(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
8 August 2013 (08.08.2013)

WIPO | PCT

(10) **International Publication Number**
WO 2013/115934 A1

(51) **International Patent Classification**:
G01F 11/06 (2006.01)

(21) **International Application Number**:
PCT/US2013/020054

(22) **International Filing Date**:
3 January 2013 (03.01.2013)

(25) **Filing Language**: English

(26) **Publication Language**: English

(30) **Priority Data**:
13/363,141 31 January 2012 (31.01.2012) US
13/363,012 31 January 2012 (31.01.2012) US

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(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, IS, JP, KE, KG, KM, 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, 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, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

(54) **Title**: FLUID ADDITIVE DELIVERY SYSTEM WITH FLOW METER

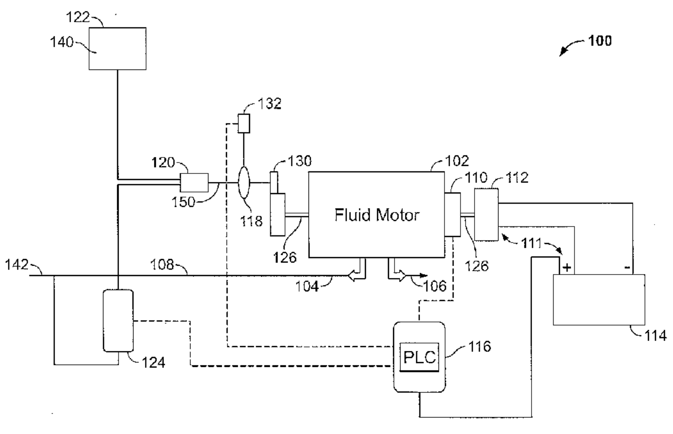

FIG. 1

(57) **Abstract**: A system for delivering an additive to a flowing fluid wherein the system is in whole or in part powered by the flow of the fluid is provided. The fluid-additive delivery system includes a fluid motor, a speed sensor, an electricity generation and storage system, a clutch, an additive pump, and a flow meter, where the fluid motor and the flow meter are in fluid communication with a piping of the fluid to which the fluid additive is to be added. The flow meter provides high resolution with infinite turndown, providing a flow meter which may be used in low flow situations and with fluid additives. The flow rate of an additive fluid is determined in real time with high resolution by providing a novel reciprocating positive-displacement flow meter using magnetically coupled components and a transducer to identify the flow rate of the fluid.

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Fluid additive delivery system with flow meter

FIELD OF THE INVENTION

[0001] The present invention provides a system for delivery of an additive to a flowing fluid. More particularly, the invention relates to a system for delivering an additive to a flowing fluid wherein the system is in whole or in part powered by the flow of the fluid. The present invention further provides a system for determining the flow rate of a fluid. The invention may be used for measuring the rate of fluid flow and may be included in a larger system for controlling the flow rate of the fluid. The system may include an improved flow meter which includes a ferrous floating internal piston in a reciprocating flow meter, wherein the internal piston is magnetically tied to a coupling arm with an end in magnetic contact with a linear digital encoding transducer equivalent in operable length to the full stroke of the ferrous floating internal piston and which provides immediate data regarding the smallest movement of the internal piston.

DESCRIPTION OF THE RELATED ART

[0002] Systems for introducing measured fluids into flowing fluids are well known. A popular means of injecting chemical additives into various liquid streams, particularly fuels, is to use a signal generated from a flow meter in the recipient line to control an injection pump. Various systems exist to meter the amount of additive(s) injected into a fluid, usually drawing electrical power from the system associated with the fluid delivery. These systems generally inject the fluid additive into the flow of the main fluid, causing the fluid additive to stratify and not blend thoroughly, often precluding the desired outcome or requiring excessive amounts of fluid additive to obtain the desired benefit. Some additives such as lubricity agents and conductivity agents that are injected at a very low rate (PPM) can be ineffective if not blended thoroughly.

[0003] Moreover, each additive requires its own reservoir and generally its own pump, particularly where multiple additives may be simultaneously added.

[0004] Current systems suffer from a number of shortcomings. Most systems are not self-contained, requiring substantial effort to address any issues within the system or to make changes. Additionally, some systems use error-correcting control systems which, based on data reported to a computer from product and additive meters, open or close a valve attached to a highly pressurized additive supply line (such as 165 psi (1,137.63 kPa)) until the desired volume of additive has been delivered for the product, according to volume of product reported by the main product meter. As a result of the error correction system employed, these systems typically provide an oversupply of additive to ensure minimum delivery, an undesirable and costly approach, as are constantly in a state of correction in search of the calculated ratio.

[0005] Among the systems known in the art which have attempted to address some of these shortcomings are U.S. Patent 5,513,963 issued to Walton for a direct action fluid motor and injection pump, U.S. Patent 6,910,405 issued to Walton, et. al. for an on/off switch for a liquid additive injection pump, and U.S. Patent 7,066,353 issued to Hammonds for a fluid powered additive injection system. However, none of these systems have provided a self-contained system incorporating a fluid motor, speed sensor, electricity generator and battery, a clutch operated additive control pump, a flow meter and a computer controller, particularly one capable of relatively-low pressure operation.

[0006] Systems for measuring fluid flow rates are desirable in devices or systems where flow rates must be controlled or verified. Measurement of flow which is accurate, highly precise (high resolution), and consistent is important in various systems utilizing fluid flow for operation. Measurement of those flow rates often must be expressed and communicated in an electronic format that is compatible with programmable logic devices. Moreover, it is desirable to have a high turndown in these systems, although typically one of the most substantial problems with existing meters. Existing meters thus have a narrow (often very narrow) range of operations, problematic in cases of fuel injection where flow may operate between zero flow and high flow rates.

[0007] Systems for delivering fluids, including those for introducing fluids as additives into other fluid flows, are well known in the art and are generally desired where the fluid may have a limited duration of effectiveness after introduction to a flowing untreated fluid, particularly in cases where additives may be selected on site based on the specific need at the time. In some of these applications, it is necessary to precisely control the flow of the metered fluid, such as an additive, relative to the flow of a second fluid, such as fuel, being delivered so as to maintain a ratio of fuel to additive, usually represented in parts per million. This can be particularly critical where the flow of the second fluid is relatively low, driving down the flow rate of the metered fluid. Thus, doing so requires accurate measurement of the additive, particularly where usually delivered at a very low flow rate.

[0008] With regard to addition of a treating agent, the efficacy of the treated fluid may be effected if the proper volume of additive is not introduced to the untreated flow of a process stream at the current flow rate. Additionally, the cost of the additive to be introduced may be quite high, so cost-effectiveness requires the flow rate, as measured by a flow meter and potentially communicated to an associated logic controller which may in turn control the pump supplying the additive. Ensuring consistent delivery of additive to the untreated fluid is a necessity. Introduction of additive at actual flow rates which are above or below the desired flow rate is undesirable, such as in cases where the additive is introduced to an untreated flow of a petroleum-based fluid where combustion may be over- or under-pressurized in the engine, potentially posing a danger to operators and others. Moreover, other additives effect lubricity or conductivity of fuel with each having the need to be injected accurately over a wide (often very wide) range of flow.

[0009] Thus, accuracy, high resolution, and consistency are needed for systems utilizing fluid flow, including systems where additives are used in conjunction with motor and aviation fuels, water-treatment systems, and other systems.

[0010] Among the prior art devices directed to determining the flow rate of a fluid flow, either for determination of flow rates or for addition of a treating agent are positive displacement meters such as oval gear flow meters, which may consist of two close tolerance oval gears which, when fluid is passed between the two, produce a rotary motion within the meter housing. A shaft connected to one of the meter oval gears includes a rotating hall affect sensor that is used to signal the speed of the rotating shaft. A revolution of the shaft represents a certain volume of fluid passing through the meter by virtue of the volumetric displacement between the two gears inside the meter housing. Meters of this type are very sensitive to solids since the tolerances within the meter are very close. Such meters are prone to clogging and locking up as a result of various foreign material found in fluids such as additives or treating agents. In addition, many fluids, additives or treating agents have solids that are a part of the fluid, additive or treating agent itself which tend to be highly abrasive. This abrasiveness quickly wears the meter and causes it to quickly lose efficiency and its ability to accurately reflect the volume passing through the meter. Additives such as dyes are very abrasive with a high solids content making them inappropriate for use with oval gear meters. Many fuel additives are injected at extremely small ratios as low as 1 PPM. Oval gear meters require minimum flow rates that far exceed those rates found in additive injection, making them inoperable in these applications.

[0011] Other prior art metering systems have included float type flow meters that have utilized floats in static, vertically-aligned flows, and reciprocating pistons which have generally measured flow rate according to travel of the reciprocating piston from one end of the associated cylinder to the other.

[0012] Such metering systems are of limited utility in measuring flow rates. Float systems similarly are of limited benefit where the system is susceptible to being out of vertical alignment.

[0013] Where used for additive delivery in fuels, such metering systems are of limited utility, specifically where the volume of additive introduced is particularly small relative of the untreated fluid (such as less (preferably substantially less) than 0.25% or, non-equivalently less than 2500 parts per million (PPM) (additive to fuel)). Substantially higher ratios approach the concept of blending.

[0014] In addition to the foregoing, due to the minute amount of additive dispensed, and the long time needed for the typical reciprocating metering system to complete one cycle (and hence provide a flow rate) that real time flow rates cannot be obtained the resulting flow rate has not assurance that the resulting average is consistent with the dispensing rate throughout the cycle.

[0015] There is therefore a need for an accurate meter flow which performs without reference to the system's orientation with minimal moving parts. There is also a need for a flow meter with a high turndown, providing a wide range of operation. There is also a need to control the flow rate of a relatively minute volume of additive to be dispensed into a flow of untreated fluid by providing a high resolution additive delivery system, to monitor the flow rate of a fluid with high resolution, or to maintain at high resolution a desired flow rate of additive.

SUMMARY OF THE INVENTION

[0016] It is therefore, a principle object of the present invention to provide a system for delivering an additive to a flowing fluid wherein the system is in whole or in part powered by the flow of the fluid and which provides the additive at lower pressure, preferably only that needed to inject additive fluid into a product flow.

[0017] This achieved by providing a fluid motor adapted to receive a fluid from a piping and having an output shaft rotatably driven by the fluid as it moves between the fluid inlet of the fluid motor and its fluid output, a speed sensor adapted to be associated with the output shaft and adapted to provide a signal to a computer indicative of rotational speed of the output shaft, an electricity generation and storage system comprising a direct current generator and an electrical battery, where the direct current generator is adapted to be driven by the fluid motor's output shaft and adapted to provide electricity to the electrical battery, a clutch adapted to be associated with the output shaft and adapted to engage a shaft of an additive pump upon activation by a computer, where the additive pump is adapted to be rotatably driven by the output shaft (upon engagement by the clutch and is in fluid communication with a reservoir of a fluid additive and adapted to pump the fluid additive to a flow meter, where the flow meter has a meter input adapted for fluid communication with the additive pump, a meter output adapted for fluid communication of the fluid additive to the fluid in the piping, and is adapted to provide a signal to the computer indicative of the actual flow rate from the additive pump.

