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(54) FLUID DELIVERY SYSTEM AND METHOD

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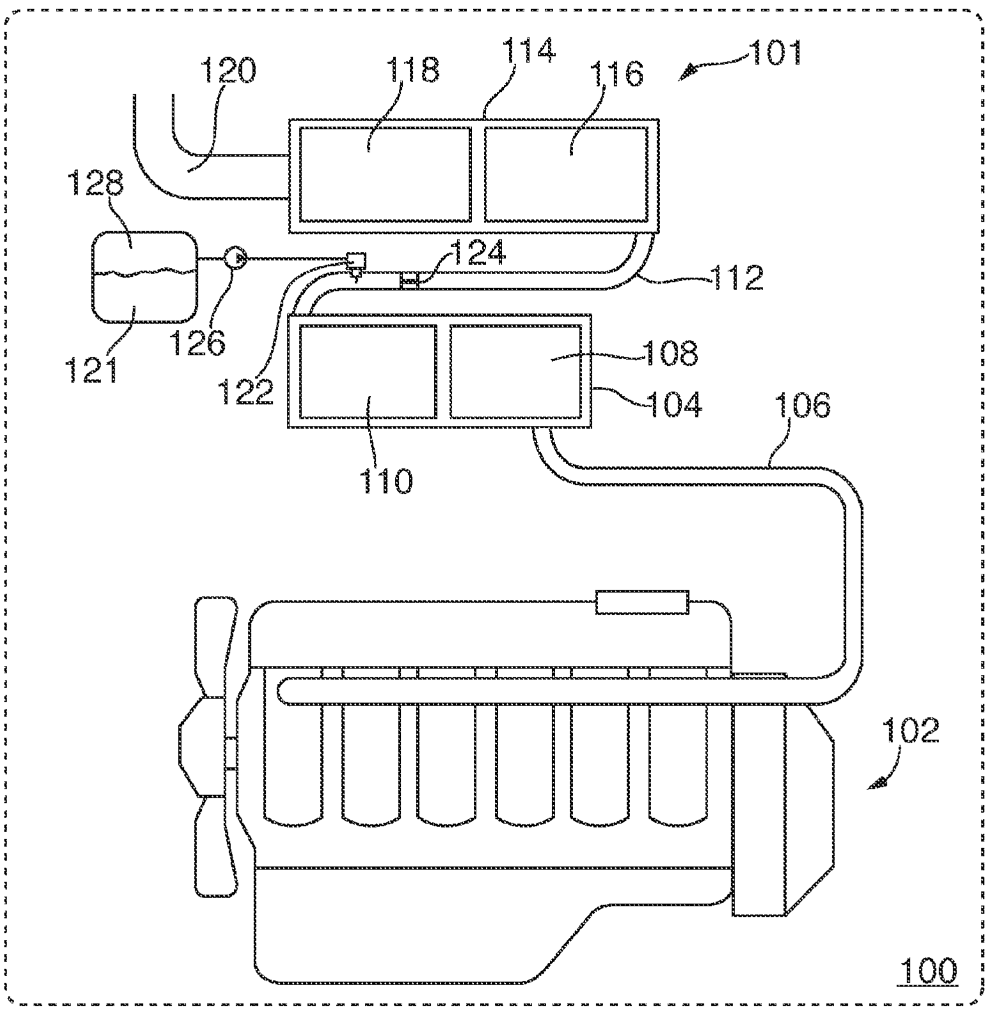
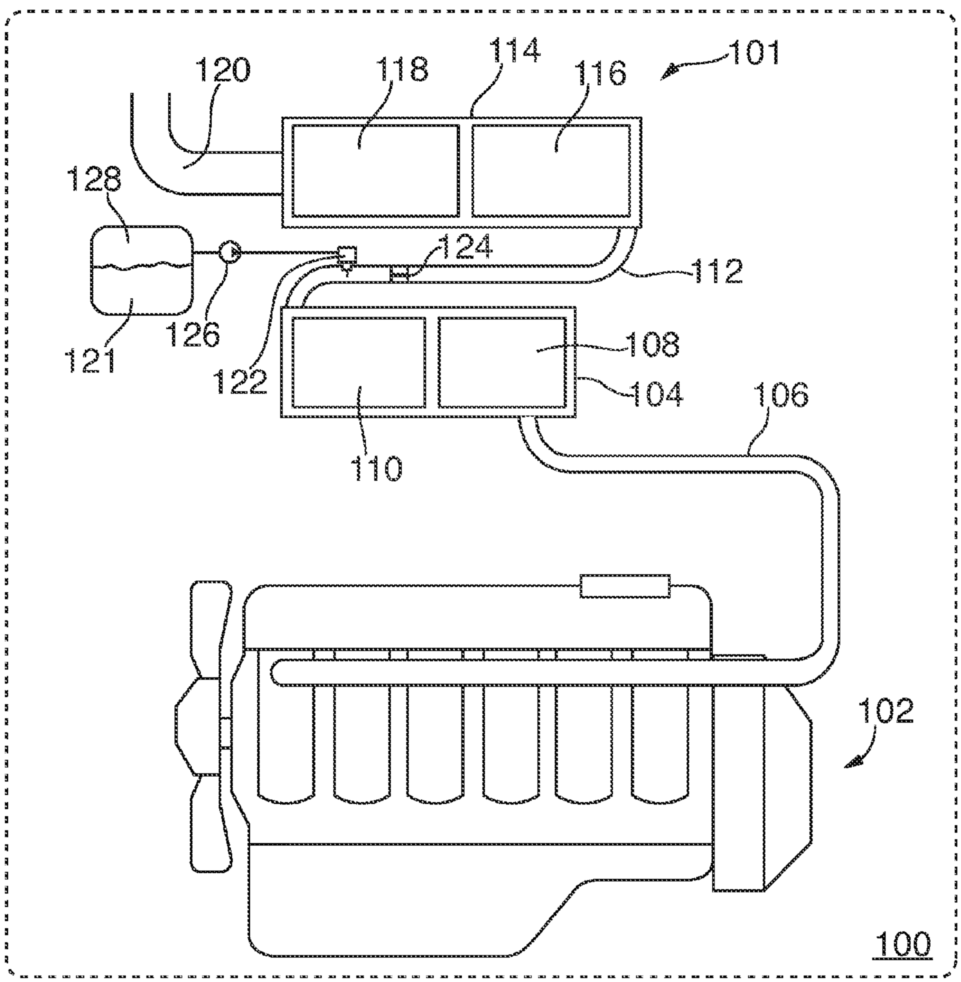
(57) ABSTRACT

