utilizing a slurry pump (of the blender) to provide a concentrated slurry flow rate of a concentrated slurry, wherein the concentrated slurry has a higher concentration of the proppant than the proppant slurry, wherein the total flow rate of the proppant slurry is greater than a maximum slurry pump flow rate of a preferred operating range (POR) of the slurry pump, and wherein the concentrated slurry flow rate is less than or equal to the maximum slurry pump flow rate; and utilizing a clean fluid pump (e.g., to augment the concentrated slurry pump rate) to provide a clean pump flow rate of a clean fluid, wherein the clean fluid is substantially proppant-free; and combining the clean pump flow rate of the clean fluid with the concentrated slurry flow rate of the concentrated slurry to provide the total pump flow rate of the proppant slurry.

(76) A second embodiment can include the method of the first embodiment further comprising determining the maximum slurry pump flow rate by: determining a wear service class of the concentrated slurry; finding or estimating a best efficiency point (BEP) flow rate of the slurry pump being utilized to provide the concentrated slurry; finding or estimating, as a percentage of the BEP flow rate, a (e.g., manufacturer recommended) preferred operating range (POR) of the slurry pump being utilized to pump the concentrated slurry in the wear service class, from a minimum recommended percentage of the BEP flow rate to a maximum recommended percentage of the BEP flow rate; and calculating the maximum pump slurry flow rate by multiplying the maximum recommended percentage of the POR by the BEP flow rate.

(77) A third embodiment can include the method of the first or second embodiment further comprising maintaining the concentrated slurry flow rate (e.g.) just below (e.g., within 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, or 20% of) the maximum slurry pump flow rate (e.g., maintaining the slurry pump rate above the BEP and/or maintaining the concentrated slurry flow rate within the POR of the slurry pump).

(78) A fourth embodiment can include the method of any one of the first to third embodiments, wherein combining the clean pump flow rate of the clean fluid with the concentrated slurry flow rate of the concentrated slurry to provide the total pump flow rate of the proppant slurry further comprises providing the concentrated slurry and the clean fluid to a blender header and extracting the proppant slurry from (e.g., one or more discharge hoses fluidly connected to) the blender header.

(79) A fifth embodiment can include the method of the fourth embodiment, wherein the slurry pump, the clean pump, and the blender header are positioned on a (e.g., same) mobile blender apparatus (e.g., a blender trailer or skid(s)).

(80) A sixth embodiment can include the method of the fourth or fifth embodiment, wherein providing the concentrated slurry and the clean fluid to the blender header further comprises introducing the clean fluid from a clean side of the blender header and via a proportional valve to a dirty side of the blender header.

(81) A seventh embodiment can include the method of the sixth embodiment further comprising maintaining the clean fluid at or above a clean fluid pressure that is at least 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, or 20 psi (or at least 15, 20, 25, 30, or 35%) greater than a concentrated slurry pressure of the concentrated slurry (such that only clean fluid passes through the proportional valve).
(82) An eighth embodiment can include the method of the sixth or seventh embodiment, wherein providing the concentrated slurry and the clean fluid to the blender header further comprises providing the concentrated slurry to the blender header from the slurry pump via a concentrated slurry flow line and providing the clean fluid from the clean fluid pump to the blender header via a clean fluid flow line, and wherein the method further comprises utilizing a control system to monitor the concentrated slurry flow rate in the concentrated slurry line and the clean fluid flow rate of the clean fluid in the clean fluid line, the concentrated slurry pressure and the clean fluid pressure, and control a speed of the concentrated slurry pump, a speed of the clean fluid pump, and a position of the proportional valve to provide the proppant slurry having the total flow rate.
(83) A ninth embodiment can include the method of any one of the first to eighth embodiments, wherein the slurry pump and the clean pump are positioned on a (e.g., same or different) mobile blender apparatus (e.g., a blender trailer or skid(s)).
(84) A tenth embodiment can include the method of any one of the first to ninth embodiments, wherein combining the clean pump flow rate of the clean fluid with the concentrated slurry flow rate of the concentrated slurry to provide the total pump flow rate of the proppant slurry further comprises providing the concentrated slurry and the clean fluid, separately or in combination as the proppant slurry, to a manifold (e.g., trailer) configured to feed the proppant slurry to one or more (e.g., “dirty”) hydraulic fracturing pumps.
(85) An eleventh embodiment can include the method of any one of the first to tenth embodiments further comprising introducing the proppant slurry downhole in a hydraulic fracturing operation.
(86) In a twelfth embodiment, a method of providing a total flow rate of a proppant slurry comprising a proppant comprises: determining a maximum (e.g., a preferred operating) slurry pump flow rate for minimizing wear on a slurry pump pumping a concentrated slurry by: determining a wear service class of the concentrated slurry; finding or estimating a best efficiency point (BEP) flow rate of the slurry pump being utilized to provide the concentrated slurry; finding or estimating, as a percentage of the BEP, a (e.g., manufacturer recommended) preferred operating range (POR) of the slurry pump being utilized to pump the concentrated slurry in the wear service class, from a minimum recommended percentage of the BEP flow rate to a maximum recommended percentage of the BEP flow rate; and calculating the maximum pump slurry flow rate by multiplying the maximum recommended percentage of the POR by the BEP flow rate; and combining (e.g., downstream of the slurry pump) a clean pump flow rate of a clean fluid from a clean fluid pump with a concentrated slurry flow rate of the concentrated slurry from the slurry pump to provide the total pump flow rate of the proppant slurry, wherein the concentrated slurry has a higher concentration of the proppant than the proppant slurry, wherein the total flow rate of the proppant slurry is greater than the maximum slurry pump flow rate of the slurry pump, wherein the concentrated slurry flow rate is less than the maximum slurry pump flow rate, and wherein the clean fluid is substantially proppant-free.
(87) A thirteenth embodiment can include the method of the twelfth embodiment further comprising maintaining the concentrated slurry flow rate (e.g., just) below (e.g., within 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, or 20% of) the maximum slurry pump flow rate.
(88) A fourteenth embodiment can include the method of the twelfth or thirteenth embodiment, wherein combining the clean pump flow rate of the clean fluid with the concentrated slurry flow rate of the concentrated slurry to provide the total pump flow rate of the proppant slurry further comprises providing the concentrated slurry and the clean fluid to a blender header and extracting the proppant slurry from (e.g., one or more discharge hoses fluidly connected to) the blender

