ABSTRACT

A metering pump for providing relatively small, precise volumes of fluid is provided. The pump piston and/or the interior of the cylinder has a surface finish exhibiting a roughness average within selected limits and a vapor deposited polymer such as polytetrafluoroethylene. A drive mechanism is provided for simultaneously rotating and reciprocating the piston within a cylindrical chamber. Fluid is thereby drawn into the chamber and expelled.
POSITIVE DISPLACEMENT PUMP HAVING PISTON AND/OR LINER WITH VAPOR DEPOSITED POLYMER SURFACE

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The field of the invention relates to metering pumps for pumping relatively precise volumes of fluid.

[0003] 2. Brief Description of the Prior Art

[0004] Positive displacement metering pumps and dispensers are used in single-shot or multiple-dispense and continuous-dispensing application for a variety of industries. Some examples are medical diagnostic, industrial, and agricultural to name a few. U.S. Pat. Nos. 3,168,872, 5,020,980 and 5,015,157 disclose positive displacement pumps with various means for rotating and reciprocating a piston and adjusting piston stroke length. These patents are incorporated by reference herein. While some positive displacement pumps have pistons that are caused to rotate continuously about their longitudinal axes as they are reciprocated, other such pumps have pistons that oscillate back and forth about their longitudinal axes while being caused to reciprocate along their axes. These pumps are sometimes referred to as reciprocating oscillating pumps.

[0005] Precision positive displacement metering pumps and dispensers are used to accurately control the movement or transport of fluids through a fluidic system as needed. Such pumps and dispensers are used when very small volumes of a given fluid are to be transported with a very small margin of error relative to volumetric accuracy and precision. (The term “pump” is generally employed in applications where fluid is transported in a substantially continuous manner. The term “dispenser” is used in applications where fluid is dispensed on demand or at selected intervals. For the purposes of this patent application, the terms “pump” and “dispenser” are used interchangeably.)

[0006] One problem with prior metering pumps and dispensers when moving crystal-forming aggressive solutions is the pump/piston assembly has the potential to seize, i.e., get stuck and/or freeze. In worst case conditions, under intermittent use, pumps sit dry and solids are formed in the pumping chamber, creating a seize condition. In order to prevent a seize, pumps should be kept wet at all times whenever possible, and be flushed out in between runs as well as during any down or idle time. Metering pumps typically have very tight tolerance mating components and completely flushing out a system is very difficult.

[0007] Another approach employed to prevent a seize condition is to create a smooth-surface-profile on the piston O.D., the sliding surface. The smooth-surface-profile could prevent crystal formations on the surface substrate. The super-smooth surface could reduce the incidence of crystals drying and attaching to the piston O.D. substrate and ultimately causing a freeze condition. A problem associated with the super-finish approach is a seal-weepage condition. The super-finish condition may further prevent proper pump seal burnishing or wear-in. If a surface profile is too smooth, a slip-stick condition occurs, i.e., no material transfer from the seal to the mating seal surface. This is essential for proper seal operation. Pump seal manufacturers recommend a specific seal surface profile. The smooth finish causes a seepage condition. The seepage condition does not directly affect the pump’s performance but it does affect overall product reliability. Fluids that seep out over time dry up, forming crystals that assist in causing seal failures. In addition to this, the seepage can attack the external pump components over time. In order to prevent this, pump users employ preventative maintenance procedures, spraying the assembly with a cleaning solution. However, the external pump components are then attacked by the cleaning media, which may be corrosive and potentially damaging to the pump body.

[0008] Another problem associated with the super-finish approach is pump performance relative to precision and accuracy, and siphoning effects. Precision positive displacement pumps and dispensers require very-tight-tolerance mating parts to assure proper operation. With a smooth-finish surface profile, the mean roughness as well as peak-to-valley ratios are greatly reduced. This condition significantly increases the pump component clearances which in turn increases siphoning through the pump. Minimal siphoning is an important feature of positive displacement metering pumps and dispensers.

[0009] Another problem associated with metering pumps relative to piston surface profiles are the microscopic imperfections on the piston surface. When a pump is moving a given fluid in either a dispense- or continuous-mode, the fluid will be subjected to internal tangential shear stresses. These stresses act along the surface of the piston parallel to the surface. This causes system friction at the piston surface. Ideally the fluid flow-path through the pumping chamber is laminar, but turbulence created by microscopic imperfections on the surface profile enhances these imperfections. These imperfections trip the smooth laminar flow into an unpredictable turbulent flow which in turn causes pump system inaccuracies relative to precision and accuracy. In order to reduce this effect, pump users typically add a surfactant to the fluid media. This assists in creating a hydroscopic, lubricous surface.

[0010] It would be desirable to have a pump/seal combination that has reduced incidents of seize, stuck or freeze condition, a reduced seal seepage as well as reduced siphoning, and improved flow characteristics.