A fluid delivery system includes a reservoir, a pump, an injector, and a pressure regulator. The reservoir encloses a fluid and includes a reservoir body forming a reservoir volume that encloses the fluid. The reservoir includes a draw conduit and a return conduit. The pump has an inlet connected to the draw conduit and provides fluid at the operating pressure and at a desired flow to a pressure line that is fluidly connected to an outlet of the pump. The injector selectively opens to allow an injected fluid flow to pass therethrough. The return orifice fluidly connects the pressure line with the return conduit, and the pressure regulator provides a regulated fluid flow to the fluid reservoir. During operation, the desired fluid flow is equal to a sum of the injected fluid flow, the return fluid flow and the regulated fluid flow.




120
118
114
116
101
128
124
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121
122
108
104
106
110
102
100

FIG. 1

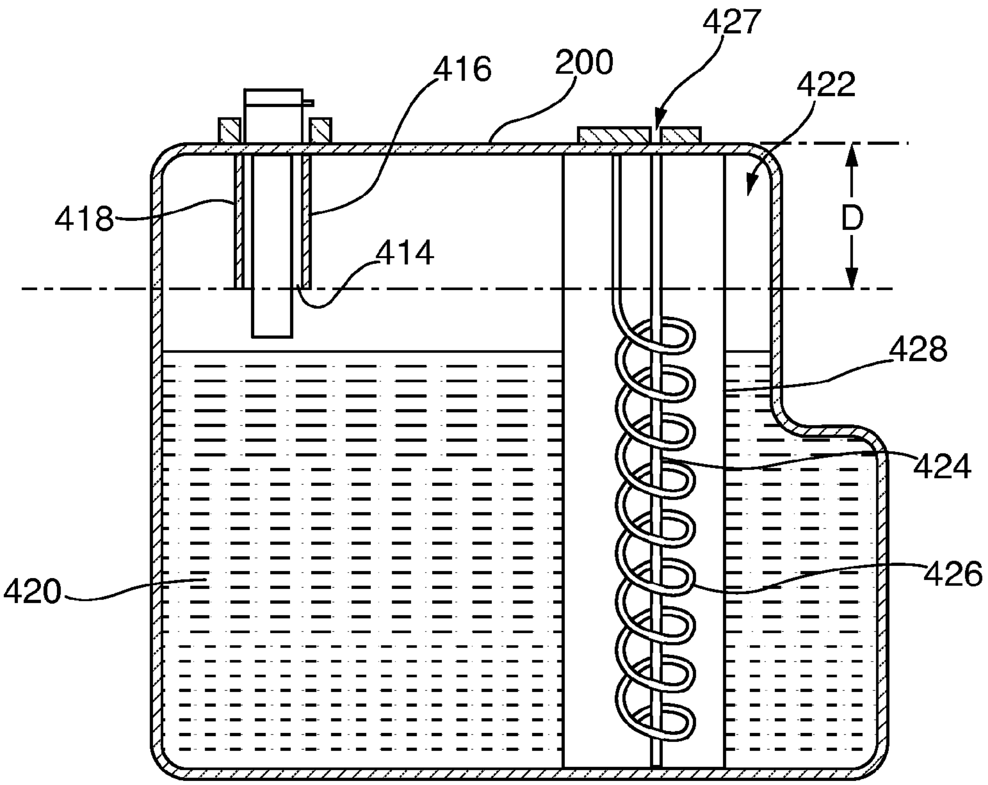


FIG. 2

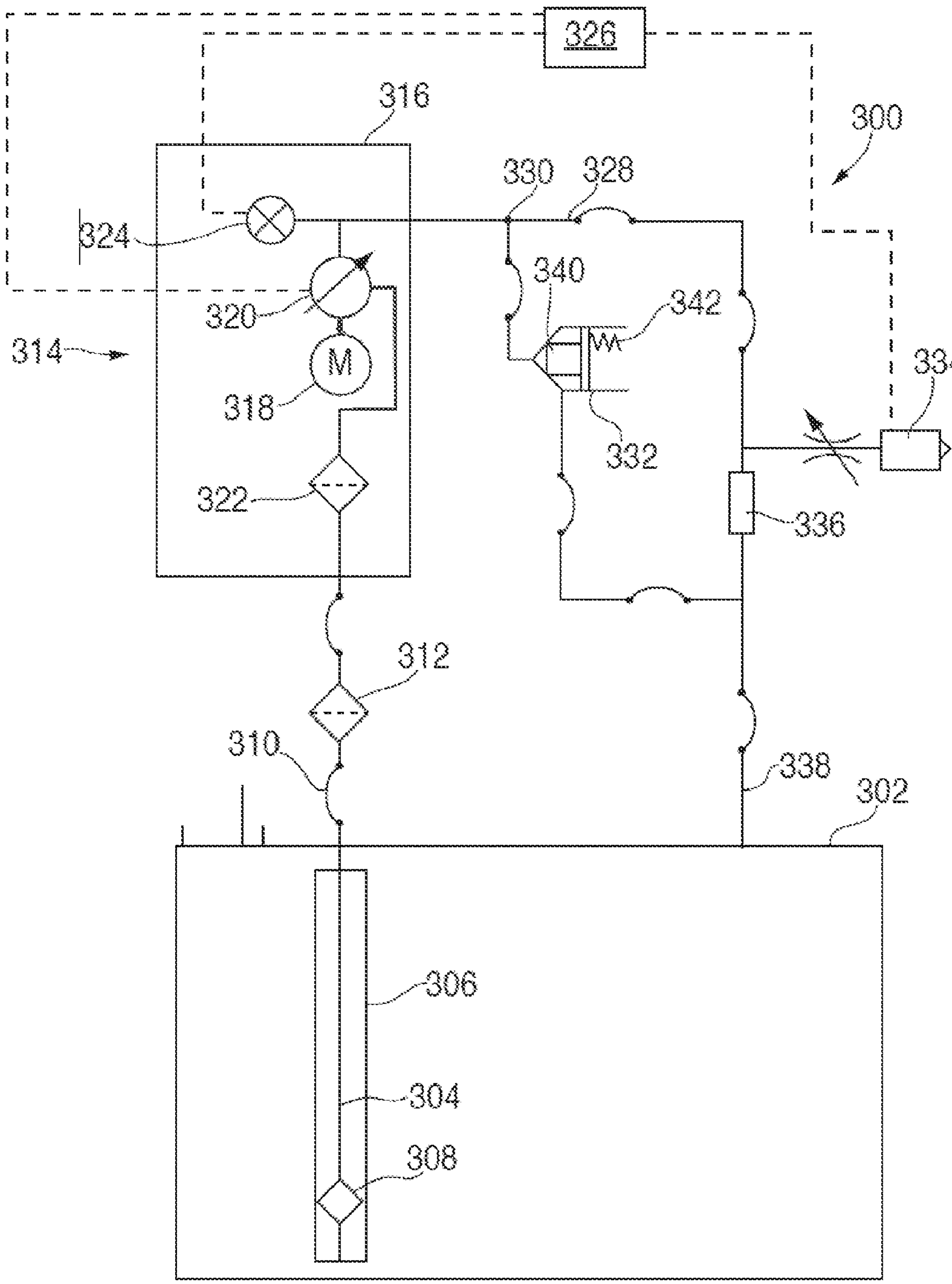
326
300
316
330
328
324
340
342
320
314
318
334
332
322
336
312
310
338
302
306
304
308