[0018] Alternatively, the system may provide a fluid motor in communication with a piping of fluid where the fluid motor has an output shaft rotatably driven by the fluid moving between the fluid motor's fluid inlet and fluid output, a speed sensor associated with the fluid motor's output shaft and providing a signal to a computer indicative of rotational speed of said output shaft, a direct current generator in mechanical connection with the fluid motor's output shaft and electrically connected to an electrical battery, a clutch associated with the fluid motor's output shaft and engaging a shaft of an additive pump upon activation, where the additive pump is rotatably driven by the fluid motor's output shaft upon engagement by the clutch, where the additive pump is in fluid communication with a reservoir of fluid additive and impels the fluid additive to a flow meter having a meter input in fluid communication with the additive pump, having a meter output in one-way fluid communication with the piping, and which provides a signal to a computer indicative of the actual flow rate from said additive pump.

[0019] It is also a principle object of the present invention to provide a flow meter, particularly a positive displacement reciprocating flow meter, which produces accurate metering with minimal moving parts and which is accurate over time, regardless of pump efficiency or system leakage. This achieved by providing a cylindrical body with fluid connectors at its sealed ends, a ferrous floating internal piston, a cylindrical ring freely encircling the cylindrical body and magnetically coupled to the ferrous floating internal piston, a high resolution linear digital encoding transducer (preferably cylindrical and absolute) preferably parallel to and equivalent in length to the cylindrical body, a coupling arm integrally affixed to the magnetic ring so as to function as a single unit therewith and having a magnetic section contacting the linear digital encoding transducer, with a valve system providing additive to reciprocate the ferrous floating internal piston and to dispense additive to the untreated fluid, and a computer adapted to determine the position of the coupling arm relative to said linear digital encoding transducer to determine position, and, by measurement of time and determination of change in direction, velocity and a valve controller to control the valve system to reciprocate the ferrous floating internal piston. The sealed ends of the cylindrical body and the magnetic coupling between the ferrous floating internal piston and the linear digital encoding transducer provide reduce or eliminate leakage and maintenance associated with meters since there are no dynamic seals involved.

[0020] The valve system may have a fluid input from the flowing supply of fluid, such an additive, a fluid output, and be in fluid communication with a first end connector at one end of the reciprocating flow meter and in fluid communication with a second end connector at the opposite end of the reciprocating flow meter. The valve system may be switchably operable among a first position and a second position to provide for reciprocation of the ferrous floating internal piston. Switching may be accomplished by a valve driven by solenoids or other actuators. In the first position, the fluid input is in communication with the flowing supply of an additive and the fluid output is in communication with the flow of untreated fluid. Thus the first position connects the fluid input and the second end connector and connects the first end connector with the fluid output and the second position connects the fluid input and the first end connector and connects the second end connector with the fluid output. Thus, the valve system is controlled to cause reciprocation of the ferrous floating internal piston between the cylinder first end and the cylinder second end when the piston approaches each end.

[0021] The present flow meter invention, by virtue of its high resolution and infinite turndown, may also be incorporated into a flow control system, such as that for introduction of a flowing additive at a very low ratio of additive fluid to untreated fluid, particularly in cases where a relatively minute volume of additive fluid is to be dispensed into a flow of untreated fluid. The flow meter invention may be used with a pumped supply of additive to monitor and, in conjunction with control of the pump, control the flow of untreated fluid to provide additive at very low ratios of additive to untreated fluid by volume.

[0022] A flow control system incorporating the flow meter invention to control the flow of liquid, such as an additive fluid, may also include an output computer providing an output signal consistent with each flow rate and an fluid flow controller intermediate the supply of fluid and the valve system which can control the flow of fluid into the system, through various flow rates or at least between flowing and non-flowing positions. The fluid flow controller may be a computer-controlled pump, potentially operable among a plurality of pump speeds (which may not need to be quantified) or may be a valve in conjunction with a supply of fluid under pressure.

[0023] In operation, the flow control system may be employed to ensure the appropriate flow rate (such as the ultralow ratios referenced above), regardless of the efficiency or accuracy of the associated additive pump. This may be accomplished by the flow control system receiving a user input for a desired flow rate of additive, which then activates an additive flow controller at an actual flow rate presumed consistent with the desired flow rate of additive. However, as pumps are prone to wear and leakage, resulting in inaccuracies, the method must verify and adjust, as necessary, the actual flow rate. This is accomplished by introducing the presumed flow rate from the pump to a positive displacement reciprocating piston flow meter for verification.

[0024] The flow control system can then compare the presumed flow rate to the output signal to identify the deviation from desired flow rate. Based on determination of this deviation, the flow control system can then adjust the pump's actual flow rate at the flow controller to obtain the desired flow rate.

[0025] Unlike the prior art, the present flow meter invention provides a high degree of accuracy by providing identification of the position of the piston in the reciprocating flow meter at all points between the ends of the flow meter. This particularly important as it provides an instantaneous, or real time, rate of flow. Thus, the lag time associated with the imprecision of measurements based on the total stroke of the piston through the flow meter is avoided. Delays in time of position data create a corresponding delay in the adjustments necessary to maintain the pre-set ratio. This lag time had historically been a problem in fuel additive delivery systems when the ratio of additive to untreated fluid was less than 1%. In operation, this results in an additive concentration of about 2500 PPM. In the fuel additive industry, anything over 2500 PPM or ¼% is considered blending and may be accomplished with the lower resolution flow meters or a rotary positive displacement device.

[0026] The foregoing and other objectives, features and advantages of the invention will be more readily understood upon consideration of the following detailed description of the invention, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] So that the manner in which the described features, advantages and objects of the invention, as well as others which will become apparent, are attained and can be understood in detail, more particular description of the invention briefly summarized above may be had by reference to the embodiments thereof that are illustrated in the drawings, which drawings form a part of this specification. It is to be noted, however, that the appended drawings illustrate only a typical preferred embodiment of the invention and are therefore not to be considered limiting of its scope as the invention may admit to other equally effective embodiments.

[0028] FIG. 1 illustrates the system for delivery of an additive.

[0029] FIG. 2 illustrates a flow meter which may be used in the system for delivery of an additive.

[0030] FIG. 3 illustrates the cylinder portion of the flow meter which may be used in the system for delivery of an additive.

[0031] FIG. 4 illustrates an alternative embodiment of the flow meter which may be used in the system for delivery of an additive.

[0032] FIG. 5 illustrates the flow control system incorporating the flow meter which may be used in the system for delivery of an additive.

[0033] FIG. 6 illustrates the workflow of the flow control system which may be used in the system for delivery of an additive.

[0034] FIG. 7 illustrates a mechanical actuator at one position for use with the flow meter which may be used in the system for delivery of an additive.

[0035] FIG. 8 illustrates the mechanical actuator of FIG. 7 at a second position for use with the flow meter which may be used in the system for delivery of an additive.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0036] The subject matter of the present invention is described with specificity; however, the description itself is not intended to limit the scope of the invention. The subject matter thus, might also be embodied in other ways, to include different steps or combinations of steps similar to the ones described herein, in conjunction with other present or future technologies. Moreover, although the term "step" may be used herein to describe different elements of methods employed, the term should not be interpreted as implying any particular order among or between various steps herein disclosed unless otherwise expressly limited by the description to a particular order. While the present invention may be applied in the oil and gas industry, it is not limited thereto and may also be applied in other industries to achieve similar results.

[0037] The present invention does away with the need for an external power supply, or supplies, to support a fluid additive delivery system to be used in connection with a flowing fluid, and which ensures proper mixing of the additive. The present invention can be operated independent of any external power supply, generating electrical power from the flowing fluid to which the additive is to be injected. In addition to avoiding the need for external power, the system further has a reduced footprint. The present invention may be operated with a plurality of additive pumps, driven by a gearhead assembly from the fluid motor's output shaft to provide the opportunity to select multiple additive fluids to be added, or to select one additive fluid from a variety of choices, or a combination thereof. The present invention also provides for thorough blending of additive(s) to the flowing fluid by introduction of the additive(s) to the fluid upstream of the fluid motor, encouraging mixing as the fluid passes through the high shear rotary motion of the vanes in the fluid motor.

[0038] Referring to FIG. **1**, the fluid-additive delivery system **100** includes a fluid motor **102**, a speed sensor **110**, an electricity generation and storage system **111**, a clutch **118**, an additive pump **120**, and a flow meter **124**, where the fluid motor **102** and the flow meter **124** are in fluid communication with a piping **108** of the fluid **142** to which the fluid additive **140** is to be added. Preferably, the fluid **142** is a fuel and the fluid additive **140** to be added is a fuel additive.

[0039] The fluid motor **102** includes a fluid inlet **104** and a fluid outlet **106**. The fluid inlet **104** permits the fluid **142** from the piping **108** to enter the fluid motor **102.** The fluid outlet permits the fluid motor **102** to expel the fluid **142** after consumption of some of the kinetic energy of the fluid **142.** The fluid motor **102** has an output shaft **126** rotatably driven by the fluid **142** as it moves through the motor and around the motor's vanes before exiting through the fluid output **106.**

[0040] The speed sensor **110** is adapted to be associated with the output shaft **126** of the fluid motor **102** and to provide a signal to a computer **116** indicative of rotational speed of said output shaft **126**. While the speed sensor may be directly mounted on the output shaft **126**, it may alternatively be mounted to a shaft related to the output shaft through a gear assembly. The speed sensor may be selected from any known in the art, such as visual encoders, but preferably is a Hall-effect sensor.

[0041] The electricity generation and storage system **111** provides the on-board power for the delivery system **100**. Preferably, the electricity generation and storage system includes a direct current generator **112**, driven by the output shaft **126** of the fluid motor **102**, for generation of electricity connected to an electrical battery **114** to store the generated electricity. Preferably the direct current generator **112** is mounted to the output shaft **126** of the fluid motor **102**, but it may alternatively be mounted to a shaft related to the output shaft through a gear assembly.

