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(54) **RECIPROCATING PUMP**

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(57) **ABSTRACT**

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A positive displacement pump can include a pump mechanism having a shaft configured to rotate about its long axis; a screw rod having a continuous thread around the circumference of the screw rod, the thread configured with an upward and downward thread component wherein the screw rod is operatively coupled to the shaft and reticulates along the long axis when the shaft is rotated about the long axis; a stylus positioned to engage the thread of the screw rod; cylindrical body forming a cavity configured to house at least a portion of the screw rod and allow movement of the screw rod along the long axis of the cylindrical body providing a pumping action in the cylindrical body cavity; an inlet and an outlet provided in the cylindrical body walls fluidly coupling the cylindrical body cavity with one or more external fluid paths.

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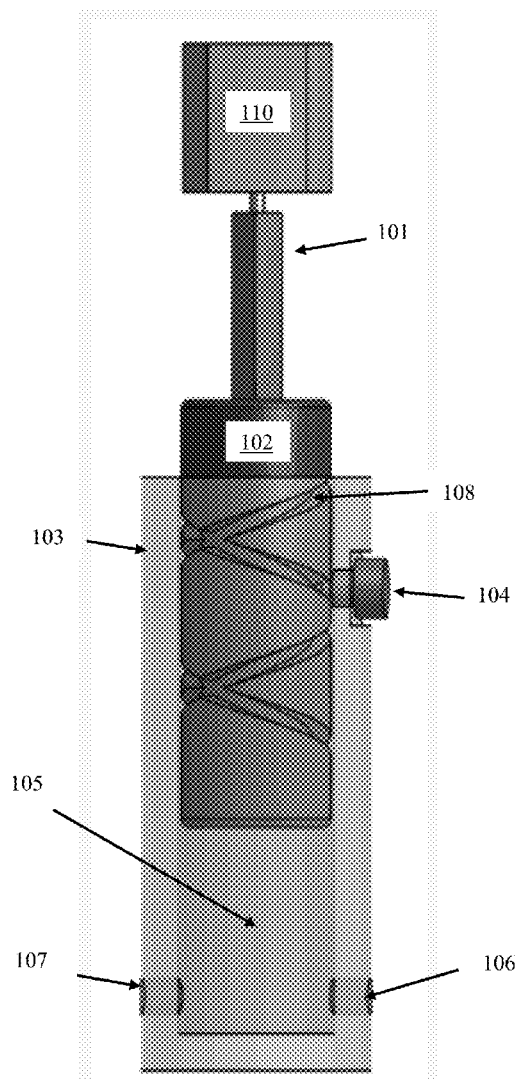
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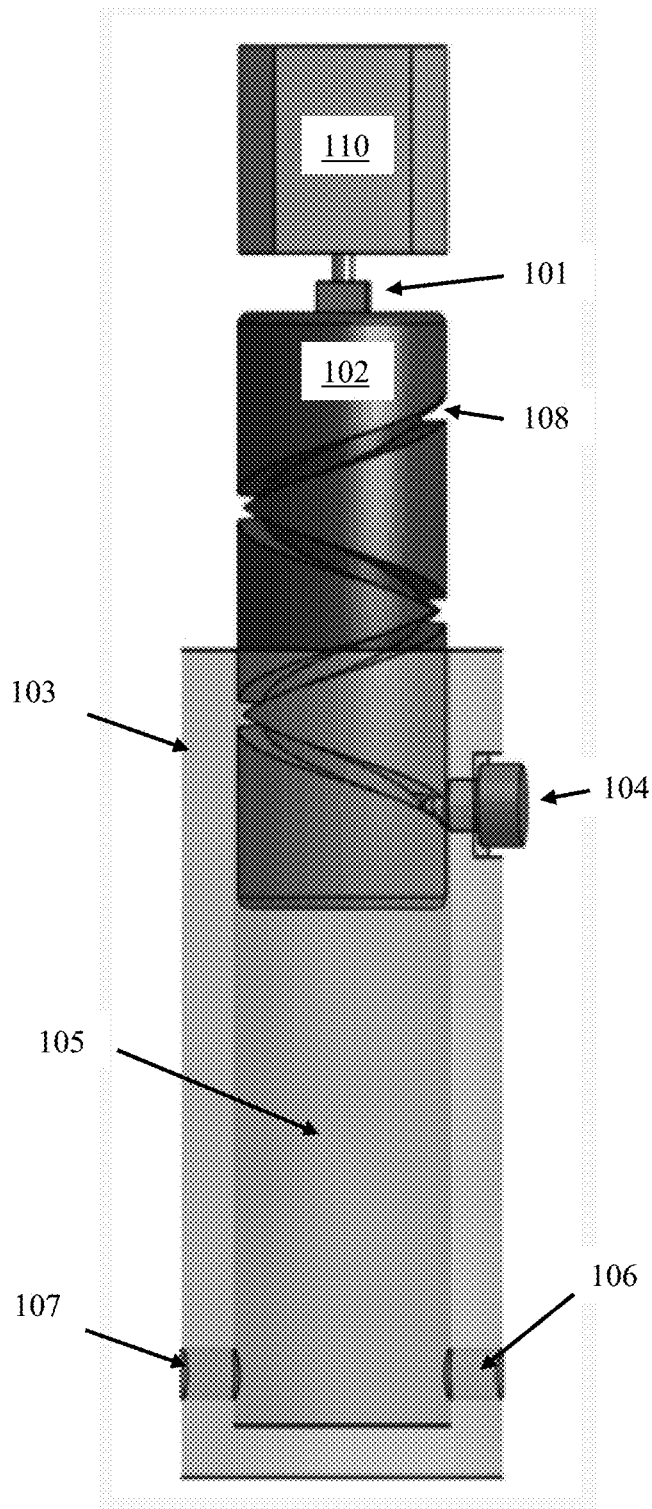