FIG. 3

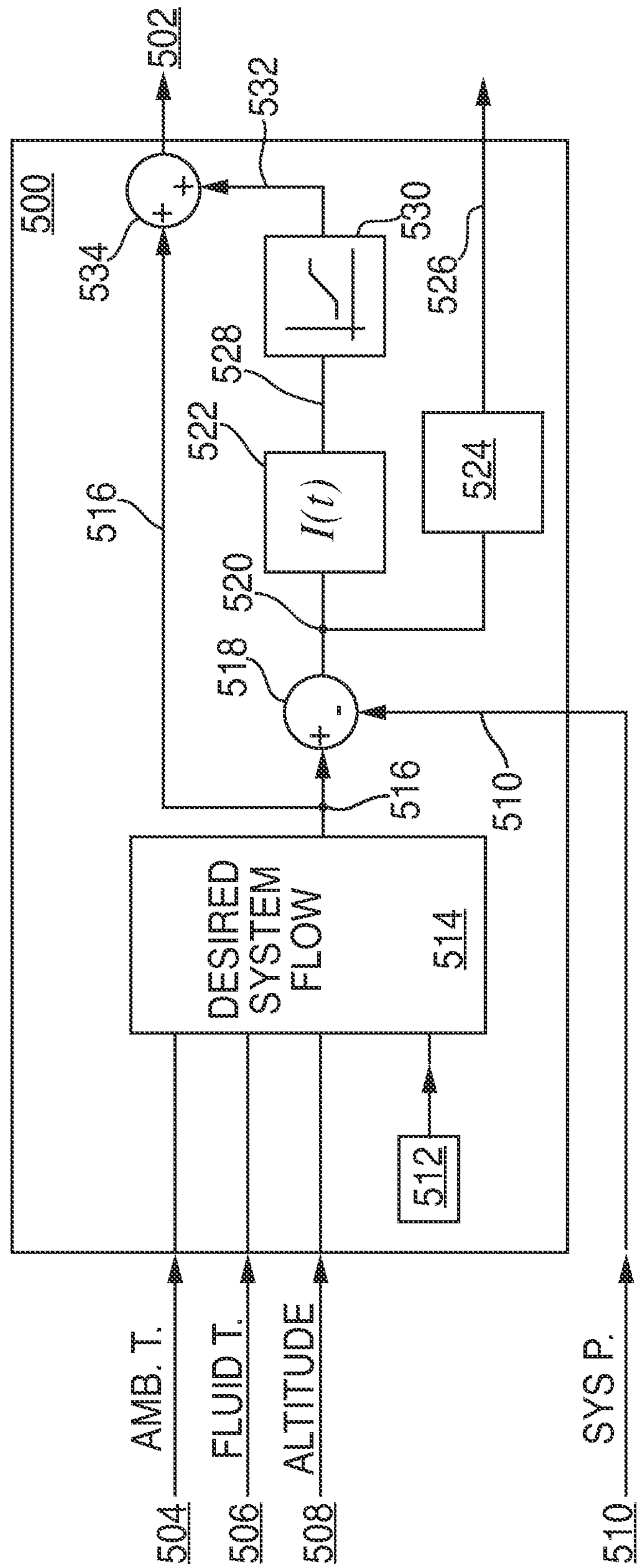
502
532
500
534
530
526
528
522
516
I(t)
524
520
518
516
510
DESIRED
SYSTEM
FLOW
514
512
AMB. T.
FLUID T.
ALTITUDE
SYS P.
504
506
508
510

FIG. 4

# FLUID DELIVERY SYSTEM AND METHOD

## TECHNICAL FIELD

**[0001]** This disclosure relates generally to fluid delivery systems used in association with vehicles and, more particularly, to a fluid delivery system for diesel exhaust fluid for use with engine emission control systems.

## BACKGROUND

**[0002]** One known method for abating certain diesel engine exhaust constituents is by use of an exhaust after-treatment system that utilizes Selective Catalytic Reduction (SCR) of nitrogen oxides. In a typical SCR system, diesel exhaust fluid (DEF), which may include urea or a urea-based water solution, is mixed with exhaust gas before being provided to an appropriate catalyst. In some applications, the DEF is injected directly into an exhaust passage through a specialized injector device. In the case of urea, the injected DEF mixes with exhaust gas and breaks down to provide ammonia ($NH_3$) in the exhaust stream. The ammonia then reacts with nitrogen oxides ($NO_x$) in the exhaust at a catalyst to provide nitrogen gas ($N_2$) and water ($H_2O$).

**[0003]** As can be appreciated, SCR systems require the presence of some form of DEF sufficiently close to the engine system such that the engine can be continuously supplied during operation. Various DEF delivery systems are known and used in engine applications. In known DEF injection systems, a reservoir is installed onto a vehicle for containing the DEF, which is drawn from the reservoir and delivered in metered amounts to the engine exhaust system.