SUMMARY OF THE INVENTION

[0011] A positive displacement pump is provided that comprises a housing that includes a cylindrical working chamber and a piston positioned at least partially within the working chamber. The piston includes a duct. Two or more passages extend through the housing and are in fluid communication with the working chamber. The passages are also communicable with the duct depending on the position of the piston. A drive mechanism(s) is coupled to the piston for rotating and reciprocating the piston, thereby causing fluid to be drawn into the working chamber through one or more of the passages and pumped out through another one or more of the passages. Piston rotation can be through 360° or, in the case of a reciprocating oscillating pump, through a smaller arc. The surface of the piston includes a vapor deposited polymer, preferably polytetrafluoroethylene (PTFE). While not required, the surface of the working chamber may also include a vapor deposited polymer.

[0012] The surface of the piston preferably has a degree of roughness prior to application of the polymer. In other
words, the super-finish approach discussed above is not employed. The combination of a rougher finish and a vapor deposited polymer coating provides a superior product that will prevent seize conditions. Moreover, it will allow quick “burn in” when the pump or dispenser is new. The surface of the piston preferably comprises a dimensionally stable material such as a ceramic or ceramic-type material, though other dimensionally stable materials such as aluminum and stainless steel that can be treated with a vapor deposited friction-reducing material could possibly be used at least in selected applications. In a preferred embodiment of the invention, the outer surface of the piston has a finish with a roughness average Ra of at least about four microinches (μin) and preferably at least about eight microinches, the average maximum height of the preferred surface profile Rz being about fifty μin. The average Ra is preferably in a range of about four to sixteen μin, and more preferably eight to sixteen μin.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an exploded elevation view of a metering pump according to the invention;

FIG. 2A is an enlarged sectional side elevation view of the piston/cylinder assembly shown in FIG. 1;

FIG. 2B is a greatly enlarged sectional view thereof;

FIG. 3A is an enlarged sectional side elevation view of a piston/cylinder assembly according to a second embodiment of the invention; and

FIG. 3B is a greatly enlarged sectional view thereof.

DETAILED DESCRIPTION OF THE INVENTION

While this invention is satisfied by embodiments in many different forms, there are shown in the drawings and will be herein described in detail preferred embodiments of the invention with the understanding that the present disclosure is to be considered exemplary of the principles of the invention and is not intended to limit the scope of the invention to the embodiments illustrated. The scope of the invention will be measured by the appended claims and their equivalents.

Referring to FIG. 1, an exploded view of a piston/cylinder assembly for a metering pump is shown. A cylinder housing 10 having an externally threaded end 12 defines a cylindrical chamber. A pair of openings 14 are provided in the housing in diametrically opposed relation. The housing is preferably made from a material that provides good chemical and temperature resistance and good mechanical strength, such as ethylene-tetrafluoroethylene. A cylindrical liner 16 is mounted within the housing 10. The liner includes a pair of diametrically opposed openings 18 that are aligned with the openings 14 in the housing 10. The liner defines the working chamber of the metering pump. It will be appreciated that the housing and liner may each have more than two openings. The housing and liner may be combined as an integral structure made of the same material in some applications.

A piston assembly 20 including a gland nut 22 and piston 24 are adapted for coupling to the housing 10. The piston 24 includes a cylindrical body and a duct in the form of a flat 26 formed at one end thereof. A typical piston diameter may be about one quarter to one half inch, though diameters outside this range are used. A channel may alternately be formed in the piston instead of a flat. The total diametrical clearance between the cylindrical portion of the piston and the liner 16 is preferably between 0.000050 and 0.000100 inches. A pin 28 extends radially from the end of the piston 24 on the opposite side of the gland nut 22. The pin is used for rotating the piston 24 as well as causing it to reciprocate within the pump working chamber. Various mechanisms are known for connection to the pin and providing adjustments in pump speed and piston stroke, such as disclosed in U.S. Pat. Nos. 3,168,872, 5,020,980 and 5,015,157. A preferred mechanism includes a drive cylinder 40 coupled to the drive shaft 42 of a motor 44. Such coupling can be effected by a lock screw 46. A ball and socket fitting 48 is mounted to the cylinder, and receives the end of the pin 28. The length of the stroke is determined by the angle formed between the longitudinal axes of the piston 24 and drive cylinder 40. Another drive mechanism (not shown) involves the use of a drive member including a sinusoidal groove in which the pin is positioned. The piston moves axially back and forth within the liner 16 as the pin is caused to travel through the groove. As discussed above, full rotation of the piston is not required, and only limited rotation is indeed provided in reciprocating oscillating pumps. In operation, fluid is drawn into the working chamber through one set of aligned openings 14, 18 as the piston moves in a first axial direction and is expelled through the other set of aligned openings 14, 18 as the piston moves in the opposite direction. Rotation of the piston causes the flat 26 to be oriented towards one set of the aligned openings and then the other, allowing precise volumes of fluid to be transported.