[0042] For each fluid additive **140** available, and therefore for each additive pump **120**, a clutch **118** is associated with the output shaft **126** of the fluid motor **102**. While the clutch may be directly mounted to the output shaft **126** of the fluid motor **102**, where multiple additive pumps **120** are desired so as to provide various additives, or where a gear reduction is desired, the clutch **118** may be mechanically coupled to the output shaft **126** by a gear assembly or serpentine belt to provide a multiple output gear head assembly intermediate the output shaft **126** of the fluid motor **102** and clutch **118**. When activated by a computer **116**, the clutch **118** is adapted to engage the shaft **150** of an additive pump **120** to provide power thereto, and thereby cause a fluid additive **140** to be pumped into the system. While the clutch **118** may be selected from among those known in the art, preferably it is a momentary wrap spring clutch. Similarly, the clutch **118** may be engaged by various actuators, but preferably is engaged by a solenoid operator. The clutch **118** may draw power from various sources, but preferably is powered by the electricity generation and storage system **111.**

[0043] Each additive pump **120,** in fluid communication with a reservoir **122** of fluid additive **140,** is adapted to be rotatably driven by the output shaft **126** of the fluid motor **102** upon engagement by the clutch **118** and to pump the associated fluid additive **140** from the reservoir **122** to a flow meter **124.** Thus, each additive pump **120** is driven mechanically through its connection to the fluid motor **102,** requiring no external power. Fluid additive **140** may be a fluid additive, or may be a solid additive in a fluid carrier. Unlike the prior art, which required the fluid additive **140** to be directed at high pressure such as 165 psi (1,137.63 kPa), additive pump **140** provides fluid at a lower pressure, sufficient to provide injection into the fluid **142.** This may be a pressure equivalent to the pressure of fluid **142** in piping **108,** which may be at any pressure less than 150 psi (1,034.21 kPa), but is preferably around 60 psi (413.69 kPa). As a low pressure system is less prone to leaks and to fluid passing around components, the system is more accurate.

[0044] The computer **116** may be any of those known in the art, including a programmable logic controller (PLC). The computer **116** may draw electrical power from various sources, but preferably is powered by the electricity generation and storage system **111.**

[0045] Each flow meter **124** associated with an additive pump **120** has a meter fluid input adapted for fluid communication with the associated fluid pump **120** to permit communication of the fluid additive therefrom. Each flow meter **124** further has a meter fluid output adapted for fluid communication of the fluid additive **140** to the fluid **142** in said piping **108,** necessarily upstream of the fluid motor **102** rather than from piping associated with the fluid output **106** of the fluid motor **102.** This introduction of fluid additives **140** upstream of the fluid motor **102**

ensures the additive fluid **140** is well mixed as the fluid **142** passes through the high shear rotary motion of the vanes in the fluid motor **102**. Each flow meter **124** is adapted to provide a signal to the computer **116** indicative of the actual flow rate from said additive pump **120**, to permit quantification of the amount of additive fluid **140** provided and the actual flow rate of that provision. The flow meter **124** may be selected from various flow meters known in the art, but preferably is a positive displacement reciprocating flow meter, which may be adapted to reciprocate by solenoid operators or actuators. The flow meter **124** may be powered by various sources, but preferably is powered by the electricity generation and storage system **111**.

[0046] Ideally, the flow meter **124** provides instantaneous flow rate data, regardless of the volume used. The flow rate of additive **140** may be reported as a factor of volumetric displacement reflected in linear dimensions or in elapsed time, such as the one described herein.

[0047] In operation, the system **100** operates when a fluid **142** flows through a piping **108** into the fluid motor **102**, through its fluid inlet **104**. The fluid **142** causes the output shaft **126** of the fluid motor **102** to rotate before exiting the fluid motor through the fluid output. The speed sensor **110**, but by virtue of its association with the output shaft **126**, such as being mounted thereon, provides a signal to the computer **116** indicative of the rotational speed of the output shaft **126**. Due to the fixed volumes involved, the rotational speed of the output shaft **126** also reflects the volumetric displacement of the fluid motor **102**. Concurrently, the system **100** generates and stores electricity to power the system **100** by virtue of a direct current generator **112** mounted to or associated with the output shaft **126** (which may exit the fluid motor at one or both ends), which generates electricity during rotation of the output shaft **126**, which is then stores in an electrical battery **114**. Power is also taken from the output shaft **126** of the fluid motor **102** when a clutch **118**, attached to the output shaft **126**, controlled by the computer **116**

and powered from the battery **114**, engages the shaft **150** of an additive pump **120**. When engaged by the clutch **118**, the additive pump **120** draws the selected fluid additive **140** from a reservoir **122** of the fluid additive **140** and pumps it to a flow meter **124**. The flow meter **124**, preferably a positive displacement reciprocating flow meter, caused to reciprocate by a computer, including computer **116**, or by mechanical means at the end of each stroke, receives the discharge from the additive pump **120**, preferably via a one-way valve, sends a signal to the computer **116** indicative of the actual flow rate from the additive pump to ensure the desired volume of the selected additive is provided. The fluid additive **140** then is discharged from the flow meter **124** upstream of the fluid motor **102**, wherein the fluid additive is vigorously mixed by the vanes of fluid motor **102**.

Flow meter device

[0048] The present invention may incorporate a flow meter involving the use of magnetically-coupled and sensitive devices to provide precise data to provide an instantaneous high resolution flow meter for monitoring the flow rate of a fluid in real time, even when measured in relatively small units and/or to precisely dispense relatively small volumes of liquid. The flow rate determination provided by the flow meter may be used to control the flow rate of fluid into the flow meter prior to disbursal of the fluid. Similarly, the control over minute volumes of liquid may be used to control the volume of fluid disbursed.

[0049] Preferably, as identified in FIG. **2**, the improved flow meter **124** performs these functions with high resolution by providing a novel positive-displacement flow meter **202** in fluid communication with a valve system **204** to prompt reciprocation of a piston within the cylinder **232** of the flow meter **202**. The cylinder **232** has a cylinder first end **220** and a cylinder second end **222**, and a first end connector **224** at or about the cylinder first end **220** and a second end connector **226** at or about the cylinder second end **222**. The flow meter **202** may also include a guide **320** intermediate the cylinder **232** and the transducer **230**, and parallel to both. Preferably the cylinder **232**, the connectors **224**, **226**, and the other fluid-conducting components including the orifices through the valve system **204**, the fluid input **208** and the fluid output **210** are of a large diameter compared to the size of particulates carried in or constituting the fluid, providing a ratio of at least 20:1.

[0050] The flow meter **202** may include a controller **206**, preferably a programmable logic controller (PLC), receiving signals from the positive-displacement flow meter **202** to identify the flow rate of the fluid. Operation of the valve system **204** may be controlled by any of various types of controllers known in the art, for example, such as with the controller **206** or with a mechanical valve controller drive by the actual flow through the flow meter **202.** Positioned near and in alignment with the cylinder **232** is a linear digital encoding transducer **230.** Associated with both the cylinder **232** and the transducer **230** is a coupling arm **218,** having a coupling arm first end **236** and a coupling arm second end **228.**

[0051] The valve system **204** associated with the invention includes a fluid input **208,** having a fluid output **210**, in fluid communication **212, 214** with a first end connector **224** of the cylinder **232** and in fluid communication with a second end connector **226** of the cylinder **232,** respectively. This may be a two-position valve, or a combination of valves providing the same effect. As illustrated in FIG. **2**, the valve system **204** is preferably a four-way, two-position valve positioned by two opposing actuators **234**, preferably solenoids, although two three-way, two-position valves could be used. Alternatively, the second actuator **234** may be replaced with a spring return. Thus, the valve system **204** is switchably operable among a first position **246** and a second position **248**. Switching may be accomplished by one or more solenoid actuators **234** or by other actuators. Preferably, the valve system **204** includes solenoid valves, preferably of the self-cleaning poppet type as these do not utilize wearing surfaces, thus providing a longer system life.

[0052] By virtue of the accuracy of the transducer **230**, the controller **206** may determine the position of the coupling arm **218** relative to the linear digital encoding transducer **230** at all positions between the cylinder first end **220** and the cylinder second end **222**, and may do so in connection with identification of an associated point in time. Beneficially, as the displacement of the piston **304** may be measured by the transducer **230** and as the cross sectional area of the interior of the cylinder **232** is a fixed and known value, the displacement of the piston **304** as measured by the transducer **230** defines the volume of any fluid passing through the system. Thus, the transducer **230** functions like a micrometer, simply telling the system where the piston **304** is relative to the end of the cylinder **232**. As the system (program) knows what the displacement of the cylinder is, a linear unit of measurement therefore represents a fixed amount of fluid. As the distance from the beginning of the stroke is reported, the system knows how much fluid has been displaced. The linear transducer **230** thus serves as a device to measure distance, where distance is directly proportional to volume based on the displacement of the cylinder **232**. Alternatively, the controller **206** may record positions of the coupling arm second end **228** relative to the transducer **230** at associated points in time and may thus determine the speed and direction of movement of the coupling arm second end **228** as a function of change in said position per change in time. The cross-sectional internal area of the cylinder **232** is fixed and constant throughout, so this data also provides the change in volume per unit time, and thus the actual flow rate of the fluid therethrough.

[0053] Referring to FIG. **3**, the positive displacement flow meter **202** includes a cylinder

232, a ferrous floating internal piston **304**, a cylindrical ring **306** slidably positioned about and closely encircling the cylinder **232**, a linear digital encoding transducer **230**, and a coupling arm **218** integrally and fixedly associated with the cylindrical ring **306** at its coupling arm first end **236** so as to function as a single unit therewith and in association with the transducer **230**. The coupling arm **218** and the cylindrical ring **306** may be constructed as a single unit and may be formed or created as a single piece.

[0054] The cylinder **232** and internal piston **304** are necessary constituents of a positive displacement reciprocating piston flow meter **202**. The cylinder **232**, composed of a non-ferrous material, has length **312**, a cylindrical (circular tubular) exterior **314**, and a cylinder centerline **316**. The cylinder **232** also has a cylinder axis **322** at the cylinder centerline **316** along the cylinder's length **312**. The internal piston **304**, composed at least in part of a ferrous material and preferably generates a magnetic field, is freely slidable within the cylinder **232** between the cylinder first end **220** and the cylinder second end **222**. The outer surface of the piston **304** is fitted sufficiently close to the interior of the cylinder **232** to preclude appreciable leakage between the two resulting chambers **328**, **330** divided by the piston **304**. The piston **304** further has a length **332** sufficient to prevent the piston from binding during movement and thus to maintain its relationship to the cylinder axis **322**. The cylindrical ring **306** is slidably positioned about and closely encircles the cylinder exterior **314**, thus capable of sliding along the cylinder exterior **314** without binding and maintained substantially concentric about the cylinder axis **322**. The cylindrical ring **306** is composed of magnetic material to magnetically couple to the ferrous floating internal piston **304**, but could alternatively be of a ferrous material if the piston generates a magnetic field. Thus, as the piston **304** travels within the cylinder **232**, the cylindrical ring **306** likewise travels and maintains its position relative to the piston **304**. Preferably, a low-friction material **308**, such as a Teflon® ring, may be positioned or inserted between the cylindrical ring **306** and the cylinder **232** to support the cylindrical ring **306**, and to maintain the cylinder ring **306** centered about the cylinder **232.** Preferably, the low friction material **308** is constructed as a ring to fit within the cylindrical ring **306**, but alternatively may be constructed as a sleeve about the cylinder **232**. Alternatively the cylinder exterior **314** and the interior of the cylinder ring **306** may each have a low coefficient of friction so the cylinder ring **306** may freely slide and not be susceptible to increased and undesirable friction by a small number of particulates. Additionally, the cylinder exterior **314** or the interior of cylinder ring **306** may be lubricated to reduce friction.