**[0004]** In most engine applications, a precise delivery of DEF is required to achieve a desired and sufficient abatement of undesirable exhaust constituents as well as to avoid frequent fluid replenishments. For example, a fluid flow that is below a desired rate, depending on engine operating conditions, may not sufficiently abate engine emissions. Similarly, a fluid flow that is above a desired rate may deplete fluid supply in the vehicle prematurely, which can lead to more frequent vehicle service and/or insufficient emissions abatement due to lack of fluid after the fluid has been prematurely depleted and before it can be replenished.

## SUMMARY

**[0005]** The disclosure describes, in one aspect, a fluid delivery system. The fluid delivery system includes a fluid reservoir adapted to enclose a fluid therewithin, the fluid reservoir comprising a reservoir body forming a reservoir volume that encloses the fluid therewithin and that includes a fluid draw conduit, which is configured to draw fluid from the reservoir volume, and a fluid return conduit, which is configured to return fluid to the reservoir volume. The fluid delivery system further includes a pump having an inlet fluidly connected to the fluid draw conduit such that the pump can draw fluid from the fluid reservoir, increase a pressure of the fluid to an operating pressure, and provide fluid at the operating pressure and at a desired fluid flow to a pressure line that is fluidly connected to an outlet of the pump. The fluid delivery system also includes a fluid injector fluidly in communication with the pressure line, the fluid injector configured to selectively open and allow pressurized fluid at a predetermined, injected fluid flow to pass therethrough when the fluid injector is open. A return orifice fluidly connecting the pressure line at a location downstream of the fluid injector with the fluid return conduit such that a return fluid flow is returned to the fluid reservoir can optionally be used, but is not required for all embodiments. A pressure regulator having a regulator inlet in fluid communication with the pressure line and a regulator outlet in fluid communication with the fluid return conduit is configured to provide a regulated fluid flow to the fluid reservoir when the operating pressure exceeds a pressure regulator opening pressure. During operation, the desired fluid flow is equal to a sum of the injected fluid flow, the return fluid flow and the regulated fluid flow.

**[0006]** In another aspect, the disclosure describes an exhaust after-treatment system for a machine. The system includes a diesel exhaust fluid (DEF) container adapted to enclose a DEF fluid therewithin. The DEF container comprises a reservoir body forming a reservoir volume that encloses the DEF and that includes a DEF draw conduit, which is configured to draw DEF from the reservoir volume, and a DEF return conduit, which is configured to return DEF to the reservoir volume. A DEF injector is configured to inject DEF from the container into an exhaust passage of an engine. A pump has an inlet fluidly connected to the DEF draw conduit such that the pump can draw DEF from the fluid reservoir and provide it at an operating pressure to the DEF injector through a pressure line. A return line has a return orifice and configured to return unused DEF from the DEF injector to the DEF container. A pressure regulator is configured to maintain a fluid pressure of the DEF provided to the DEF injector substantially constant by continuously shunting DEF from an outlet of the DEF pump to the DEF container. During operation, a DEF flow provided by the pump is equal to a DEF flow injected by the DEF injector, a second DEF flow returned to the DEF container, and a third DEF flow shunted to the DEF container by the pressure regulator.

**[0007]** In yet another aspect, the disclosure describes a method for operating a fluid system. The method includes drawing fluid from a reservoir with a pump, pressurizing the fluid with the pump to provide a desired fluid flow to a pressure line, circulating a return flow of fluid from the pressure line back to the reservoir through a return orifice continuously during operation, selectively injecting an injected flow of fluid from the pressure line through a fluid injector, shunting a regulated flow of fluid of fluid from the pressure line, and returning the regulated flow back to the reservoir continuously during operation, and adjusting, over a long term, the desired flow by comparing a pressure of fluid in the pressure line with a desired pressure. The desired flow is selected, based on environmental variables, and selectively set by appropriately commanding the pump. At all times during operation, the desired flow is equal to the sum of the return flow, the injected flow, and the regulated flow, not considering any leakage of fluid or other fluid loss from the system.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0008]** FIG. **1** is a block diagram of an engine having a SCR system in accordance with the disclosure.

**[0009]** FIG. **2** is a cross section of a fluid reservoir in accordance with the disclosure.

**[0010]** FIG. **3** is a schematic representation of a fluid delivery system in accordance with the disclosure.

**[0011]** FIG. **4** is a flowchart for a process in accordance with the disclosure.

## DETAILED DESCRIPTION

[0012] This disclosure relates to emission control systems for engines and, more particularly, to DEF metering and delivery systems for use with SCR-based after-treatment systems for diesel engines used on stationary or mobile machines. The machines contemplated in the present disclosure can be used in a variety of applications and environments. For example, any machine that performs some type of operation associated with an industry such as mining, construction, farming, transportation, marine or any other industry known in the art is contemplated. For example, the type of machine contemplated herein may be an earth-moving machine, such as a wheel loader, excavator, dump truck, backhoe, material handler, locomotive, paver or the like. Apart from mobile machines, the machine contemplated may be a stationary or portable machine such as a generator set, an engine driving a gas compressor or pump, and the like. Moreover, the machine may include or be associated with work implements such as those utilized and employed for a variety of tasks, including, for example, loading, compacting, lifting, brushing, and include, for example, buckets, compactors, forked lifting devices, brushes, grapples, cutters, shears, blades, breakers/hammers, augers, and others.

[0013] FIG. **1** is a block diagram of an exhaust after-treatment system **101** associated with an engine **102** of a machine **100**. The system **101** may be modularly packaged as shown in the illustrated embodiment for retrofit onto existing engines or, alternatively, for installation on new engines. In the illustrated embodiment, the system **101** includes a first module **104** that is fluidly connected to an exhaust conduit **106** of the engine **102**. During engine operation, the first module **104** is arranged to internally receive engine exhaust gas from the conduit **106**. The first module **104** may contain various exhaust gas treatment devices such as a diesel oxidation catalyst (DOC) **108** and a diesel particulate filter (DPF) **110**, but other devices may be used. The first module **104** and the components found therein are optional and may be omitted for various engine applications in which the exhaust-treatment function provided by the first module **104** is not required. In the illustrated embodiment, exhaust gas provided to the first module **104** by the engine **102** may first pass through the DOC **108** and then through the DPF **110** before entering a transfer conduit **112**.