FIG. 1

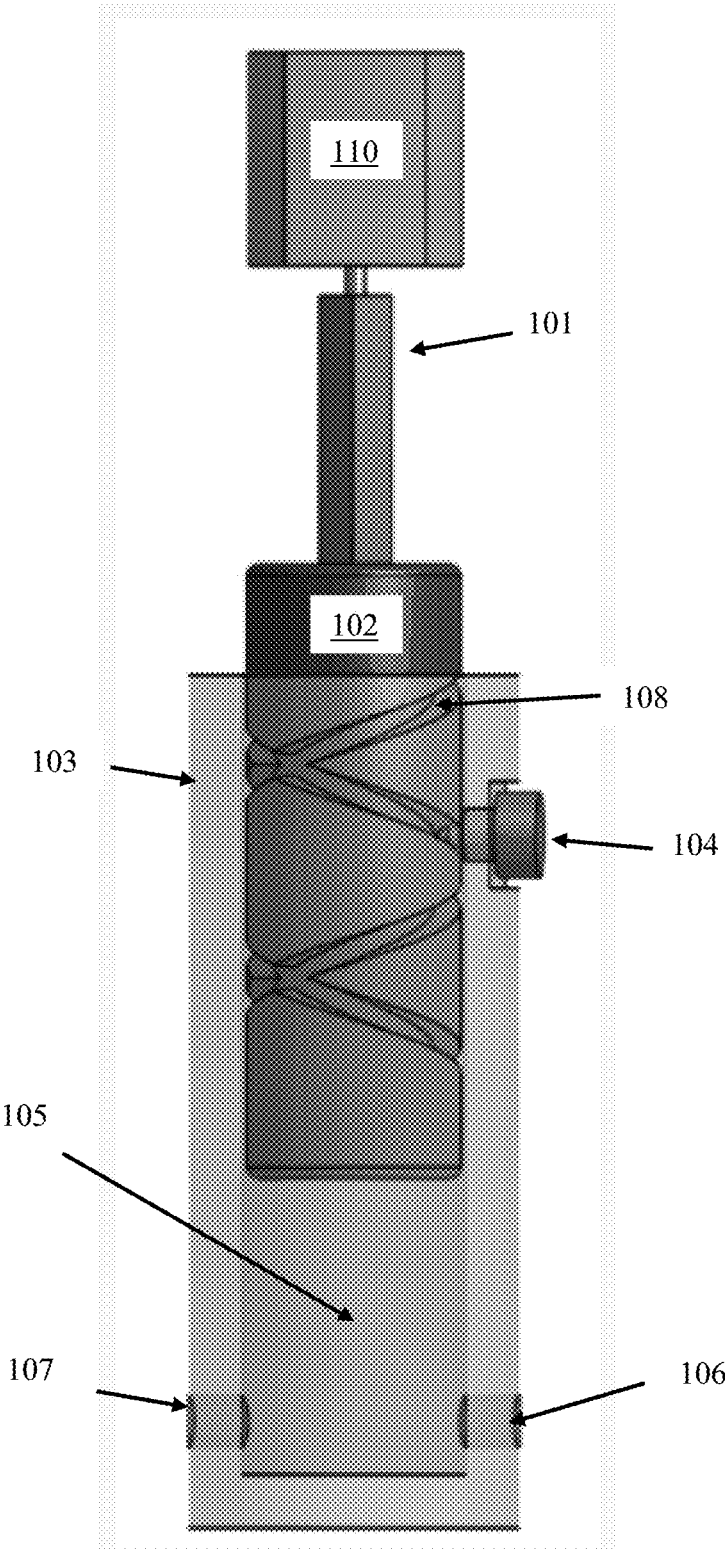


FIG. 2

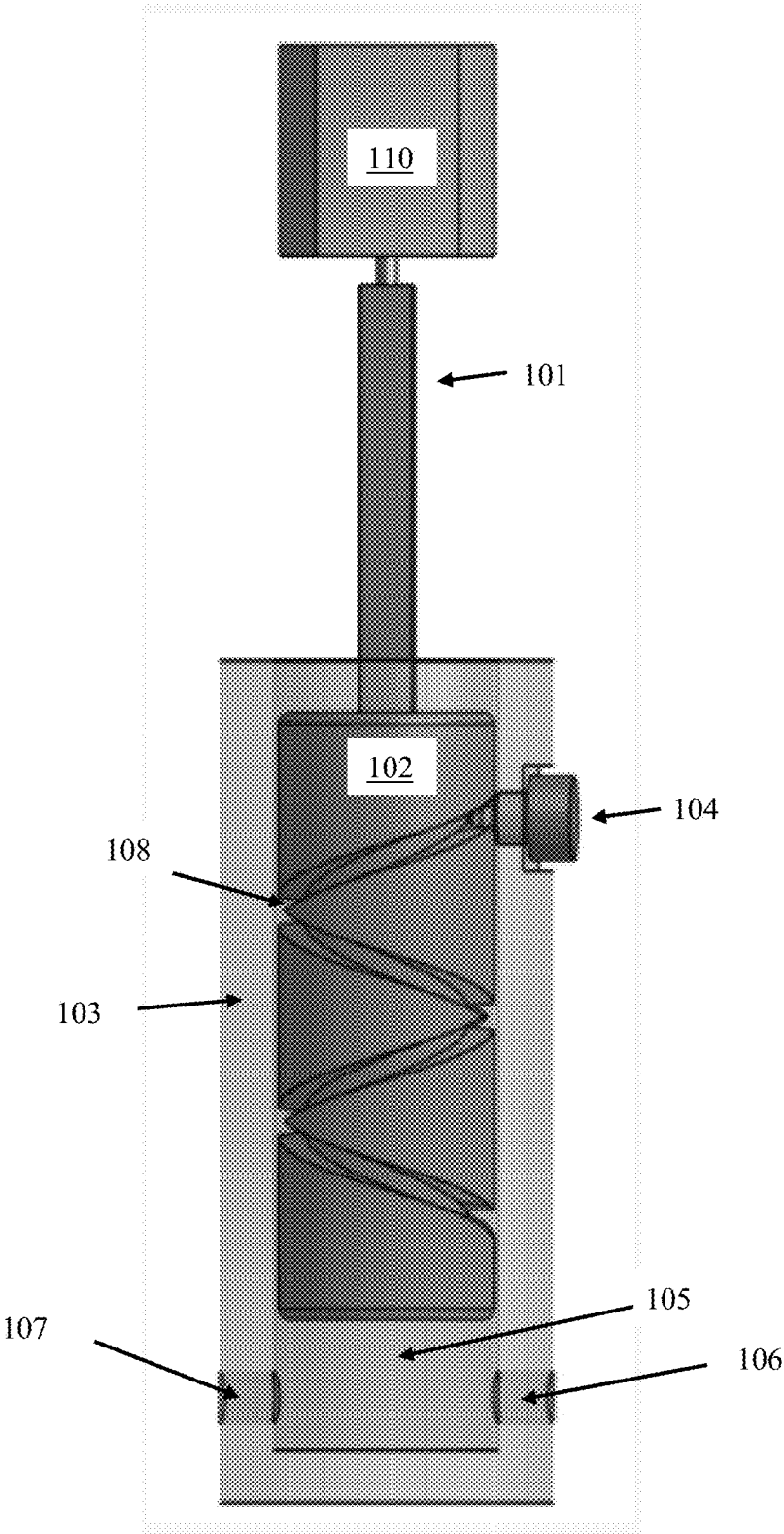


FIG. 3

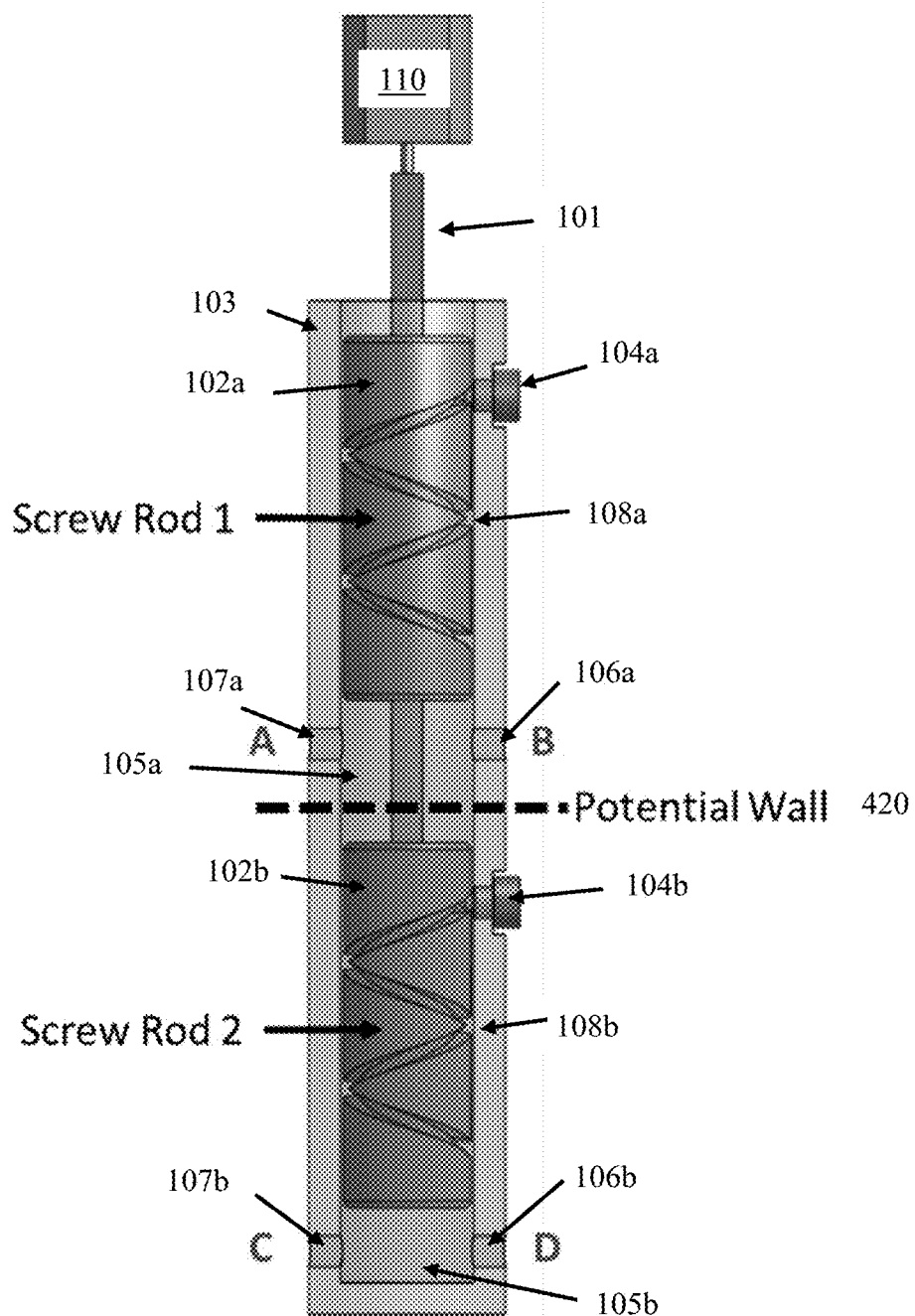


FIG. 4

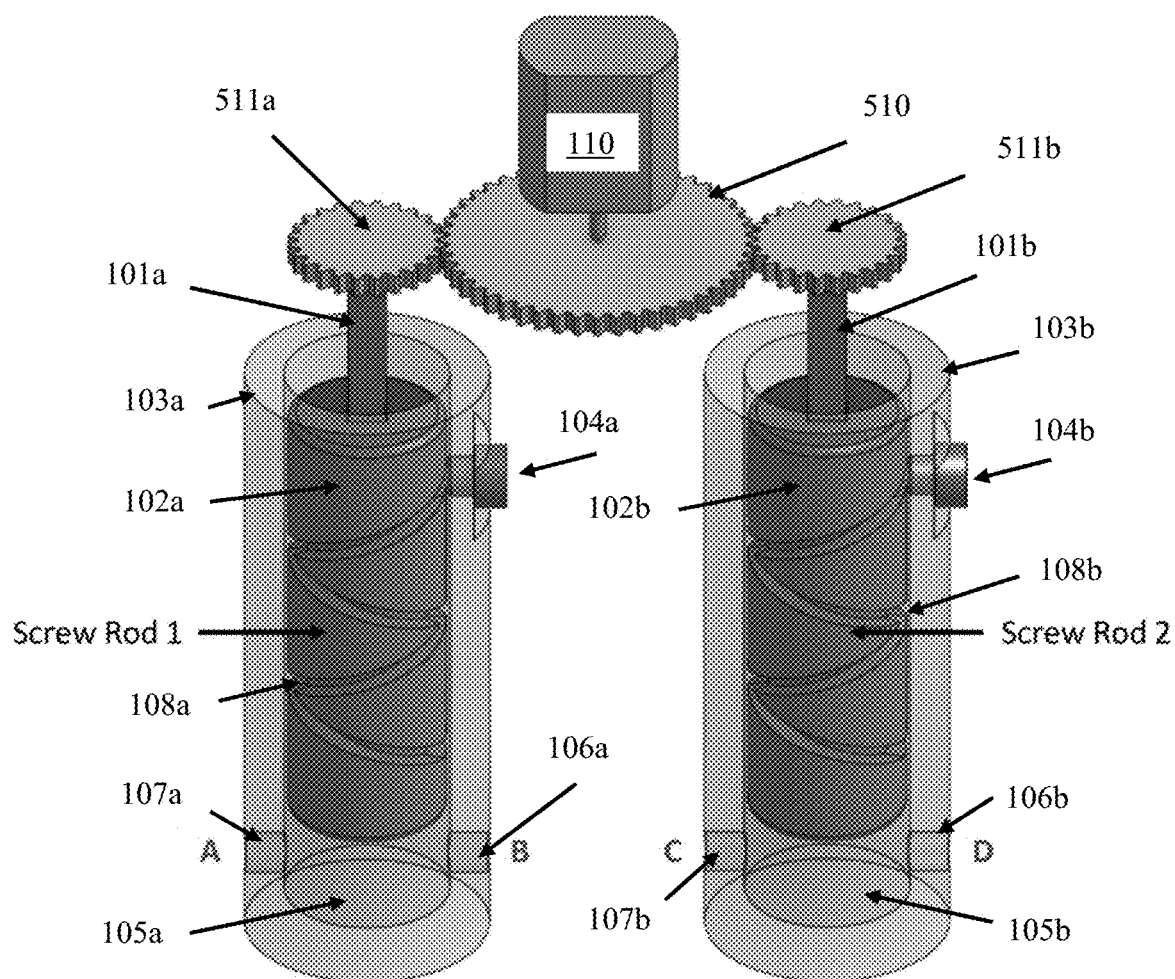


FIG. 5

RECIPROCATING PUMP

PRIORITY

[0001] This application claims priority to U.S. Provisional Application Ser. No. 63/251,115 file Oct. 1, 2021 which is incorporated here by reference in its entirety.

STATEMENT REGARDING FEDERALLY FUNDED RESEARCH

[0002] None.

BACKGROUND

[0003] Reciprocating fluid pumps are used in many industries. Reciprocating fluid pumps generally include a fluid chamber in a pump body. A reciprocating piston or shaft is driven back and forth within the pump body. One or more plungers (e.g., diaphragms or bellows) may be connected to the reciprocating piston or shaft. As the reciprocating piston moves in one direction, the movement of the plungers results in a subject fluid (gas or liquid) being drawn into a chamber. As the reciprocating piston moves in the opposite direction, the movement of the plungers results in fluid being expelled from the chamber.