[0055] A linear digital encoding transducer **230**, preferably absolute, having a transducer length **336** and a transducer axis **338** along its length is also provided. The transducer axis **338** is substantially parallel (preferably parallel) to the cylinder axis **322**. The transducer length **336** is generally equivalent to the cylinder length **312**. Preferably, the transducer axis **338** is generally parallel to the cylinder axis **322**.

[0056] The coupling arm **218** may be integrally affixed to or formed with the cylindrical ring **306** at the coupling arm first end **340** so as to function, preferably permanently, as a single unit therewith and maintained generally perpendicular to the cylinder axis **322**. The coupling arm **310**, which may be constructed of a ferrous metal, includes a magnetic section **344**, which may be a magnet **350** or a magnetized section, at the coupling arm second end **228** of sufficient strength to generate a magnetic field contacting or interacting with the linear digital encoding transducer **230** as it rides over or about the transducer **230** to indicate the position of the coupling arm **218** (and thus the cylindrical ring **306**) relative to the transducer **230.** This may be accomplished by a single arm riding adjacent the transducer **230** or by a section of coupling arm second end **228** or a cylindrical ring integrally affixed to or formed with the cylindrical ring **306**

at the coupling arm second end **228** so as to function, preferably permanently, as a single unit therewith, having an opening to encircle the transducer **230**. By avoiding a mechanical couple between the piston **304** and the transducer **230**, seals through the cylinder first end **220** or the cylinder second end **222** are avoided, particularly as each seal are prone to leakage and may result in unequal operation as the piston **304** reciprocated in the cylinder **232.** By avoiding a mechanical couple, the risk of contact by the couple with other metal components, a fire hazard, and the need for additional components to transform the mechanical couple's movement to movement along the transducer **230** are avoided.

[0057] Positioning the transducer **230** separate from the cylinder **232,** rather than directly in contact or immediately adjacent, is necessary for the accuracy of the transducer **230.** Positioning the transducer **230** separate from the cylinder **232** ensures the magnetic field of the internal piston **304** does not interfere with the accuracy of the transducer **230**, which utilizes a magnetic field to determine the slightest change in position of the internal piston **304** via the coupling arm **218.** Separation, together with the transducer-encircling segment of coupling arm second end **228,** provides accurate readings, particularly of the accuracy needed incident to the potentially quite low flow rates involved. This is particularly important as the transducer **230** necessarily must provide a high degree of accuracy with respect to each movement of the piston **304**, preferably in the precision of about 1/1,000 (0.0025 cm) of an inch of travel, rather than the per cycle signal associated with the prior art. The movement over the transducer may be of a length selected in light of the fluid, flow rate and length of stroke desired in the flow meter, whether it be 3 inches (7.62 cm), 10 inches (25.40 cm) or 20 inches (50.80 cm).

[0058] Since the floating internal piston **304** and coupling arm **218** are magnetically coupled, as the floating internal piston **304** moves along the length of the metering cylinder **232,**

the coupling arm **218** is carried precisely at the same relative position along the length **336** of the linear digital encoding transducer **230**. The linear digital encoding transducer **230** translates the relative position of the magnetic section **344** of the coupling arm **218** into an electrical signal which is communicated to the controller **206**, which may be a programmable logic controller.

[0059] A guide **320** is preferably used and positioned intermediate the cylinder **232** and the transducer **230**, and parallel to both. The guide **320** limits the motion of the coupling arm **218** to a plane parallel to both the cylinder **232** and the transducer **230**, reducing the likelihood of the coupling arm **218** binding about the cylinder **232** and the transducer **230**. This limitation may be accomplished, for example, by the coupling arm **218** encircling the cross section of the guide **320** as depicted in FIGS. **2** and **3**, or the coupling arm **218** having a track on its periphery mating to the guide **320**. The guide **320** may provide a low friction point of contact and may be a flat plate. Regardless of its construction, the guide **320** maintains the magnetic section **344** of the coupling arm second end **228** about the transducer **230**, preferably concentrically, without contacting the transducer **230**.

[0060] Referring again to FIG. **2**, the controller **206** may also control the valve system **204** to reciprocate the ferrous floating internal piston **304** between the cylinder first end **220** and the cylinder second end **222** at least when the piston **304** approaches, nearly reaches or reaches the cylinder first end **220** or the cylinder second end **222**. The valve system **204** may accomplish this by generating an electric pulse to cause one of the solenoids **234** or another actuator **234** to change position.

[0061] Alternatively, as illustrated in FIG. **4**, the cylinder **232** may have, exiting through either its cylinder first end **220** or its cylinder second end **222**, a first rod **402** coupled to the valve system **204** at an actuator **234** to effect flow reversal at the end of the stroke, that is when the piston **304** reaches or nearly reaches the cylinder first end **220** or the cylinder second end **222.** A matching second rod **403**, not coupled to any device, would necessarily exit the cylinder **232** at its opposite side and be similarly related to the piston **304** to ensure the volumes of the two chambers **328**, **330**, and therefore their displacement, are equivalent. The first rod **402** is preferably coupled to the piston **304** to ensure motion in both directions, but could be loaded, such as by a spring, to move with the piston **304.** In one embodiment, this could be accomplished with a snap action, spring-loaded shifter to work with a single actuator, such as depicted in Figs. **7** and **8.** Alternatively, a three-way valve could be coupled to each of the two rods **402, 403** to effect operation.

[0062] With reference to FIGS. **7** and **8**, an automatic shifting mechanism **700**, that shifts the valve system **204** via and in response to the movement of first rod **402** among the first position **246** and the second position **248,** thus also reversing the direction of movement of the piston **304** in the flow meter **202**.

[0063] As shown in more detail in FIG. 7, yoke **706** and a lever **710** are commonly mounted on a bushing **716** fixed to a stationary standard **714**. The yoke **706** is shown in a retracting (not upward) position. Yoke **706** and lever **710** are free to independently rotate about bushing **716**, except that a torsion spring **708** resiliently couples the free end of lever **710** with an internal arm **718** in yoke **706**. The free end of lever **710** is coupled to linkage arm **720** by ball joint connection **712**. Pin **702**, located at the end of first rod **402**, is captured and slides within a narrow neck **704** of yoke **706** and causes yoke **706** to rotate about bushing **716**.

[0064] In FIG. 7, first rod **402** has reached its outermost limit of travel, and the yoke **706** has actuated to cause lever **710** to be in the downward position. The flow meter **202** has reversed and first rod **402** reverses direction, retracting. As pin **702** moves toward flow meter **202**, yoke

706 rotates clockwise about bushing **716**, causing internal arm **718** to rotate clockwise. Such clockwise rotation compresses torsion spring **708**. The force exerted by torsion spring **708** upon ball joint **712** is still in the direction of retraction. As the first rod **402** approaches its point of travel furthest in retraction, the internal arm **718** is horizontally aligned with ball joint **712** and torsion spring **708** is at maximum compression. Any further motion toward flow meter **202** by first rod **402** causes torsion spring **708** to present an outward force on ball joint **712**, which rapidly snaps to its upper position, thereby changing the positions of valve system **204** and changing the direction of fluid flow into flow meter **202**.

[0065] FIG. **8** shows yoke **706** of the automatic shifting mechanism in the retracted position. As first rod **402** extends, the torsion spring **708** compresses against ball joint **712** in the outward direction until internal arm **718** is horizontally aligned (i.e. reaches minimum distance) with ball joint **712**. Ball joint **712**, carrying linkage arm **720** then snaps back into the retracting position, thus completing the cycle.

[0066] Referring again to FIGS. **2** and **3**, since the change in volume of each chamber **328**, **230** of the metering cylinder **232** is calculated based on change in position, each thousandths of an inch (or 0.0025 cm) in length, or any small unit of length, of each chamber **328**, **230** the metering cylinder **202** corresponds to a position on the linear digital encoding transducer **230**, and therefore accurately represents the flow passing through the flow meter loop **216**. Preferably, when the floating internal piston **304** reaches an end of the metering cylinder **220**, **222**, and when the controller **206** is used to control the valve system **204**, the signal from the linear digital encoding transducer **230** as processed by the controller **206** to effect a change in position of the valve system **204** among the first and second positions **246**, **248** (such as by activating the solenoid actuator **234** to change its position), changing the direction of flow from one end of the metering cylinder to the opposite end **220**, **222**.

[0067] Thus, in operation the fluid from the fluid input **208**, and the associated pressure, entering the metering cylinder **232** works against the floating piston **304**, and drives the fluid on the opposing, and now discharging, side of the floating piston **304** to be discharged by valve system **204**. This is accomplished by ensuring in the first position **246**, the fluid input **208** is connected to the second end connector **226** and the first end connector **224** is connected to the fluid output **210**. In the second position **248**, the fluid input **208** is connected to the first end connector **224** and the second end connector **226** is connected to the fluid output **210**, thus reversing the flow of fluid through the flow meter loop **216**, and reversing the direction of movement of the piston **304**.

[0068] Due to the large diameter of the metering cylinder **202** and the orifice diameters throughout the meter, the flow meter **202** is very tolerant of solids and abrasives and thus provides longer life in addition to improved accuracy. Thus, the flow meter **202** is unique in that it does not rely on close tolerance meshing machined parts in order to measure the flow of fluid.

Flow meter incorporating flow control system

[0069] Because the flow meter **202** provides precise determination of the flow rate of a fluid and/or volume of distribution, it may be incorporated into a flow control system **500**, such as depicted in FIG. **5**, for use in the present system such that the fluid output **210** from the flow meter **202** may be discharged where desired, including being introduced into a second fluid **502** as an additive for blending.

[0070] The flow control system **500** integrates the flow meter **202** intermediate a source **504** of fluid and a destination **550**. The source **504** of fluid to be metered, such as an additive, in a supply **506** may be connected to the fluid input **208** of the flow meter **202** and may be permitted to introduce the fluid to the fluid input **208**. The controller **206** may then provide an output signal consistent with the associated flow rate to a flow controller **508**, operable at least among a fluid flowing position and a fluid non-flowing position, intermediate the supply **506** and the valve system **204**. The flow controller **508** may be a computer-controlled pump, including one operable among a plurality of pump speeds, or a valve. The fluid supply **506** may be any type of fluid source, including one flowing and one of fixed volume, which may or may not be under pressure. Here the fluid supply **506** is the output from the additive pump **120.** The destination **550**, in communication with the output **210** from the valve system **204** (preferably through an injection point check value **552** to prevent contamination or backflow pressure in the system) may be another volume, a container, or even a flow of untreated fluid for introduction of an additive or for blending. Here the destination **550** is the piping **108**.