[0014] The transfer conduit **112** fluidly interconnects the first module **104** with a second module **114** such that exhaust gas from the engine **102** may pass through the first and second modules **104** and **114** in series before being released at a stack **120** that is connected to the second module. In the illustrated embodiment, the second module **114** encloses a SCR catalyst **116** and an Ammonia Oxidation Catalyst (AMOX) **118**. The SCR catalyst **116** and AMOX **118** operate to treat exhaust gas from the engine **102** in the presence of ammonia, which is provided after degradation of a urea-containing solution injected into the exhaust gas in the transfer conduit **112**.

[0015] More specifically, a urea-containing water solution, which is commonly referred to as diesel exhaust fluid (DEF) **121**, is injected into the transfer conduit **112** by a DEF injector **122**. The DEF **121** is contained within a reservoir **128** and is provided to the DEF injector **122** by a pump **126**. As the DEF **121** is injected into the transfer conduit **112**, it mixes with exhaust gas passing therethrough and is carried to the second module **114**. To promote mixing of DEF with exhaust, a mixer **124** may be disposed along the transfer conduit **112**. The amount of DEF that may be injected into the transfer conduit **112** may be appropriately metered based on engine operating conditions. Accordingly, a desired amount of fluid at desired times may be provided to the transfer conduit **112** by the DEF delivery system.

[0016] As can be appreciated, the location of the DEF injector **122** on the transfer conduit **112** can expose the injector to relatively high temperatures due to heating from exhaust gas during operation. In the illustrated exemplary embodiment, a flow of engine coolant is provided through the injector, but such coolant flow is optional. Alternatively, DEF may be used as a coolant medium.

[0017] A cross section of one embodiment for the urea container or delivery reservoir **128** is shown in FIG. **2**. In this embodiment, the reservoir is denoted by reference numeral **200**. To further facilitate the expedient filling of the reservoir **200**, in the installation shown in FIG. **2**, an air gap or fill-vent opening **414** may be provided. In the illustrated embodiment, the fill-vent opening **414** is formed by a gap provided between inner and outer cylindrical walls **416** and **418** that are concentrically disposed within the fill opening of the reservoir **200**. As shown, the inner and outer walls **416** and **418** extend at the same distance, D, within the reservoir **200** to define a maximum reservoir fill level. In this way, when the fluid **420** reaches the fill level at the height D below the top wall of the reservoir **200**, the venting will cease and the operator will know that the reservoir has been filled to capacity. The desired fill level of the reservoir may be selected on numerous parameters such as reservoir capacity and the like, and may also provide a free space **422** at the top of the reservoir to account for fluid expansion due to heating and/or freezing without damaging the reservoir walls. A sock filter **428** surrounds the heater **426** and the pickup tube or fluid draw conduit **424**.

[0018] Fluid **420** may be drawn from the reservoir **200** via a draw line **424**. The draw line **424** may dray fluid from the bottom of the reservoir **200** and be surrounded by a heater **426** that can effectively melt frozen DEF fluid under cold operating conditions such that liquid DEF can be provided at a supply outlet **427**. The liquid DEF at the supply outlet **427** may be delivered to a pump, for example, the pump **126** shown in FIG. **1**.

[0019] A schematic of one embodiment for a fluid delivery system **300** is shown in FIG. **3**. This embodiment, and especially the DEF filtering shown are exemplary and should not be understood as limiting. The delivery system **300** includes a reservoir **302**, for example, the reservoir **200** as shown in FIG. **2**, which contains DEF fluid for use by the system **300**. A fluid draw conduit **304** is disposed within the reservoir **302** and arranged and configured to draw DEF fluid from therewithin. A staged filter arrangement includes an outer filter **306**, such as the sock filter **428** shown in FIG. **2**, and a secondary filter **308** disposed along the fluid draw conduit **304**. Fluid drawn from the draw conduit **304** is provided to a suction line **310** that includes a primary filtration device **312**. Filtered fluid from the suction line **310** is provided to a DEF pump **314**. The DEF pump **314** may be enclosed in a housing **316** that includes a motor **318** connected to a pump **320**. The pump **320** may be a variable or fixed displacement pump operating at a variable or fixed speed depending on system configuration, as will be discussed hereinafter. An internal filter **322** may further filter the fluid before the same enters the pump **320**. A pressure sensor **324** disposed to measure fluid pressure at the outlet of the pump **320** is configured to provide a pressure signal indicative of a fluid pressure at the pump outlet to a controller **326** associated with the system **300**.

**[0020]** Pressurized fluid at the outlet of the pump **320** is provided to a pressure line **328**. The pressure line **328** as shown in the illustrated embodiment includes a pressure junction **330** that provides, in parallel fluid circuit arrangement, fluid at pump pressure to a pressure regulator **332** and to a DEF injector **334**, for example, the DEF injector **122** (FIG. **1**). During operation, a continuous flow of DEF fluid passes through the pressure line **328** and through a return orifice **336**, which is disposed downstream of the DEF injector **334**, before being provided back to the reservoir **302** via a return line **338**. In other words, in one embodiment, the pressure regulator and the return orifice are in parallel fluid connection between the pressure junction and the reservoir. Of course, the return orifice may be placed elsewhere in the system, in series with the pressure regulator, and at other locations. When the return orifice is placed along a circuit branch that includes the DEF injector, a continuous flow of DEF can also act to cool the injector. Such continuous fluid circulation can also act to maintain the fluid well mixed, can control the temperature of the fluid under certain operating conditions such as cold operation, as well as ensure that an ample supply of pressurized fluid is available to the DEF injector **334** at all times during operation. In this way, in the embodiment illustrated, when a predetermined amount of fluid is desired for injection from the injector **334**, the controller **326**, based on the pressure signal from the sensor **324**, may send a command signal such as a Pulse Width Modulated (PWM) signal to open the injector **334** for a predetermined period to allow a predetermined amount of fluid to be injected thereby.