SUMMARY

[0004] The design described herein allows for the positive displacement piston to be directly in line with the pump motor. The linear orientation decreases the footprint of the overall pump. Additionally, the minimal number of components makes manufacturing easy and increases the lifetime of the pump. The performance of the pump is very easy to tune, as it only depends on three variables of the pump design: the radius of the reciprocating rod, the travel distance of the reciprocating rod, and the rotational speed of the motor. This type of pump can be used in any field where fluid transport is desired, ranging from medical devices to power generation to aerospace.

[0005] Certain embodiments are directed to a positive displacement pump comprising a pump mechanism having: (i) a shaft configured to rotate about its long axis; (ii) a screw rod having a continuous thread around the circumference of the screw rod, the thread is configured to have an upward thread component (i.e., as that portion of the thread is engaged the screw rod moves upward from the distal end of the cylinder) and a downward thread component (i.e., as that portion of the thread is engaged the screw rod moves downward towards the distal end of the cylinder) wherein the screw rod is operatively coupled to the shaft and rotates along the long axis when the shaft is rotated about the long axis; (iii) a stylus positioned to engage the thread of the screw rod; (iv) cylindrical body forming a cavity configured to house at least a portion of the screw rod and allow movement of the screw rod along the long axis of the cylindrical body providing a pumping action in the cylindrical body cavity by alternately expanding or displacing the contents of the cylindrical body (the proximal end of the cylinder being closest to the motor and distal end of the cylinder furthest from the motor); and (v) one or more inlets and one or more outlets provided in the distal portion of the cylindrical body walls fluidly coupling the cylindrical body cavity with one or more external fluid paths. In certain aspects the pump can further comprising a pump motor aligned along the long axis of the pump mechanism config-

ured to rotate the shaft when in use, optionally the motor is coupled to the shaft via gearing mechanism and need not be aligned along the long axis. In certain aspects one or more inlet, one or more outlet, or one or more inlet and outlet is coupled to a valving mechanism to regulate the flow into and out of the cylindrical body.

[0006] Certain embodiments are directed to a system or pump assembly comprising a plurality of pumps as described herein. In certain aspects the pumps are configured in series, parallel, or a combination thereof with respect to fluid flow or fluid paths. The system can include pumps in series and pumps in parallel. The term “in series” refers to a configuration of pumps where a fluid path is from one pump to the next successively. The term “in parallel” refers to a configuration of pumps where two fluid paths are separate relative to two pumps where fluid may or may not flow concurrently, the two fluid paths may or may not be part of the fluidic system and may interconnect indirectly via a common fluidic system.

[0007] The term “screw rod” refers to a cylindrical component or piston that translates along the long axis of a shaft and is configured to provide a pumping force within a pump cylinder. The rotation of the screw rod is modulated by threads in the screw rod surface that are engaged with a stylus or similar implement.

[0008] The term “fluid” refers to gas, liquid, and/or mixtures of gases and liquids.

[0009] The term “fluid path means” refers all conduits, tubing, pipes, openings, or ports which convey or transport fluids.

[0010] Other embodiments of the invention are discussed throughout this application. Any embodiment discussed with respect to one aspect of the invention applies to other aspects of the invention as well and vice versa. Each embodiment described herein is understood to be embodiments of the invention that are applicable to all aspects of the invention. It is contemplated that any embodiment discussed herein can be implemented with respect to any method or composition of the invention, and vice versa. Furthermore, compositions and kits of the invention can be used to achieve methods of the invention.

[0011] The use of the word “a” or “an” when used in conjunction with the term “comprising” in the claims and/or the specification may mean “one,” but it is also consistent with the meaning of “one or more,” “at least one,” and “one or more than one.”

[0012] Throughout this application, the term “about” is used to indicate that a value includes the standard deviation of error for the device or method being employed to determine the value.

[0013] The use of the term “or” in the claims is used to mean “and/or” unless explicitly indicated to refer to alternatives only or the alternatives are mutually exclusive, although the disclosure supports a definition that refers to only alternatives and “and/or.”

[0014] As used in this specification and claim(s), the words “comprising” (and any form of comprising, such as “comprise” and “comprises”), “having” (and any form of having, such as “have” and “has”), “including” (and any form of including, such as “includes” and “include”) or “containing” (and any form of containing, such as “contains” and “contain”) are inclusive or open-ended and do not exclude additional, unrecited elements or method steps.

[0015] As used herein, the terms “comprises,” “comprising,” “includes,” “including,” “has,” “having,” “contains,” “containing,” “characterized by” or any other variation thereof, are intended to encompass a non-exclusive inclusion, subject to any limitation explicitly indicated otherwise, of the recited components. For example, a chemical composition and/or method that “comprises” a list of elements (e.g., components or features or steps) is not necessarily limited to only those elements (or components or features or steps) but may include other elements (or components or features or steps) not expressly listed or inherent to the chemical composition and/or method.