[0071] In operation, the flow control system **500** may be employed to ensure the desired flow rate of an additive fluid is actually obtained. This may be accomplished by the flow control workflow **600**.

[0072] At step **602**, the system receives a user input for said desired flow rate of additive fluid and a desired quantity.

[0073] At step **604,** the system activates the additive flow controller **508** at a presumed flow rate consistent with said desired flow rate of additive fluid.

[0074] At step **606**, the system introduces the additive fluid at presumed flow rate to the flow meter **202** via the valve system **204** as controlled by the controller **206.**

[0075] At step **608**, controller **206** determines the actual flow rate via the movement of the ferrous floating internal piston **304**, i.e. based on position related to displacement (particularly based on the relative position along the length of the transducer), and provides at least one output signal consistent with the actual associated flow rate to the system.

[0076] At step **610**, the system determines if the actual flow rate is within the margin of error of the desired flow. If the actual flow rate is within the margin of error of the desired flow rate, the system proceeds to step **614**. Otherwise, the system continues to step **612**.

[0077] At step **612**, the system adjusts the actual flow rate at said additive flow controller **408508** to obtain the desired flow rate from step **602**.

[0078] At step **614**, the system determines if the desired quantity of additive fluid has been provided, which may be based on the actual flow rate(s) and elapsed time(s) or may be based on the displacement of the piston **304** as measured by the transducer **230**. If the system determines if the desired quantity of additive fluid has been provided, the method ends. If not, the system returns to step **608**.

[0079] The resulting system **500** may provide delivery of the fluid to ensure delivery from a flowing supply of a fluid into a flow of a second fluid at a low ratio consistent with additive treatment. Thus, the output of the additive pump **120** may be verified and controller with a unique flow meter to ensure the appropriate volume of additive

[0080] While the present invention has been described in connection with presently preferred embodiments, it will be understood by those skilled in the art that it is not intended to limit the invention to those embodiments. It is therefore, contemplated that various alternative embodiments and modifications may be made to the disclosed embodiments without departing from the spirit and scope of the invention defined by the appended claims and equivalents thereof.

CLAIMS

I claim:

1. A fluid-additive delivery system for addition of a fluid additive to a fluid flowing in a piping, comprising,

a fluid motor, said fluid motor having a fluid inlet and a fluid outlet, said fluid motor adapted to receive said fluid from said piping at said fluid inlet, said fluid motor adapted to expel said fluid at said fluid output, and said fluid motor having an output shaft rotatably driven by said fluid moving between said fluid inlet and said fluid output;

a speed sensor adapted to be associated with said output shaft, said speed sensor adapted to provide a signal to a computer indicative of rotational speed of said output shaft;

an electricity generation and storage system, said electricity generation and storage system comprising a direct current generator and an electrical battery, said direct current generator adapted to be driven by said output shaft, said direct current generator adapted to provide electricity to said electrical battery;

a clutch adapted to be associated with output shaft, said clutch adapted to engage a shaft of an additive pump upon activation by a computer;

said additive pump adapted to be rotatably driven by said output shaft upon engagement by said clutch, said additive pump in fluid communication with a reservoir of fluid additive and adapted to pump said fluid additive to a flow meter; and

said flow meter having a meter input adapted for fluid communication with said additive pump, said flow meter having a meter output adapted for fluid communication of said fluid additive to said fluid in said piping, said flow meter adapted to provide a signal to said computer indicative of the actual flow rate from said additive pump.

2. The delivery system of claim 1, wherein said speed sensor comprises a Hall-effect speed sensor.

3. The delivery system of claim 1, wherein said clutch is momentary wrap spring clutch.

4. The delivery system of claim 3, wherein said clutch is engaged by a solenoid operator.

5. The delivery system of claim 3, wherein said clutch is electrically powered by said electricity generation and storage system.

6. The delivery system of claim 1, wherein said computer is adapted to be electrically powered by said electricity generation and storage system.

7. The delivery system of claim 1, wherein said computer is a programmable logic controller.

8. The delivery system of claim 7, wherein said computer is adapted to be electrically powered by said electricity generation and storage system.

9. The delivery system of claim 1, wherein said flow meter is a positive displacement reciprocating flow meter.

10. The delivery system of claim 9, wherein said flow meter is adapted to reciprocate by solenoid operators powered by said electricity generation and storage system.

11. The delivery system of claim 9, wherein said flow meter is adapted to reciprocate by electrical powered by said electricity generation and storage system.

12. The delivery system of claim 1, further comprising a multiple output gear head intermediate said output shaft and said clutch.

13. The delivery system of claim 12, further comprising

a second clutch, said second clutch adapted to be associated with output shaft, said second clutch adapted to engage a shaft of a second additive pump upon activation by a computer, said second clutch connected to said multiple output gear head;

said second additive pump adapted to be rotatably driven by said output shaft upon engagement by said second clutch, said additive pump in fluid communication with a second reservoir of a second fluid additive and adapted to pump said second fluid additive to a second flow meter; and

said second flow meter having a second meter input adapted for fluid communication with said second pump, said second flow meter having a second meter output adapted for fluid communication of said second fluid additive to said fluid in said piping, said second flow meter adapted to provide a signal to said computer indicative of the actual flow rate from said second additive pump.

14. The delivery system of claim 1, wherein said fluid flowing in a piping flows at a pressure of less than 150 psi (1,034.21 kPa) and said additive pump pumps said fluid additive to said flow meter at a pressure of less than 60 psi (413.69 kPa).

15. A fluid-additive delivery system for addition of a fluid additive to a fluid flowing in a piping, comprising,

a fluid motor, said fluid motor having a fluid inlet and a fluid outlet, said fluid motor in communication with said piping at said fluid inlet, said fluid motor in communication with said fluid output, and said fluid motor having an output shaft rotatably driven by said fluid moving between said fluid inlet and said fluid output;

a speed sensor associated with said output shaft, said speed sensor providing a signal to a computer indicative of rotational speed of said output shaft;

a direct current generator in mechanical connection with said output shaft, said direct current generator electrically connected to an electrical battery;

a clutch associated with said output shaft, said clutch engaging a shaft of an additive pump upon activation;

said additive pump rotatably driven by said output shaft upon engagement by said clutch, said additive pump in fluid communication with a reservoir of fluid additive and impelling said fluid additive to a flow meter; and

said flow meter having a meter input in fluid communication with said additive pump, said flow meter having a meter output in one-way fluid communication with said piping, said flow meter providing a signal to a computer indicative of the actual flow rate from said additive pump.

16. A flow meter, comprising:

a cylinder having a cylinder length, a cylinder exterior, a cylinder centerline, a cylinder first end and a cylinder second end, said cylinder having a cylinder axis at said cylinder centerline along said cylinder length, said cylinder having a first end connector and a second end connector, said cylinder composed of non-ferrous material;

a ferrous floating internal piston freely slidable in said cylinder between said cylinder first end and said cylinder second end, said piston having a piston length;

a cylindrical ring slidably positioned about and closely encircling said cylinder exterior, said cylindrical ring magnetically coupled to said ferrous floating internal piston, said cylindrical ring maintained substantially concentric with said cylinder axis;

an absolute linear digital encoding transducer having a transducer length and transducer axis, said transducer axis substantially parallel to said cylinder axis, said transducer length generally equivalent to said cylinder length;

a coupling arm having a coupling arm first end and a coupling arm second end, said coupling arm integrally affixed to said cylindrical ring at said coupling arm first end and maintained generally perpendicular to said cylinder axis, said coupling arm having a magnetic section at said coupling arm second end, said magnetic section having a magnetic field interacting with said linear digital encoding transducer;

a valve system having a fluid input, having a fluid output, in fluid communication with said first end connector and in fluid communication with said second end connector, said valve system switchably operable among a first position and a second position, said first position connecting said fluid input and second end connector and connecting said first end connector with said fluid output and said second position connecting said fluid input and said first end connector and connecting said second end connector with said fluid output; and

a controller adapted to determine a plurality of the positions of said coupling arm relative to said linear digital encoding transducer, recording said plurality of positions and an associated time for said plurality of positions, determining the speed and direction of movement of said coupling arm relative to said linear digital encoding transducer as a function of difference in said position between said associated times; and

a valve system controller adapted to cause said valve system to reciprocate said ferrous floating internal piston between said cylinder first end and said cylinder second end at least when said piston approaches either said cylinder first end or said cylinder second end.

17. The flow meter of claim 16, wherein

said valve system controller is a computer;

said controller is a computer,

said controller is adapted to signal said valve system controller when said coupling arm reaches said cylinder first end or said cylinder second end and said valve system controller is adapted to cause said valve system to switch among said first position and said second position.

18. A flow control system for measurement of a flowing fluid substance, comprising:

a positive displacement reciprocating piston flow meter, said positive displacement flow meter having a first end connector and a second end connector, said positive displacement flow meter comprising:

a cylinder having a cylinder length, a cylinder exterior, a cylinder centerline, a cylinder first end and a cylinder second end, said cylinder having a cylinder axis at said cylinder centerline along said cylinder length, said cylinder composed of non-ferrous material;

a ferrous floating internal piston freely slidable in said cylinder between said cylinder first end and said cylinder second end, said piston having a piston length;

a cylindrical ring slidably positioned about and closely encircling said cylinder exterior, said cylindrical ring magnetically coupled to said ferrous floating internal piston, said cylindrical ring maintained substantially concentric with said cylinder axis;

an absolute linear digital encoding transducer having a transducer length and transducer axis, said transducer axis substantially parallel to said cylinder axis, said transducer length generally equivalent to said cylinder length;

a coupling arm having a coupling arm first end and a coupling arm second end, said coupling arm integrally affixed to said cylindrical ring at said coupling arm first end and maintained generally perpendicular to said cylinder axis, said coupling arm having a magnetic section at said coupling arm second end, said magnetic section having a magnetic field interacting with said linear digital encoding transducer;

a valve system having a fluid input, having a fluid output, in fluid communication with said first end connector and in fluid communication with said second end connector, said valve system switchably operable among a first position and a second position, said first position connecting said fluid input and second end connector and connecting said first end connector with said fluid output and said second position connecting said fluid input and said first end connector and connecting said second end connector with said fluid output; and

a controller adapted to determine a plurality of the positions of said coupling arm relative to said linear digital encoding transducer, recording said plurality of positions and an associated time for said plurality of positions, determining the speed and direction of movement of said coupling arm relative to said linear digital encoding transducer as a function of difference in said position between said associated times; and

a valve system controller controlling said valve system to reciprocate said ferrous floating internal piston between said cylinder first end and said cylinder second end at least when said piston approaches either said cylinder first end or said cylinder second end.

19. The flow control system of claim 18 wherein said flowing fluid substance is an additive fluid, and wherein said additive is to be introduced into a flow of untreated fluid at a ratio of less than 2500 parts per million of volume of said additive to volume of said untreated fluid.