**[0021]** When fluid is injected from the injector **334**, fluid pressure in the pressure line may decrease, especially if an appreciable amount of fluid is injected. Such pressure drop within the pressure line **328** will be indicated to the controller **326** by the sensor **324**. In response, the controller **326** will command the motor **318** to activate the pump **320** to supply fluid into the pressure line **328** until the desired pressure is once again established in the pressure line **328**. The initiation of the pump, however, as well as the activation and deactivation of the injector **334**, typically causes pressure pulsations, for example, standing waves or a hydraulic pressure spike of fluid pressure within the pressure line **328**. Such pressure fluctuations can interfere, at least temporarily, with the pressure signal readings from the sensor **324**. Moreover, such pressure spikes may interfere with the calculations in the controller **326** of the amount of fluid injected through the injector **334** because such fluid pressure may be above or below the predetermined system pressure that exists under stable conditions within the pressure line **328**. These and other effects in the system, which can cause instability and large fluctuations in system pressure, especially under conditions when high fluid amounts are being delivered therethrough in relatively quick succession during machine operation, which can ultimately lead to a greater or lesser fluid being provided through the injector **334** than what is desired.

**[0022]** To address such and other related fluid pressure issues, at least in part, the pressure regulator **332** is configured to, at least in part, mitigate high pressure spikes in the pressure line **328**. As shown, the pressure regulator includes a valve element **340** that is biased in a closed position via a spring **342** and that, when open, fluidly bypasses the injector **334** by fluidly and directly connecting the pressure line **328** with the return line **338**. Although a mechanical pressure regulator is shown, an electronic pressure regulator valve may alternatively be used, or a mechanical arrangement having a different configuration than the one shown in FIG. **3**. In the illustrated embodiment, the spring constant of the spring **342** is selected to yield an opening pressure for the valve element **340** that is about the same or just above the normal operating pressure in the pressure line **328**. Thus, pressure spikes may cause the automatic opening of the pressure regulator **332** and dispose of high pressure fluid by returning it to the reservoir **302**. However, the pressure regulator **332** alone is not sufficient to maintain a stable, reliable pressure within the pressure line **328**, and may further lead to system instability when large and relatively frequent pressure fluctuations are present. Moreover, the pressure regulator, by its operation principles, cannot address low pressure conditions, especially when the transient response of the pump **314**, for example, owing to the transient response of the pumping element **320** and/or motor **318**, is slow to respond to pressure drops in the system, for example, when large amounts of DEF are being provided to the machine through the injector **334**.

**[0023]** These and other issues may be avoided by appropriately controlling the motor **318** with the controller **326** to drive the pump **320** such that an excess amount of fluid is provided to the pressure line **328**. In one embodiment, the pump **320** is driven by the motor **318** at a predetermined speed and/or displacement, in general, at predetermined fluid flow rate, which exceeds the return flow into the reservoir **302** through the return orifice **336** and also causes the pressure regulator **332** to be in an open position even when the injector **334** is in a fully open condition. Stated differently, the pump **320** is driven to provide an excess fluid supply to the pressure line **328** that exceeds the maximum fluid flow demand of the system **300** by a predetermined about, for example, 10 or 15% above the maximum expected flow through the DEF injector when the fluid pressure in the system is at its maximum allowable value and the injector is fully open, i.e., when the injector duty cycle is at 100%. The fluid supply from the pump, therefore, is equal to the sum of fluid injected through the injector, fluid returned to the reservoir through the return orifice, and fluid shunted from the pressure regulator at all times during operation. Of course, this equality of fluid flows does not account for other fluid losses from the system such as leaks, evaporation and the like, or fluid stored in system components such as in the various conduits or within the fluid injector, which fluid storage may occur transiently and/or occur at system startup or shutdown but is otherwise stabilized during system operation.

**[0024]** The excessive fluid supply described above during stable system operation will not cause a concomitant fluid pressure increase in the pressure line **328** because of the action of the pressure regulator **332**. In short, when the opening pressure of the pressure regulator **332** is selected to be about equal and, preferably, just below the desired fluid pressure under steady conditions within the pressure line **328**, the excess fluid provided to the pressure line **328** will be shunted back to the reservoir **302** through the pressure regulator continuously during operation. In conditions when the injector **334** is open, the excess fluid flow provided by the pump **320** will account for the flow through the injector **334**, the flow through the return orifice **336**, and will also still cause the pressure regulator **332** to open, at least partially, to shunt fluid back to the reservoir **302**. In this way, a stable pressure can be maintained at all times within the pressure line **328**, and dampening that will reduce or eliminate pressure fluctuations within the pressure line **328** can be provided by a combination of the return orifice **336** and the flow through the pressure regulator **332**.

**[0025]** To improve system control accuracy and avoid unnecessary wear on the pumping and other fluid elements of the system, the control scheme for the pump **314** operating within the controller **326** in the system **300** may account for various environmental and aging effects in the system. In one embodiment, the control algorithm, which provides a command to the motor **318** as an output, can include a closed-loop controller that is used to set the fluid flow rate of fluid provided through the pump **320** at a point that is just above the corresponding setting on the pressure regulator **332**. In one contemplated embodiment, the closed-loop controller uses a feed-forward control term to set the initial pump speed to a predetermined pump speed that yields the desired fluid flow. The predetermined pump speed can be selected or set based on pump performance mapping and environmental conditions such as ambient temp, fluid temp, altitude and pressure setting of the pressure regulator. If such predetermined pump speed setting is considered as a base or normal operating condition, the control algorithm can also monitor system pressure and use a relatively long term feedback, for example, via an integral control term having a relatively large time constant, that is based on system pressure to slowly adapt and adjust the fluid flow rate through the pump and maintain predetermined and/or desired flow margin above a maximum flow consumption of the system. In this way, the pressure can automatically control overall system pressure.

**[0026]** A block diagram for a control **500** that controls the operation of the motor **318** and/or a displacement of the pump **320**, as applicable to the system **300** as shown in FIG. **3**, is illustrated in FIG. **4**. As can be appreciated, the control **500** may adjust motor speed when the motor is associated with a fixed-displacement pump to control fluid flow, or may alternatively control a pump displacement in a variable displacement pump when the same is associated with a fixed-speed motor to control fluid flow. The control **500** may operate within the controller **326**. The controller **326** may be a single controller or may include more than one controller disposed to control various functions and/or features of a machine. For example, a master controller, used to control the overall operation and function of the machine, may be cooperatively implemented with a motor or engine controller, used to control other machine systems, for example the engine **102**. In this embodiment, the term "controller" is meant to include one, two, or more controllers that may be associated with the machine **100** (FIG. **1**) and that may cooperate in controlling various functions and operations of the machine **100**. The functionality of the controller **326**, while shown conceptually in FIG. **4** to include various discrete functions for illustrative purposes only, may be implemented in hardware and/or software without regard to the discrete functionality shown. Accordingly, various interfaces of the controller are described relative to components of the system **300** (FIG. **3**) shown in the block diagram of FIG. **4**. Such interfaces are not intended to limit the type and number of components that are connected, nor the number of controllers that are described.