header.

(89) A fifteenth embodiment can include the method of the fourteenth embodiment, wherein providing the concentrated slurry and the clean fluid to the blender header further comprises introducing the clean fluid from a clean side of the blender header and via a proportional valve to a dirty side of the blender header.

(90) A sixteenth embodiment can include the method of the fifteenth embodiment, wherein introducing the clean fluid from the clean side of the blender header and via the proportional valve to the dirty side of the blender header further comprises the clean fluid at a clean fluid pressure that is at least 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, or 20 psi (or at least 15, 20, 25, 30, or 35%) greater than a concentrated slurry pressure of the concentrated slurry (such that only clean fluid passes through the proportional valve).

(91) A seventeenth embodiment can include the method of the sixteenth embodiment, wherein providing the concentrated slurry and the clean fluid to the blender header further comprises providing the concentrated slurry to the blender header from the slurry pump via a concentrated slurry flow line and providing the clean fluid from the clean fluid pump to the blender header via a clean fluid flow line, and wherein the method further comprises utilizing a control system to monitor the concentrated slurry flow rate in the concentrated slurry line and the clean fluid flow rate of the clean fluid in the clean fluid line, the concentrated slurry pressure, and the clean fluid pressure, and control a speed of the concentrated slurry pump, a speed of the clean fluid pump, and a position of the proportional valve to provide the proppant slurry having the total flow rate.

(92) An eighteenth embodiment can include the method of any one of the twelfth to seventeenth embodiments, wherein the total flow rate of the proppant slurry is greater than the maximum slurry pump flow rate of the slurry pump.

(93) In an nineteenth embodiment, a blending system for providing a total flow rate of a proppant slurry comprises: a slurry pump operable to provide a concentrated slurry in a concentrated slurry line, wherein the concentrated slurry has a higher concentration of a proppant than the proppant slurry; a clean fluid pump operable to provide a clean fluid in a clean fluid line, wherein the clean fluid is substantially proppant-free; and a control system configured to monitor a concentrated slurry flow rate of the concentrated slurry in the concentrated slurry line and a clean fluid flow rate of the clean fluid in the clean fluid line, and control (e.g., a speed of) the concentrated slurry pump and (e.g., a speed of) the clean fluid pump, such that combination of the concentrated slurry and the clean fluid provides the proppant slurry having the total flow rate, wherein the total flow rate of the proppant slurry is greater than a maximum slurry pump flow rate of a preferred operating range (POR) of the slurry pump, and wherein the concentrated slurry flow rate is less than or equal to the maximum slurry pump flow rate.