20. The additive delivery system of claim 18 further comprising:

said controller providing an output signal consistent with said associated flow rate; and

an additive flow controller intermediate said supply of said additive and said valve system, said additive flow controller operable among at least an additive flowing position and an additive non-flowing position.

21. The flow control system of claim 18, wherein said additive flow controller is a computer-controlled pump.

22. The flow control system of claim 18, wherein said additive flow controller is a valve and said supply of said additive is pressurized.

23. The flow control system of claim 19 wherein said computer-controlled pump is operable among a plurality of pump speeds.

24. A method for obtaining a desired flow rate of fluid additive to a flow of untreated fluid at a ratio of less than 2500 parts per million of volume said fluid additive to volume of said untreated fluid, comprising:

1) receiving a user input for said desired flow rate of fluid additive;

2) activating an additive flow controller at a presumed flow rate consistent with said desired flow rate of fluid additive;

3) introducing the presumed flow rate to a positive displacement reciprocating piston flow meter, said positive displacement flow meter having a first end connector and a second end connector, said positive displacement flow meter comprising:

a cylinder having a cylinder length, a cylinder exterior, a cylinder centerline, a cylinder first end and a cylinder second end, said cylinder composed of non-ferrous material; said cylinder having a cylinder axis at said cylinder centerline along said cylinder length;

a ferrous floating internal piston freely slidable in said cylinder between said cylinder first end and said cylinder second end, said piston having a piston length;

a cylindrical ring slidably positioned about and closely encircling said cylinder exterior, said cylindrical ring magnetically coupled to said ferrous floating internal piston, said cylindrical ring maintained substantially concentric with said cylinder axis;

a linear digital encoding transducer having a transducer length and transducer axis, said transducer axis substantially parallel to said cylinder axis, said transducer length generally equivalent to said cylinder length; and

a coupling arm having a coupling arm first end and a coupling arm second end, said coupling arm integrally affixed to said cylindrical ring at said coupling arm first end and maintained generally perpendicular to said cylinder axis, said coupling arm having a magnetic section at said coupling arm second end, said magnetic section having a magnetic field interacting with said linear digital encoding transducer;

a valve system having a fluid input from said flowing supply of said fluid additive, having a fluid output, in fluid communication with said first end connector and in fluid communication with said second end connector, said valve system switchably operable among a first position and a second position, said fluid input in communication with said flowing supply of an fluid additive, said fluid output in communication with said flow of untreated fluid, said first position connecting said fluid input and second end connector and connecting said first end connector with said fluid output and said second position connecting said fluid input and said first end connector and connecting said second end connector with said fluid output; and

a controller adapted to determine a plurality of the positions of said coupling arm relative to said linear digital encoding transducer, recording said plurality of positions and an associated time for said plurality of positions, determining the speed and direction of movement of said coupling arm relative to said linear digital encoding transducer as a function of difference in said position between said associated times; and

a valve system controller controlling said valve system to reciprocate said ferrous floating internal piston between said cylinder first end and said cylinder second end at least when said ferrous floating internal piston approaches either said cylinder first end or said cylinder second end; and

4) comparing said presumed flow rate to said at least one output signal and identifying the deviation from desired flow rate; and

5) adjusting the actual flow rate at said additive flow controller to eliminate said deviation.

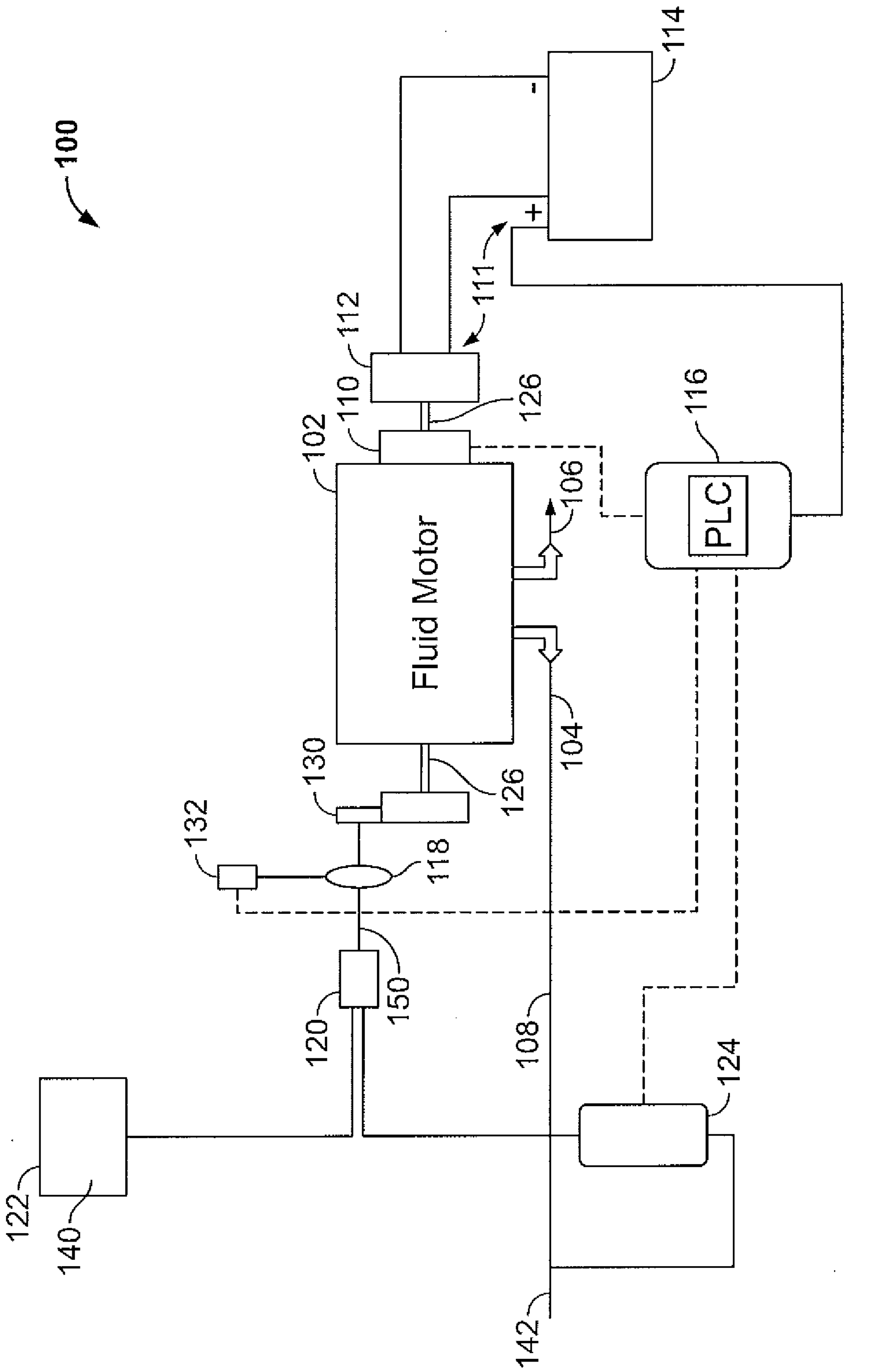
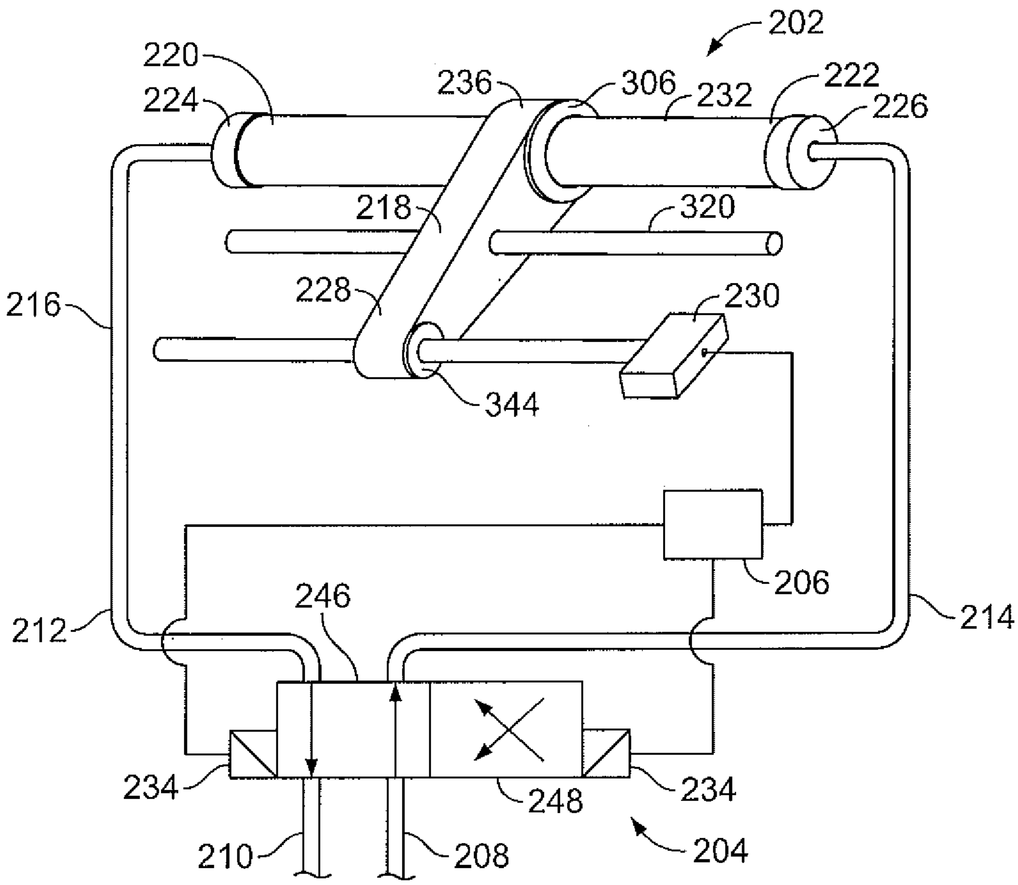

100
114
-
+
111
112
110
126
102
116
PLC
106
Fluid Motor
104
130
126
132
118
150
120
108
124
122
140
142