**[0027]** During operation, the controller **500** provides a motor/pump command signal **502**, which as previously described may control the speed of a motor operating a pump and/or a displacement of a pump. In any case, the motor/pump command signal **502** is a signal that causes a change in a fluid flow provided to a pressure line of a fluid system such as the pressure line **328** in the system **300** (FIG. **3**). Various signals are provided as inputs to the control **500**, on the basis of which the command signal **502** is determined. In the illustrated embodiment, inputs to the control **500** include ambient temperature **504**, fluid temperature **506** and altitude **508**. These inputs, which are collectively considered environmental inputs, may include more or fewer parameters. An addition input to the control **500** is system pressure **510**. The system pressure **510** is a signal indicative of the pressure of fluid at the outlet of the pump. One example of system pressure may be the pressure signal provided by sensor **324** (FIG. **3**) to the controller **326** that is indicative of the real-time pressure of fluid within the pressure line **328**.

**[0028]** The various environmental inputs, i.e., the ambient temperature **504**, fluid temperature **506** and altitude **508** in the embodiment shown in FIG. **4**, along with a constant **512** are provided to a desired system pressure determinator function **514**. The constant **512** represents the default or designed-for opening pressure of the pressure regulator. The desired system pressure determinator function **514** in the illustrated embodiment comprises various lookup tables and compensation functions that provide, based on the then-present operating conditions of the system, an indication as to the desired pressure setting for the system. As can be appreciated, static pressure conditions such as altitude, and fluid temperature, may affect the reading of the sensor or other means used to monitor and provide an indication of the system pressure **510**. To offset or compensate for such effects, as well as mechanical pump and motor effects due to temperature, the system pressure determinator function is pre-populated or pre-programmed to provide an indication of a desired system pressure **516** that is sufficient in the system to reflect an ample supply of fluid for the fluid injector and for the pressure regulator to bypass and achieve stable system performance as described above.

**[0029]** The desired system pressure **516** is provided to a summing junction **518**, where it is compared to the system pressure **510**. A pressure difference or error **520**, which is indicative of a difference between the desired system pressure **516** and the actual, measured or estimated system pressure **510** that is present in the system, is provided to an integral function **522**. The integral function, may be of the form shown in Equation 1 below:

$$I(t) = K_i \int_0^t e(\tau)\partial t$$

where I(t) is the integral term over time (t), $K_i$ is a constant, and e(τ) is a function that is integrated over a period (τ). As is known, integral terms can address residual steady-state error that can occur in systems. In this case, such errors may result from various sources such as sensor error, sensor creep, system aging, filter clogging, and other effects. In the illustrated embodiment, the pressure difference or error **520** may also be provided to a sentry function **524** that can provide a system fault signal **526** indicating that system service is required or that notifies the operator of a fault when the error **520** exceeds a maximum allowable error for a predetermined period.

**[0030]** The integral function **522** provides a correction signal **528** which passes through a delimiter **530**. A delimited correction signal **532** and the desired system pressure **516** are provided to a summing junction **534** and are compounded to provide a corrected, desired system pressure in the form of the command signal **502**. As can be appreciated, the desired system pressure **516**, which can also be expressed as a desired system flow rate setpoint, is independent of fluid use by the system and only depends on fixed system parameters such as pump and motor operation and, optionally, on environmental parameters within which the system is operating. The flow and/or pressure setpoint provided by the determinator function **514** is independent of fluid use, which leads to an inherently stable control scheme. As previously discussed, flow changes within the system are addressed by the pressure regulator such that there is always a flow excess provided to the system. The steady-state error compensation provided by the integral function **522** addresses effects that may appear in the system over time and also helps diagnose system faults.

## INDUSTRIAL APPLICABILITY

**[0031]** The present disclosure is applicable to emission control systems for engines and, more particularly, to emission control systems using SCR processes requiring the injection of urea-based water solutions into engine exhaust streams. In the disclosed embodiments, a feed forward controller having a long-term feedback is used to create a control arrangement in which pressure fluctuations in the high-pressure DEF fluid delivery system are avoided. In one embodiment, the system sets a predetermined DEF flow which exceeds the maximum use of DEF by the injector such that an excess flow causes a pressure regulator to open, at all times, thus controlling the pressure continuously within the system.

**[0032]** It will be appreciated that the foregoing description provides examples of the disclosed system and technique. However, it is contemplated that other implementations of the disclosure may differ in detail from the foregoing examples. All references to the disclosure or examples thereof are intended to reference the particular example being discussed at that point and are not intended to imply any limitation as to the scope of the disclosure more generally. All language of distinction and disparagement with respect to certain features is intended to indicate a lack of preference for those features, but not to exclude such from the scope of the disclosure entirely unless otherwise indicated.

**[0033]** Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context.

We claim:

**1**. A fluid delivery system, comprising:

a fluid reservoir adapted to enclose a fluid therewithin, the fluid reservoir comprising a reservoir body forming a reservoir volume that encloses the fluid therewithin and that includes a fluid draw conduit, which is configured to draw fluid from the reservoir volume, and a fluid return conduit, which is configured to return fluid to the reservoir volume;

a pump having an inlet fluidly connected to the fluid draw conduit such that the pump can draw fluid from the fluid reservoir, increase a pressure of the fluid to an operating pressure, and provide fluid at the operating pressure and at a desired fluid flow to a pressure line that is fluidly connected to an outlet of the pump;

a fluid injector fluidly in communication with the pressure line, the fluid injector configured to selectively open and allow pressurized fluid at a predetermined, injected fluid flow to pass therethrough when the fluid injector is open; and

a pressure regulator having a regulator inlet in fluid communication with the pressure line and a regulator outlet in fluid communication with the fluid return conduit, the pressure regulator configured to provide a regulated fluid flow to the fluid reservoir when the operating pressure exceeds a pressure regulator opening pressure;

wherein, during operation, the desired fluid flow is equal to a sum of the injected fluid flow and the regulated fluid flow.