[0016] As used herein, the transitional phrases “consists of” and “consisting of” exclude any element, step, or component not specified. For example, “consists of” or “consisting of” used in a claim would limit the claim to the components, materials or steps specifically recited in the claim except for impurities ordinarily associated therewith (i.e., impurities within a given component). When the phrase “consists of” or “consisting of” appears in a clause of the body of a claim, rather than immediately following the preamble, the phrase “consists of” or “consisting of” limits only the elements (or components or steps) set forth in that clause; other elements (or components) are not excluded from the claim as a whole.

[0017] As used herein, the transitional phrases “consists essentially of” and “consisting essentially of” are used to define a chemical composition and/or method that includes materials, steps, features, components, or elements, in addition to those literally disclosed, provided that these additional materials, steps, features, components, or elements do not materially affect the basic and novel characteristic(s) of the claimed invention. The term “consisting essentially of” occupies a middle ground between “comprising” and “consisting of”.

[0018] Other objects, features and advantages of the present invention will become apparent from the following detailed description. It should be understood, however, that the detailed description and the specific examples, while indicating specific embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

DESCRIPTION OF THE DRAWINGS

[0019] The following drawings form part of the present specification and are included to further demonstrate certain aspects of the present invention. The invention may be better understood by reference to one or more of these drawings in combination with the detailed description of the specification embodiments presented herein.

[0020] FIG. 1 illustrates an example of a diamond screw pump at the initiation of a stroke.

[0021] FIG. 2 illustrates an example of a diamond screw pump mid stroke.

[0022] FIG. 3 illustrates an example of a diamond screw pump at the bottom of a stroke.

[0023] FIG. 4 illustrates a system with multiple pumps in a vertical or linear configuration, minimizing the pump mechanism footprint.

[0024] FIG. 5 illustrates another system with multiple pumps in a horizontal configuration connected to a motor via a bearing mechanism.

DESCRIPTION

[0025] The following discussion is directed to various embodiments of the invention. The term “invention” is not intended to refer to any particular embodiment or otherwise limit the scope of the disclosure. Although one or more of these embodiments may be preferred, the embodiments disclosed should not be interpreted, or otherwise used, as limiting the scope of the disclosure, including the claims. In addition, one skilled in the art will understand that the following description has broad application, and the discussion of any embodiment is meant only to be exemplary of that embodiment, and not intended to intimate that the scope of the disclosure, including the claims, is limited to that embodiment.

[0026] One of the most common types of pumps is a positive displacement pump, which is a type of pump that uses a mechanism to entrap a certain amount of fluid and force it in a direction. A specific type of positive displacement pump is a reciprocating pump, which utilizes a component that repeatedly enters and exits a cavity. When the component enters the cavity, it displaces the fluid that is in the cavity, and when the component exits the cavity, it draws new fluid into the cavity. The flow of fluid into and out of the cavity are usually regulated by one-way valves. One example of a reciprocating pump would be the cylinders/pistons in a car engine.

[0027] FIG. 1, FIG. 2, and FIG. 3 illustrate one embodiment of a positive displacement or reciprocating pump having a diamond screw mechanism (a threaded surface regulating the movement of the screw rod in a cylinder). FIG. 1 illustrates one example of the pump mechanism at about the top of a stroke, FIG. 2 illustrates one example of the pump mechanism mid-stroke, and FIG. 3 illustrates one example of the pump mechanism at about bottom stroke. The reciprocating pump comprises shaft **101**, screw rod **102**, cylindrical body or cylinder **103** forming a cavity **105**, stylus **104**, and valving system (**106**, **107**). Screw rod **102** forms or has a thread or groove **108** spiraling around the circumference of screw rod **102** down the length of screw rod **102** and back to the top forming a continuous diamond screw pattern (e.g., a diamond screw). The thread or groove **108** can engage with stylus **104**. When in operation with the shaft being rotated about its long axis the stylus engaging with the thread or groove results in rotation of the screw rod **102** as it extends into and retracts from cavity **105** formed by cylindrical body **103**.

[0028] A diamond screw, sometimes referred to as a level-wind screw or reversing screw, is a rod that has a single screw thread or groove (e.g., **108**) that turns both clockwise and counterclockwise. The clockwise and counterclockwise threads are routed into each other at each end of the rod. The rod is typically fixed (with the ability to rotate about the axial direction) and a component (stylus **104**), which mates with the diamond screw thread, is placed on it. As the rod turns, the component slides back and forth from rod end to rod end. Because of the diamond screw thread, the rod only needs to rotate in one direction in order to move the component in both directions. In certain aspects the clockwise pitch and counter-clockwise pitch are the same or approximately the same (the term “pitch” refers to the vertical distance between adjacent turns of the separator at corresponding locations). In other aspects the clockwise pitch and the counter-clockwise pitch differ. The clockwise pitch can be 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1, 2, 3,

4, 5, 6, 7, 8, 9, 10 mm, cm, dm, or m (depending on the size of the pump), including all values and ranges there between. The counter-clockwise pitch can be 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 mm, cm, dm, or m (depending on the size of the pump), including all values and ranges there between. The clockwise thread angle can be 0.5 to 89.5, 1 to 89.5, 10 to 89.5, 20 to 89.5, 30 to 89.5, 40 to 89.5, 50 to 89.5, 60 to 89.5, 70 to 89.5, 80 to 89.5, 0.5 to 70, 1 to 70, 10 to 70, 20 to 70, 30 to 70, 40 to 70, 50 to 70, 60 to 70, 0.5 degree to 50, 1 to 50, 10 to 50, 20 to 50, 30 to 50, 40 to 50, including all values and ranges there between, degree with respect to the long axis of the screw rod. The counter-clockwise angle can be 0.5 to 89.5, 1 to 89.5, 10 to 89.5, 20 to 89.5, 30 to 89.5, 40 to 89.5, 50 to 89.5, 60 to 89.5, 70 to 89.5, 80 to 89.5, 0.5 to 70, 1 to 70, 10 to 70, 20 to 70, 30 to 70, 40 to 70, 50 to 70, 60 to 70, 0.5 degree to 50, 1 to 50, 10 to 50, 20 to 50, 30 to 50, 40 to 50 degree, including all values and ranges there between, with respect to the long axis of the screw rod.