FIG. 1


202
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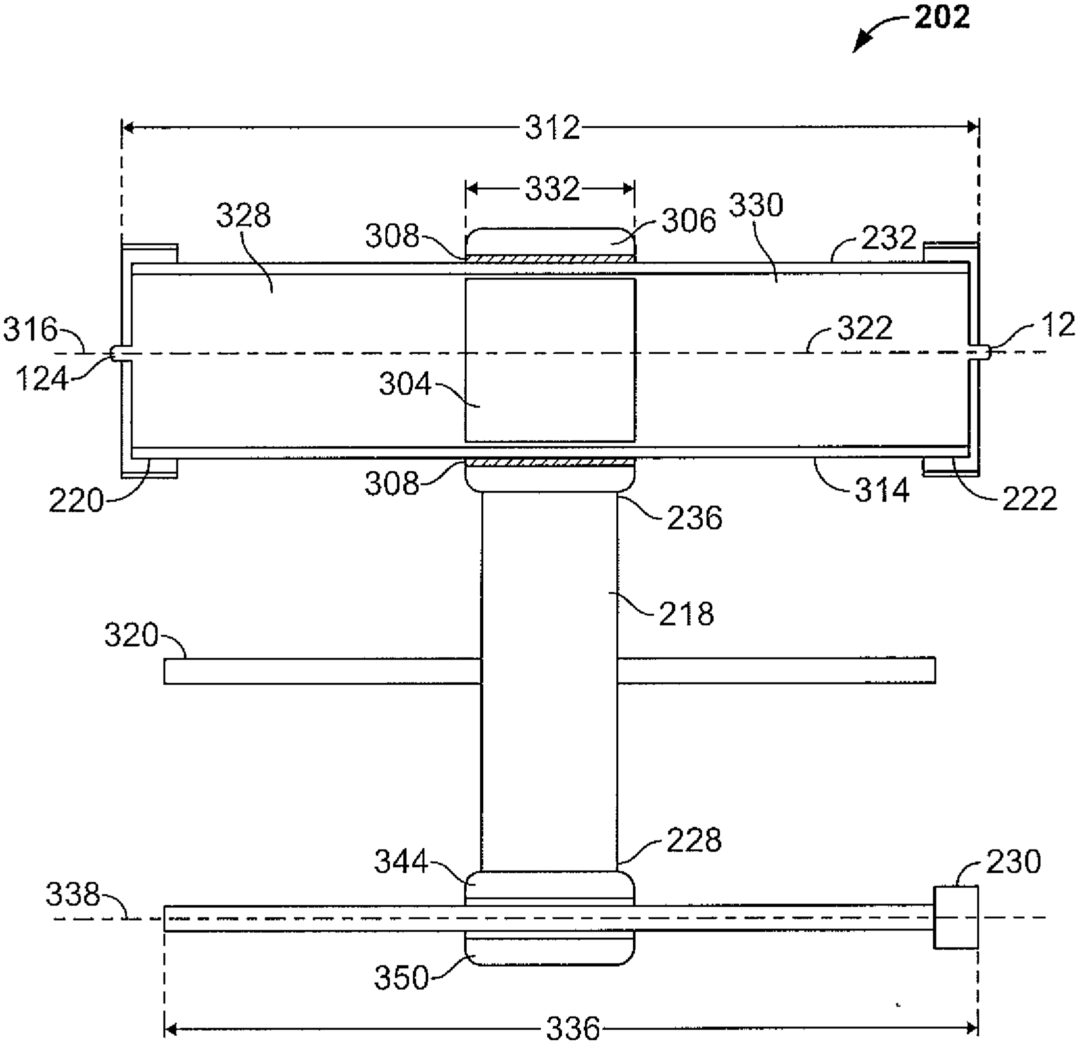
224
236
306
232
222
226
218
320
228
230
216
344
206
212
246
214
234
248
234
210
208
204

FIG. 2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330
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236
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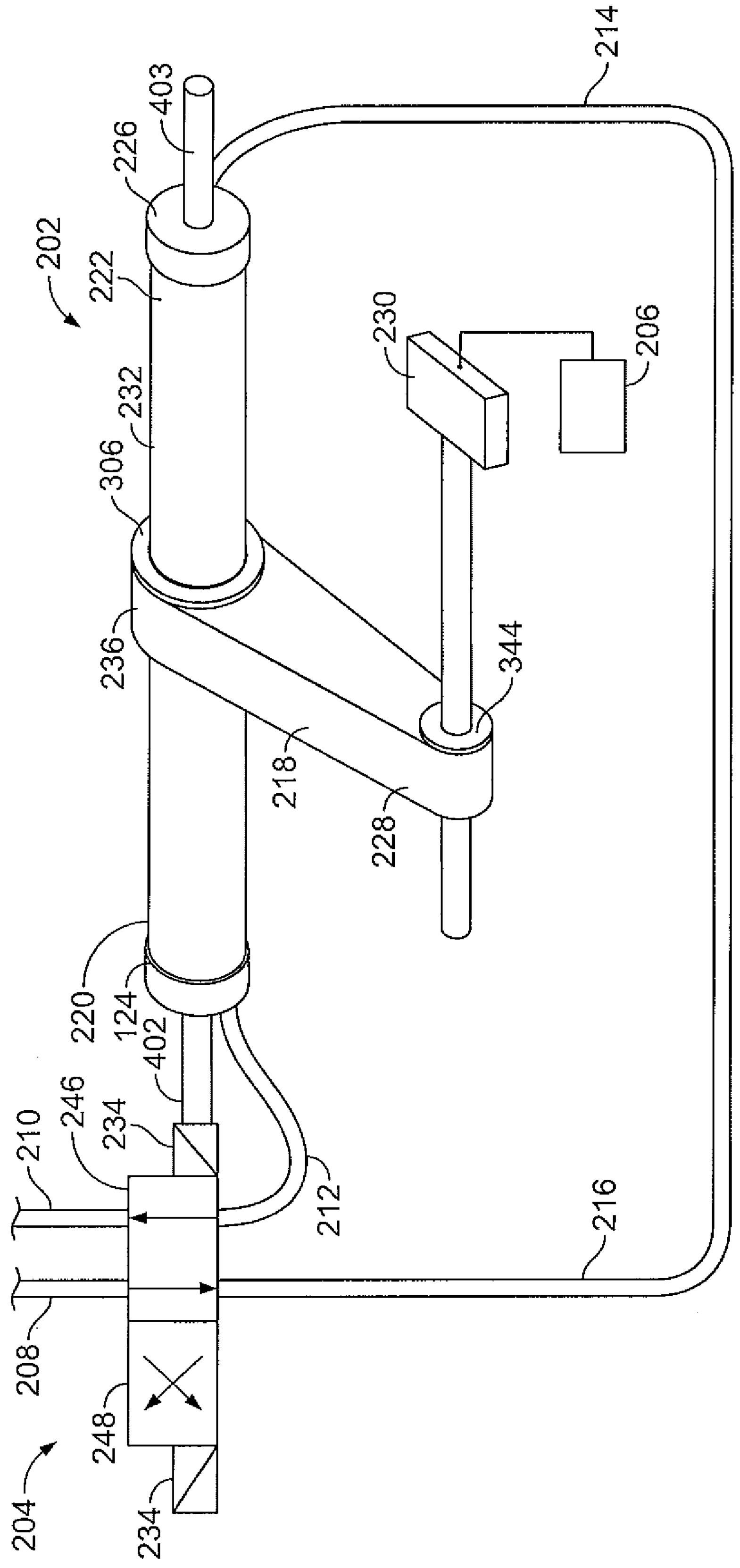
344
230
338
350
336

FIG. 3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306
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228
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124
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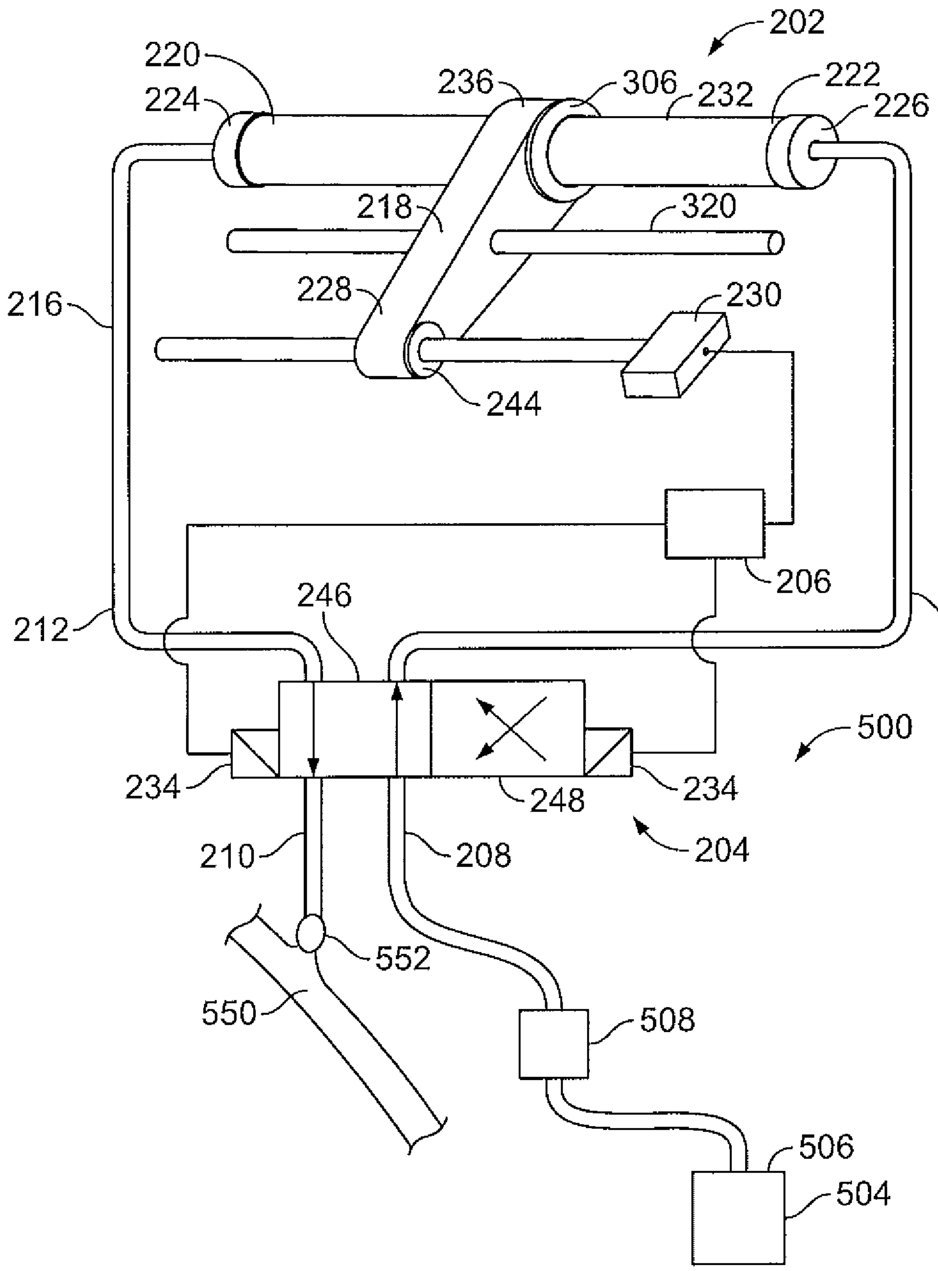
208
248
204
234

FIG. 4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248
234
210
208
204
552
550
508
506
504