**2**. The fluid delivery system of claim **1**, further comprising:

a pressure sensor disposed in fluid communication with the pressure line and configured to measure a fluid pressure within the pressure line and provide a pressure signal; and

an electronic controller disposed to receive the pressure signal.

**3**. The fluid delivery system of claim **2**, wherein the pump is a fixed displacement pump that is operated by a variable speed motor, the variable speed motor being responsive to a command signal provided by the electronic controller based, at least in part, on the pressure signal.

**4**. The fluid delivery system of claim **3**, wherein the command signal provided by the electronic controller uses environmental variables as primary control parameters to determine the command signal that will provide the desired fluid flow to the pressure line.

**5**. The fluid delivery system of claim **4**, wherein the environmental variables include ambient temperature, fluid temperature, and altitude.

**6**. The fluid delivery system of claim **3**, wherein the electronic controller includes an integrator function that provides a compensation factor based on a difference between a desired pressure and the operating pressure, said compensation factor having a long term.

**7**. The fluid delivery system of claim **2**, wherein the motor has a fixed speed and the pump has a variable displacement such that the pump is a variable displacement pump, the variable displacement pump being responsive to a command signal provided by the electronic controller based, at least in part, on the pressure signal.

**8**. The fluid delivery system of claim **7**, wherein the command signal provided by the electronic controller uses environmental variables as primary control parameters to determine the command signal that will provide the desired fluid flow to the pressure line.

**9**. The fluid delivery system of claim **1**, further comprising a return orifice fluidly connecting the pressure line at a location downstream of the fluid injector with the fluid return conduit such that a return fluid flow is returned to the fluid reservoir, wherein, during operation, the desired fluid flow is equal to a sum of the injected fluid flow, the return fluid flow and the regulated fluid flow.

**10**. The fluid delivery system of claim **7**, wherein the electronic controller includes an integrator function that provides a compensation factor based on a difference between a desired pressure and the operating pressure, said compensation factor having a long term.

**11**. The fluid delivery system of claim **1**, wherein the pressure line is part of a fluid flow circuit that includes a pressure junction disposed between the pressure regulator and the fluid injector such that the pressure regulator is disposed in parallel circuit connection with the return orifice between the pressure junction and the fluid reservoir.

**12**. The fluid delivery system of claim **1**, wherein the pressure regulator includes a valve element that is biased in a closed position by a spring, and wherein the spring is selected to have a spring constant that enables the valve element to open and fluid connect the pressure line with the reservoir when a pressure of fluid upstream of the valve element exceeds a force applied on the valve element by the spring.

**13**. An exhaust after-treatment system for a machine, comprising:

a diesel exhaust fluid (DEF) container adapted to enclose a DEF fluid therewithin, the DEF container comprising a reservoir body forming a reservoir volume that encloses the DEF and that includes a DEF draw conduit, which is configured to draw DEF from the reservoir volume, and a DEF return conduit, which is configured to return DEF to the reservoir volume;

a DEF injector configured to inject DEF from the container into an exhaust passage of an engine;

a pump having an inlet fluidly connected to the DEF draw conduit such that the pump can draw DEF from the container and provide it at an operating pressure to the DEF injector through a pressure line;

a return line configured to return unused DEF from the DEF injector to the DEF container; and

a pressure regulator configured to maintain a fluid pressure of the DEF provided to the DEF injector substantially constant by continuously shunting DEF from an outlet of the DEF pump to the DEF container;

wherein, during operation, a DEF flow provided by the pump is equal to a DEF flow injected by the DEF injector, a second DEF flow returned to the DEF container, and a third DEF flow shunted to the DEF container by the pressure regulator.

**14**. The exhaust after-treatment system for a machine of claim **1**, further comprising:

a pressure sensor disposed in fluid communication with the pressure line and configured to measure a DEF pressure within the pressure line and provide a pressure signal; and

an electronic controller disposed to receive the pressure signal.

**15**. The exhaust after-treatment system for a machine of claim **14**, wherein the pump has a fixed displacement and is operated by a variable speed motor, the variable speed motor being responsive to a command signal provided by the electronic controller based, at least in part, on the pressure signal, wherein the command signal provided by the electronic controller uses environmental variables as primary control parameters to determine the command signal that will provide the desired fluid flow to the pressure line, and wherein the environmental variables include ambient temperature, fluid temperature, and altitude.

**16**. The exhaust after-treatment system for a machine of claim **15**, wherein the electronic controller includes an integrator function that provides a compensation factor based on a difference between a desired pressure and the operating pressure, said compensation factor having a long term.

**17**. The exhaust after-treatment system for a machine of claim **14**, wherein the motor has a fixed speed and the pump has a variable displacement such that the pump is a variable displacement pump, the variable displacement pump being responsive to a command signal provided by the electronic controller based, at least in part, on the pressure signal, wherein the command signal provided by the electronic controller uses environmental variables as primary control parameters to determine the command signal that will provide the desired fluid flow to the pressure line, and wherein the environmental variables include ambient temperature, fluid temperature, and altitude.

**18**. The exhaust after-treatment system for a machine of claim **17**, wherein the electronic controller includes an integrator function that provides a compensation factor based on a difference between a desired pressure and the operating pressure, said compensation factor having a long term.

**19**. The exhaust after-treatment system for a machine of claim **14**, wherein the pressure line is part of a fluid flow circuit that includes a pressure junction disposed between the pressure regulator and the return orifice such that the pressure regulator is disposed in parallel circuit connection with the return orifice between the pressure junction and the fluid reservoir.

**20**. A method for operating a fluid system, comprising:

drawing fluid from a reservoir with a pump;

pressurizing the fluid with the pump to provide a desired flow to a pressure line;

circulating a return flow of fluid from the pressure line back to the reservoir through a return orifice continuously during operation;

selectively injecting an injected flow of fluid from the pressure line through a fluid injector;

shunting a regulated flow of fluid of fluid from the pressure line, and returning the regulated flow back to the reservoir continuously during operation; and

adjusting, over a long term, the desired flow by comparing a pressure of fluid in the pressure line with a desired pressure;

selecting, based on environmental variables, the desired flow and selectively setting the same by appropriately commanding the pump;

wherein, at all times during operation, the desired flow is equal to the sum of the return flow, the injected flow, and the regulated flow.

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