[0029] The idea for a diamond screw pump is to use the diamond screw rod **102** to displace a fluid. By rigidly fixing the stylus **104** the rotation of the rod **102** will cause rod **102** to move in and out of cavity **105**, linearly along the shaft **101**. The end of the reciprocating screw rod can be positioned in cavity **105**, ultimately drawing fluid in and pushing fluid out of the cylindrical body **103**. When used in combination with a stationary motor to drive a diamond screw pump, shaft **101** needs to be inserted to the screw rod **102**. Shaft **101** will slide in and out of screw rod **102** as it reciprocates and moves in and out of cavity **105**. Shaft **101** can be operatively coupled to a motor **110** or other type of drive or control mechanism. In certain aspects the pump can have 1, 2, 3, 4 or more cylindrical bodies and 1, 2, 3, 4, 5, 6, or more valves operatively coupled to various flow paths within or between cylindrical bodies.

[0030] In certain aspects 1, 2, 3, 4, 5, 6, 7, or more pumps can be fluidically couple or operatively couple to form a pump system. Multiple pumps can be oriented, with respect to each other, vertically, horizontally, circumferentially, staggered, or in any other configuration.

[0031] In one embodiment two or more screw rods can be assembled and connected to the same motor **110** and shaft **101** (see FIG. 4 for an example). In certain configuration the assembly can have an optional wall **420** separating the cylinder body **103** into multiple compartments, e.g., a top and bottom compartment. In the top compartment valving system **106a/107a** can provide for inlet flow A and outlet flow B for Screw Rod **102a** and the in the bottom compartment valving system **106b/107b** can provide for inlet flow C and outlet flow D for Screw Rod **102b**. In certain aspects outlet flow B could feed into inlet flow C to pump fluid twice. Without a wall **420** separating the cylinder body into multiple compartments inlet flow A and outlet flow B for Screw Rod **102a** and Screw Rod **102b** inlet flow C and outlet flow D for Screw Rod **102b** could not exist; so only fluid being pumped would be from A to B by both screw rods **102a** and **102b**. Inlet flow A and inlet flow C could come from same reservoir, and/or outlet flow B and out flow D could go to same reservoir. Screw rods **102a** and **102b** would rotate at same rate, but move at different axial rates determined by thread **108a** and **108b**. Threads can be configured to have inconsistent spacing to create nonlinear flow rates (e.g., the right-handed thread could start at 0.5" spacing and finish at 0.125" spacing). The motor can have variable speed to create

nonlinear flow rates. In other aspects, the threads on different screw rods can be configured differently. The cylindrical bodies can be configured with additional inlets and/or outlets. Each screw rod can be configured to pump different fluids (or multiple different fluids depending on number of inlet or outlet ports). Various system or pump configurations can use, implement, or incorporate one more design features of a screw pump as described herein.

[0032] FIG. 5 illustrates an example of a horizontal configuration. In certain aspects two or more pumps **102a** and **102b** positioned on separate axis are connected to one or more motor **110** via different shafts **101a** and **101b** via gears **511a**, **510**, **511b**. In certain aspects the gear ratio can be adjusted to alter rotation speeds of each screw rod **102a**, **102b** independently. A motor **110** can have variable speeds to create nonlinear flow rates. As illustrated in FIG. 5, A represents the inlet flow through valve **107a** and B represents the outlet flow through valve **106a** for Screw Rod **102a** while C represents the inlet flow through valve **107b** and D represents the outlet flow through **106b** for Screw Rod **102b**. In certain aspects, outlet flow B can feed into inlet flow C to pump fluid twice, inlet flow A and inlet flow C can come from same or different reservoirs, outflow B and outlet flow D can go to same or different reservoir. In certain aspects the gearing and groove pitch can be selected independently so that the screw rods could rotate at same or different rates, and move at same or different axial rates determined by threading **108a**, **108b**. Threads can have inconsistent spacing to create nonlinear flow rates (e.g., the right-handed thread could start at 0.5" spacing and finish at 0.125" spacing). Threads on different screw rods could be the same or different. Additional inlets and outlets can be added to cylindrical body(s) **103a** and/or **103b**. Each screw rod **102a**, **102b** could pump the same or different fluids (or multiple different fluids depending on number of inlet or outlet ports). Certain designs or configurations can implement any design features of single screw pump described herein.

[0033] In other embodiments a vertical and horizontal configuration can be combined in a single pumping system. Depending on the pump (or combination of pump) designs, any flow profile could be created: a constant flow, waveform flow (square, sinusoidal, etc.), linear ramp up/down flow, nonlinear ramp up/down flow, intermittent flow, or any combination of the above.