FIG. 5

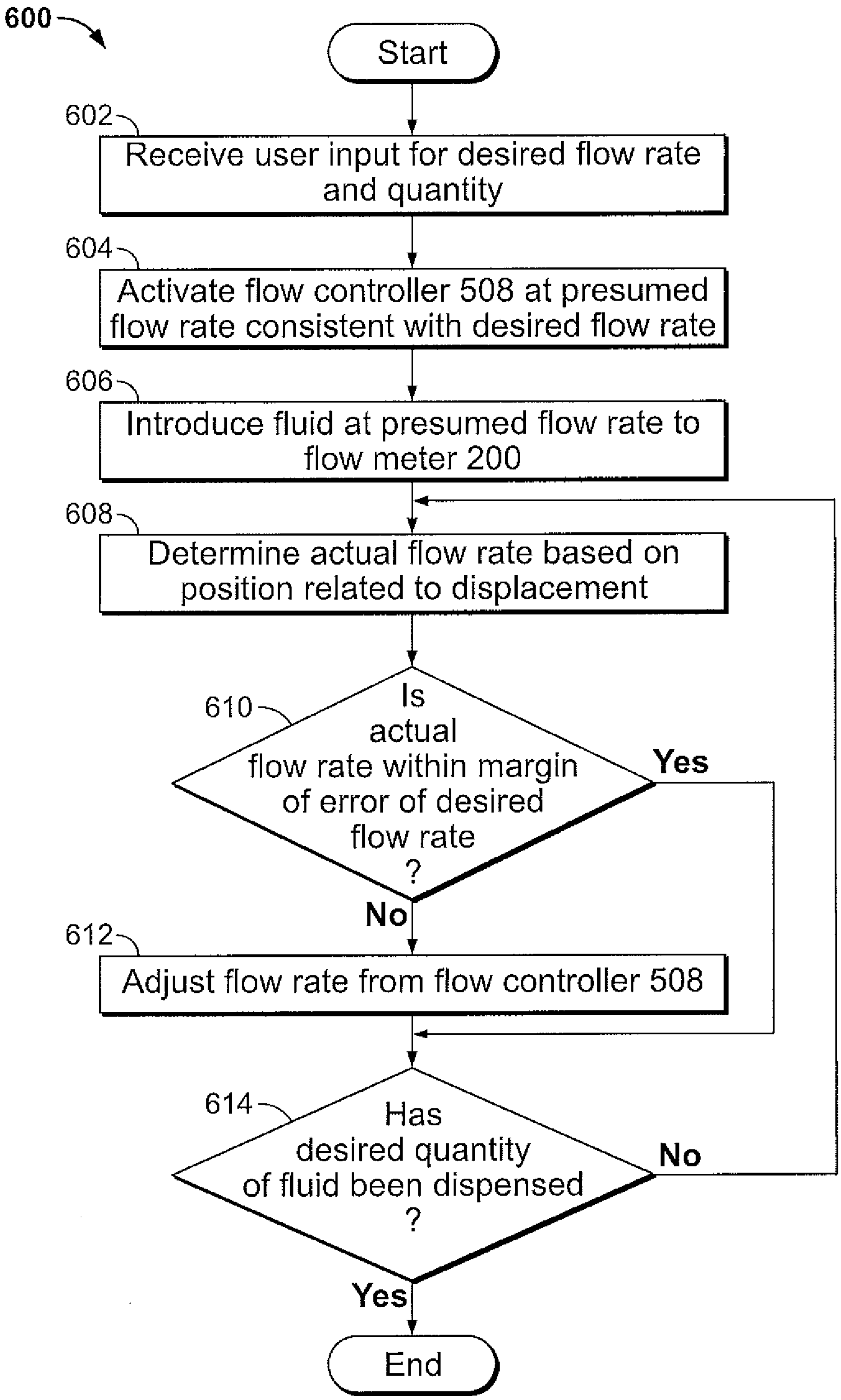
600
Start
602
Receive user input for desired flow rate and quantity
604
Activate flow controller 508 at presumed flow rate consistent with desired flow rate
606
Introduce fluid at presumed flow rate to flow meter 200
608
Determine actual flow rate based on position related to displacement
610
Is actual flow rate within margin of error of desired flow rate ?
Yes
No
612
Adjust flow rate from flow controller 508
614
Has desired quantity of fluid been dispensed ?
No
Yes
End

FIG. 6

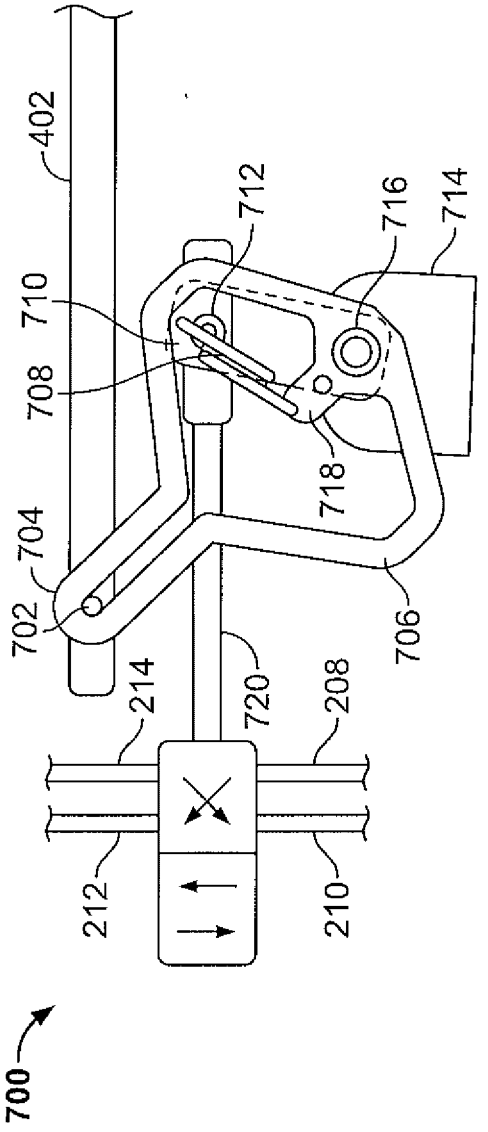
402
712
716
714
710
708
718
704
702
706
214
720
208
212
210
700

FIG. 7

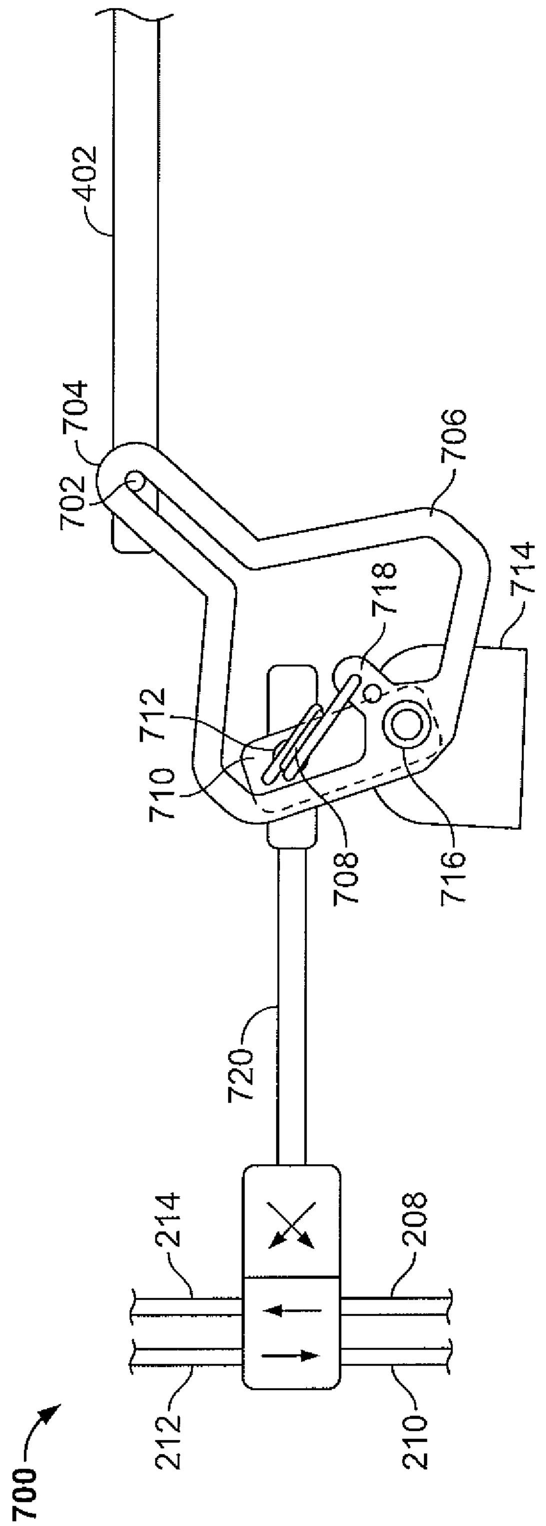
402
704
702
706
714
718
712
710
708
716
720
214
208
212
210
700

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/020054

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - G01F 11/06 (2013.01)
USPC - 222/63
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - B67D 7/04; F01L 15/12, F04B 9/10; G01F 3/16, 11/06; G05D 11/00 (2013.01)
USPC - 73/239, 861; 91/330, 331; 92/15; 137/624.13, 624.15; 141/104; 222/17, 63, 71; 239/61; 366/136; 417/408, 409

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - B01F 15/0416 (2013.01)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase, Google Patents, Youtube

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,286,175 A (HAMMONDS) 15 February 1994 (15.02.1994) entire document	1-24
A	US 7,066,353 B2 (HAMMONDS) 27 June 2006 (27.06.2006) entire document	1-24
P, A	US 8,251,022 B2 (YACCARINO) 28 August 2012 (28.08.2012) entire document	1-24
A	EP 2 041 396 B1 (ELLERO) 14 September 2011 (14.09.2011) entire document	1-24
A	EP 0 508 528 B1 (PAVESI) 21 June 1995 (21.06.1995) entire document	1-24

☐ Further documents are listed in the continuation of Box C. ☐

* 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	Date of mailing of the international search report
30 April 2013	14 MAY 2013

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/020054

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 extra 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 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.:

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.

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees need to be paid.

Group I, claims 1-15 are drawn to a fluid-additive delivery system.
Group II, claims 16-24 are drawn to a flow meter.

The inventions listed in Groups I and II do not relate to a single general inventive concept under PCT Rule 13.1, because under PCT Rule 13.2 they lack the same or corresponding special technical features for the following reasons:

The special technical features of Group I, a fluid-additive delivery system comprising a fluid motor, a speed sensor, a clutch, an additive pump, and a flow meter, are not present in Group II; and the special technical features of Group II, a flow meter comprising a cylinder, a ferrous floating internal piston, a cylindrical ring, an absolute linear digital encoding transducer, a coupling arm, a valve system, a controller, and a valve system controller, are not present in Group I.

Since none of the special technical features of the Group I and II inventions are found in more than one of the inventions, unity is lacking.