(94) A twentieth embodiment can include the blender of the nineteenth embodiment further comprising a blender header fluidly connected to the concentrated slurry line and the clean fluid line, wherein the concentrated slurry line is fluidly connected with a dirty/slurry side of the blender header and wherein the clean fluid line is fluidly connected with another/clean side of the blender header, and wherein the blender header further comprises one or more outlets for extracting the proppant slurry therefrom, and wherein the controller is further configured to monitor a concentrated slurry pressure of the concentrated slurry in the concentrated slurry line and a clean fluid pressure of the clean fluid in the clean fluid line, and control (e.g., a position of) a proportional valve between the clean side of the blender header and the dirty side of the blender header to ensure that (e.g., only) clean fluid (e.g., and not concentrated slurry) passes through the proportional valve.

(95) A twenty first embodiment can include the system of the nineteenth or twentieth embodiment, wherein the controller controls operation of the blender such that the clean fluid pressure of the clean fluid in the clean fluid line is at least 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, or 20 psi (or at least 15, 20, 25, 30, or 35%) greater than the concentrated slurry pressure of the

concentrated slurry in the concentrated slurry line (such that only clean fluid passes through the proportional valve).
(96) A twenty second embodiment can include the system of the twentieth or twenty first embodiment, wherein the slurry pump, the clean pump and the blender header are positioned on a (e.g., same) mobile blender apparatus (e.g., a blender trailer or skid(s)).
(97) A twenty third embodiment can include the system of any one of the twentieth to twenty second embodiments further comprising a flow meter on the concentrated slurry line, a flow meter on the clean fluid line, a pressure transducer on the concentrated slurry line, and a pressure transducer on the clean fluid line, wherein the controller receives concentrated slurry flow rate information from the flow meter on the concentrated slurry line, clean fluid flow rate information from the flow meter on the clean fluid line, concentrated slurry pressure from the pressure transducer on the concentrated slurry line, and clean fluid pressure information from the transducer on the clean fluid line to control operation of the blending system.
(98) A twenty fourth embodiment can include the system of any one of the nineteenth to twenty third embodiments, wherein the slurry pump and the clean pump are positioned on a (e.g., same or different) mobile blender apparatus (e.g., a blender trailer or skid(s)).
(99) A twenty fifth embodiment can include the system of any one of the nineteenth to twenty fourth embodiments further comprising a manifold (e.g., a manifold trailer downstream from the blender) configured to feed the proppant slurry to one or more (e.g., “dirty”) hydraulic fracturing pumps, wherein the manifold is configured to receive: (a) the concentrated slurry and the clean fluid, or (b) the proppant slurry from the blender.
(100) A twenty sixth embodiment can include the system or method of any prior embodiment, wherein combining the clean pump flow rate of the clean fluid with the concentrated slurry flow rate of the concentrated slurry to provide the total pump flow rate of the proppant slurry is effected downstream of the slurry pump.
(101) While embodiments have been shown and described, modifications thereof can be made by one skilled in the art without departing from the spirit and teachings of this disclosure. The embodiments described herein are exemplary only, and are not intended to be limiting. Many variations and modifications of the embodiments disclosed herein are possible and are within the scope of this disclosure. Where numerical ranges or limitations are expressly stated, such express ranges or limitations should be understood to include iterative ranges or limitations of like magnitude falling within the expressly stated ranges or limitations (e.g., from about 1 to about 10 includes, 2, 3, 4, etc.; greater than 0.10 includes 0.11, 0.12, 0.13, etc.). For example, whenever a numerical range with a lower limit, Rl, and an upper limit, Ru, is disclosed, any number falling within the range is specifically disclosed. In particular, the following numbers within the range are specifically disclosed: $R=Rl+k*(Ru-Rl)$, wherein k is a variable ranging from 1 percent to 100 percent with a 1 percent increment, i.e., k is 1 percent, 2 percent, 3 percent, 4 percent, 5 percent, . . . 50 percent, 51 percent, 52 percent, . . . 95 percent, 96 percent, 97 percent, 98 percent, 99 percent, or 100 percent. Moreover, any numerical range defined by two R numbers as defined in the above is also specifically disclosed. Use of broader terms such as comprises, includes, having, etc. should be understood to provide support for narrower terms such as consisting of, consisting essentially of, comprised substantially of, etc. When a feature is described as “optional,” both embodiments with this feature and embodiments without this feature are disclosed. Similarly, the present disclosure contemplates embodiments where this “optional” feature is required and embodiments where this feature is specifically excluded.
(102) Accordingly, the scope of protection is not limited by the description set out above but is only limited by the claims which follow, that scope including all equivalents of the subject matter of the claims. Each and every claim is incorporated into the specification as embodiments of the present disclosure. Thus, the claims are a further description and are an addition to the embodiments of the present disclosure. The discussion of a reference herein is not an admission that it is prior art,

especially any reference that can have a publication date after the priority date of this application. The disclosures of all patents, patent applications, and publications cited herein are hereby incorporated by reference, to the extent that they provide exemplary, procedural, or other details supplementary to those set forth herein.