[0034] As with any positive displacement pump, the fluid's direction needs to be regulated. One example of regulating fluid flow is by using appropriate valving (e.g., **106** and/or **107**). In one example fluid flow can be achieved with two one-way valves. One valve would be oriented so that it only lets fluid enter the cavity and the other valve would be oriented so that it only lets fluid exit the cavity. This allows the reciprocating rod to pull fluid into the cavity as it retracts (up stroke) and push fluid out of the cavity as it extends (down stroke).

[0035] In certain embodiments multiple inlets and/or outlets can be incorporated into the cylindrical body. This configuration can allow for different fluids and/or different sources of the same fluid to move through the cylindrical body. In certain aspects fluids can be mixed in cavity **105a/105b**. In certain aspects, a flow regulating feature can be incorporated on the bottom of the piston (e.g., propeller blades or fins) that would capitalize on the rotating motion of the piston to increase mixing of a fluid in the cylindrical body cavity (whether it's one fluid or multiple fluids). If

there was an arm attached to the piston that extended out to the side of the device, then it would move up and down with the piston. If the outlet was routed into a line/tube/hose that was connected to that arm, then the device would essentially spray fluid in a sweeping motion. In certain aspects, if the threads are not machined symmetrically, then it will alter the in/out stroke of the piston. For example, if the right-hand threads had 2 rotations and the left-hand threads had 3 rotations. This would mean it could pull fluid in at one rate and push fluid out at another rate (or vice versa).

[0036] In other embodiments a pump described herein can be one component of a system. The system can include a fluid reservoir fluidically coupled to the pump and other downstream components.

[0037] The relationship between motor torque (T) and the force (F) applied to the fluid can be calculated if the linear distance of rod travel for one rotation (pitch, L), pitch angle (α), mean diameter (d_m), and friction (f) are known. That relationship is shown in the following equation:

$$T = \frac{F d_m}{2} \left(\frac{L + \pi d_m f \sec \alpha}{\pi d_m - f L \sec \alpha} \right)$$

Dividing that force by the surface area of the end face of the screw rod will provide the maximum potential pressure of the fluid. Dimensions of the device can vary depending on application. The circumferences, lengths, and diameters can range from millimeters to meters or more as guided by the relationship shown.

[0038] The device will be manufactured from any rigid materials. Components can be plastic, glass, aluminum, steel, or other rigid material. In certain aspects, the material is selected to be compatible with the fluid to be pumped. In certain aspects, seals (e.g., O rings, gaskets, etc.) will be employed and can be chosen based on the character of the fluid being pumped as well.

[0039] Pump devices described herein can be employed in various applications such as but not limited to:

[0040] Vacuum pumps. A vacuum pump incorporating a mechanism described herein can be designed, manufactured, and used to pull fluid out of a location or container.

[0041] Compressors. A compressor incorporating a mechanism described herein can be designed, manufactured, and used to push fluid into a location or container.

[0042] Medical devices. Any medical application that needs to move fluids, either gas or liquid can use or incorporate a device as described herein. It would be particularly helpful for liquid pumping applications that are in need of flow control within the 100 $\mu\text{L}/\text{min}$ -1 L/min orders of magnitude. For example, this could be used to drive a flow loop for dialysis, extracorporeal membrane oxygenation, or resuscitation.

[0043] Power generation, oil, or gas. A device as described herein can be used or incorporated into a device or system

used to deliver combustible fluids, propellants, water in heat exchangers, or water recirculation.

[0044] The device(s) described herein can be used to extract oil and gas, or transport it via pipelines. The device(s) can be used in irrigation, for example to deliver water and/or pesticides to crops or vegetation.

[0045] The device(s) can be used in water treatment, for example, to transport wastewater to and/or within a water treatment facility or transport clean water away from a water treatment facility.

[0046] In certain aspects the device(s) described herein could be used in amusement parks, for example, to deliver/circulate water to swimming pools, lazy rivers, water slides, etc.

[0047] The device(s) described herein can be used vehicles, for example, to deliver/circulate fuel, engine coolant, refrigerant, windshield wiper fluid, heated/conditioned air, etc.

[0048] The device(s) described herein can be incorporated and/or used anywhere that a normal fluid (gas or liquid) pump is used.

1. A positive displacement pump comprising a pump mechanism having:

- (i) a shaft configured to rotate about its long axis;
- (ii) a screw rod having a continuous thread around the circumference of the screw rod, the thread configured to have an upward thread component and a downward thread component, wherein the screw rod is operatively coupled to the shaft and reticulates along the long axis when the shaft is rotated about the long axis;
- (iii) a stylus positioned to project into the cavity and engage the thread of the screw rod;
- (iv) cylindrical body forming a cavity configured to house at least a portion of the screw rod and allow movement of the screw rod along the long axis of the cylindrical body providing a pumping action in the cylindrical body cavity by expanding and displacing the volume of the cylindrical body; and
- (v) one or more inlets and one or more outlets provided in the cylindrical body walls fluidly coupling the cylindrical body cavity with one or more external fluid paths.

2. The pump of claim 1, further comprising a pump motor aligned along the long axis of the pump mechanism configured to rotate the shaft when in use.

3. The pump of claim 1, wherein one or more inlet, one or more outlet, or one or more inlet and outlet is coupled to a valving mechanism.

4. A system comprising a plurality of pumps of claim 1.

5. The system of claim 4, wherein the pumps are configured in a series with respect to fluid flow.

6. The system of claim 4, wherein the pumps are configured parallel with respect to fluid flow.

7. The system of claim 4, wherein the system includes both pumps in series and in parallel.

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