Claims

1. A method comprising: providing a total flow rate of a proppant slurry by: utilizing a slurry pump to provide a concentrated slurry flow rate of a concentrated slurry, wherein the concentrated slurry has a higher concentration of the proppant than the proppant slurry, wherein the total flow rate of the proppant slurry is greater than a maximum slurry pump flow rate of a preferred operating range (POR) of the slurry pump, wherein the concentrated slurry flow rate is less than or equal to the maximum slurry pump flow rate, and wherein determining the maximum slurry pump flow rate comprises: determining a wear service class of the concentrated slurry; finding or estimating a best efficiency point (BEP) flow rate of the slurry pump being utilized to provide the concentrated slurry; finding or estimating, as a percentage of the BEP flow rate, a preferred operating range (POR) of the slurry pump being utilized to pump the concentrated slurry in the wear service class, from a minimum recommended percentage of the BEP flow rate to a maximum recommended percentage of the BEP flow rate; and calculating the maximum pump slurry flow rate by multiplying the maximum recommended percentage of the POR by the BEP flow rate; utilizing a clean fluid pump to provide a clean pump flow rate of a clean fluid, wherein the clean fluid is substantially proppant-free; and combining the clean pump flow rate of the clean fluid with the concentrated slurry flow rate of the concentrated slurry to provide the total pump flow rate of the proppant slurry.
2. The method of claim 1 further comprising maintaining the concentrated slurry flow rate below the maximum slurry pump flow rate, below the BEP, and/or within the POR of the slurry pump.
3. The method of claim 1, wherein combining the clean pump flow rate of the clean fluid with the concentrated slurry flow rate of the concentrated slurry to provide the total pump flow rate of the proppant slurry further comprises providing the concentrated slurry and the clean fluid to a blender header and extracting the proppant slurry from the blender header.
4. The method of claim 3, wherein providing the concentrated slurry and the clean fluid to the blender header further comprises introducing the clean fluid from a clean side of the blender header and via a proportional valve to a dirty side of the blender header.
5. The method of claim 4 further comprising maintaining the clean fluid at or above a clean fluid pressure that is at least 5 psi greater than a concentrated slurry pressure of the concentrated slurry.
6. The method of claim 4, wherein combining the clean pump flow rate of the clean fluid with the concentrated slurry flow rate of the concentrated slurry to provide the total pump flow rate of the proppant slurry further comprises providing the concentrated slurry from the slurry pump via a concentrated slurry flow line and providing the clean fluid from the clean fluid pump via a clean fluid flow line, and wherein the method further comprises utilizing a control system to monitor the concentrated slurry flow rate in the concentrated slurry line and the clean fluid flow rate of the clean fluid in the clean fluid line, the concentrated slurry pressure and the clean fluid pressure, and control a speed of the concentrated slurry pump, a speed of the clean fluid pump, and a position of the proportional valve to provide the proppant slurry having the total flow rate.
7. The method of claim 1, wherein combining the clean pump flow rate of the clean fluid with the concentrated slurry flow rate of the concentrated slurry to provide the total pump flow rate of the proppant slurry further comprises providing the concentrated slurry and the clean fluid, separately or in combination as the proppant slurry, to a manifold configured to feed the proppant slurry to one or more hydraulic fracturing pumps.
8. The method of claim 1 further comprising introducing the proppant slurry downhole in a

hydraulic fracturing operation.
9. The method of claim 1, wherein the slurry pump, the clean fluid pump, and the blender header are positioned on a mobile blender apparatus.
10. A method of providing a total flow rate of a proppant slurry comprising a proppant, the method comprising: determining a maximum slurry pump flow rate for minimizing wear on a slurry pump pumping a concentrated slurry by: determining a wear service class of the concentrated slurry; finding or estimating a best efficiency point (BEP) flow rate of the slurry pump being utilized to provide the concentrated slurry; finding or estimating, as a percentage of the BEP, a preferred operating range (POR) of the slurry pump being utilized to pump the concentrated slurry in the wear service class, from a minimum recommended percentage of the BEP flow rate to a maximum recommended percentage of the BEP flow rate; and calculating the maximum pump slurry flow rate by multiplying the maximum recommended percentage of the POR by the BEP flow rate; and combining a clean pump flow rate of a clean fluid from a clean fluid pump with a concentrated slurry flow rate of the concentrated slurry from the slurry pump to provide the total pump flow rate of the proppant slurry, wherein the concentrated slurry has a higher concentration of the proppant than the proppant slurry, wherein the concentrated slurry flow rate is less than the maximum slurry pump flow rate, and wherein the clean fluid is substantially proppant-free.
11. The method of claim 10 further comprising maintaining the concentrated slurry flow rate below the maximum slurry pump flow rate.
12. The method of claim 10, wherein combining the clean pump flow rate of the clean fluid with the concentrated slurry flow rate of the concentrated slurry to provide the total pump flow rate of the proppant slurry further comprises providing the concentrated slurry and the clean fluid to a blender header and extracting the proppant slurry from the blender header.
13. The method of claim 12, wherein providing the concentrated slurry and the clean fluid to the blender header further comprises introducing the clean fluid from a clean side of the blender header and via a proportional valve to a dirty side of the blender header.
14. The method of claim 13, wherein introducing the clean fluid from the clean side of the blender header and via the proportional valve to the dirty side of the blender header further comprises the clean fluid at a clean fluid pressure that is at least 5 psi greater than a concentrated slurry pressure of the concentrated slurry.
15. The method of claim 14, wherein providing the concentrated slurry and the clean fluid to the blender header further comprises providing the concentrated slurry to the blender header from the slurry pump via a concentrated slurry flow line and providing the clean fluid from the clean fluid pump to the blender header via a clean fluid flow line, and wherein the method further comprises utilizing a control system to monitor the concentrated slurry flow rate in the concentrated slurry line and the clean fluid flow rate of the clean fluid in the clean fluid line, the concentrated slurry pressure, and the clean fluid pressure, and control a speed of the concentrated slurry pump, a speed of the clean fluid pump, and a position of the proportional valve to provide the proppant slurry having the total flow rate.
16. The method of claim 10, wherein the total flow rate of the proppant slurry is greater than the maximum slurry pump flow rate of the slurry pump.
17. A blending system for providing a total flow rate of a proppant slurry, the system comprising: a slurry pump operable to provide a concentrated slurry in a concentrated slurry line, wherein the concentrated slurry has a higher concentration of a proppant than the proppant slurry; a clean fluid pump operable to provide a clean fluid in a clean fluid line, wherein the clean fluid is substantially proppant-free; a blender header fluidly connected to the concentrated slurry line and the clean fluid line, wherein the concentrated slurry line is fluidly connected with a dirty/slurry side of the blender header and wherein the clean fluid line is fluidly connected with another/clean side of the blender header, and wherein the blender header further comprises one or more outlets for extracting the proppant slurry therefrom; and a control system configured to monitor a concentrated slurry flow

rate of the concentrated slurry in the concentrated slurry line and a clean fluid flow rate of the clean fluid in the clean fluid line, and control the concentrated slurry pump and the clean fluid pump, such that combination of the concentrated slurry and the clean fluid provides the proppant slurry having the total flow rate, and wherein the controller is further configured to monitor a concentrated slurry pressure of the concentrated slurry in the concentrated slurry line and a clean fluid pressure of the clean fluid in the clean fluid line, and control a proportional valve between the clean side of the blender header and the dirty side of the blender header to ensure that clean fluid passes through the proportional valve, wherein the total flow rate of the proppant slurry is greater than a maximum slurry pump flow rate of a preferred operating range (POR) of the slurry pump, and wherein the concentrated slurry flow rate is less than or equal to the maximum slurry pump flow rate.

18. The system of claim 17, wherein the controller controls operation of the blender such that the clean fluid pressure of the clean fluid in the clean fluid line is at least 5 psi greater than the concentrated slurry pressure of the concentrated slurry in the concentrated slurry line.

19. The system of claim 17 further comprising a flow meter on the concentrated slurry line, a flow meter on the clean fluid line, a pressure transducer on the concentrated slurry line, and a pressure transducer on the clean fluid line, wherein the controller receives concentrated slurry flow rate information from the flow meter on the concentrated slurry line, clean fluid flow rate information from the flow meter on the clean fluid line, concentrated slurry pressure from the pressure transducer on the concentrated slurry line, and clean fluid pressure information from the transducer on the clean fluid line to control operation of the blending system.

20. The system of claim 17 further comprising a manifold configured to feed the proppant slurry to one or more hydraulic fracturing pumps, wherein the manifold is configured to receive: (a) the concentrated slurry and the clean fluid, or (b) the proppant slurry from the blender.

21. The system of claim 17, wherein the slurry pump, the clean fluid pump and the blender header are positioned on a mobile blender apparatus.