The gland nut 22 is internally threaded, and can be coupled to the threaded end 12 of the housing 10. A gland washer 30 and a three lip seals 32 are provided for preventing fluid leakage. It will be understood that a cartridge seal or other type of sealing mechanism can be employed. The particular materials chosen for the washer and seals should be compatible with the fluid to be pumped. A washer made from polytetrafluoroethylene (PTFE) and seals made from a corrosion and wear-resistant material exhibiting low friction are acceptable for a number of applications. PTFE-based materials such as RULON AR have been used in the industry for sealing purposes, as well as virgin PTFE. It will be understood that the number of seals and their composition is application-specific, and that other arrangement for sealing the working chamber could be employed in accordance with the invention.

The piston 24 and liner 16 are both preferably comprised of a ceramic material such as alumina or zirconia. YTZP (Yttria TZP) is a suitable form of zirconia for a number of applications. ZTA (Zirconia toughened alumina) is another acceptable material for these elements.

The finish on the piston 24 is important for optimal performance of the pump. In combination with the finish, the presence of a vapor deposited polymer on the piston provides significant performance benefits. Referring to FIG. 2A, the vapor deposited polymer 34 extends from one end of the piston to a point outside the working chamber extending beyond the pump seal(s). The portion of the
piston that will contact fluid and the seals are accordingly provided with the vapor deposited polymer, preferably PTFE. Vapor deposition of the polymer ensures that the polymer will not wear off the piston during use. In contrast, polymers applied as coatings tend to wear over time. In addition to the resulting degradation of pump performance, a coating that wears off the piston of a metering pump or which otherwise degrades has other potentially serious ramifications in certain applications where positive displacement metering pumps are employed. For example, metering pumps can be used in the manufacture of semiconductor wafers where the introduction of any impurities from a wearing or degrading coating can seriously impair the quality of the finished product. Impurities must also be avoided where metering pumps are used for delivering precise quantities of fluid in medical applications or for scientific studies.

[0024] Referring to FIG. 2B, the finishes of both the piston 24 and the liner 16 have a roughness average Ra, an average maximum roughness Rz and a maximum profile depth Rm. (This figure is for illustrative purposes, and may not be representative of the actual surface profiles of the piston and liner surfaces.) The surface finish of the piston is such that it does not tend to wear out the seal(s) of the pump as it rotates and reciprocates, provides an acceptable surface for vapor deposition of the polymer, and allows the piston 24 to move smoothly within the liner 16. In this preferred embodiment, there is no polymer deposited on the inner surface of the liner, and the piston and liner both have a roughness average of at least about four and more preferably at least about eight but less than about sixteen microinches. The preferred average maximum surface roughness Rz is about fifty microinches. Maximum profile depth Rm is also preferably about fifty microinches. The combination of surface finishes of proper roughness, a vapor deposited polymer such as PTFE, and piston/liner clearance in the appropriate range provide a pump or dispenser that is highly suitable for delivering precise amounts of fluid in a reliable manner. The surface finishes of one or both the piston and liner could possibly exceed a roughness average of sixteen microinches provided that these elements do not tend to bind. The maximum roughness of either element would be likely to vary depending on the roughness of the surface finish of the other element it engages, the materials from which the elements are manufactured and the materials comprising the seals. Roughness averages of twenty or even up to twenty-four microinches may be possible using the ceramic materials discussed above, though an average of less than sixteen has proven reliable in ensuring satisfactory performance when Rm and Rz are also within the above limits.

[0025] In the alternate embodiment shown schematically in FIGS. 3A and 3B, both the piston and liner are made of a ceramic or ceramic-type material, such as alumina or zirconia, and have surface finishes as described with respect to the embodiment of FIGS. 2A and 2B. In this embodiment, both the inner surface of the liner 16 and the outer surface of the piston 24 include a vapor deposited polymer 34. The polymer preferably comprises PTFE, and more preferably is substantially pure PTFE, like the polymer on the piston 24 shown in FIGS. 2A and 2B. A third possible alternative (not shown) could include a liner having a vapor deposited polymer and a piston that includes no vapor deposited substance.

What is claimed is:

1. A metering pump for dispensing small, precise volumes of fluid, comprising:
   a pump housing;
   a chamber within said pump housing, said chamber being bounded by a cylindrical wall within said housing;
   a piston having a cylindrical body portion extending within said chamber, said cylindrical body portion of said piston having a cylindrical outer surface and a duct formed therein;
   two or more passages extending through said pump housing and communicating with said chamber;
   a drive mechanism coupled to said piston for rotating and reciprocating said piston within said chamber;
   said outer surface of said cylindrical body portion of said piston including a surface finish exhibiting a roughness average of at least about four microinches and a vapor deposited polymer.

2. A metering pump as described in claim 1, wherein said polymer comprises polytetrafluoroethylene.

3. A metering pump as described in claim 1, wherein said polymer consists essentially of polytetrafluoroethylene.

4. A metering pump as described in claim 1, wherein the total diametrical clearance between said cylindrical outer surface of said piston and said cylindrical wall of said chamber is between about 0.000050 and 0.000100 inches.

5. A metering pump as described in claim 4, wherein said surface finish exhibits a roughness average of at least about eight microinches.

6. A metering pump as described in claim 5, wherein said piston is comprised of a ceramic material and said surface finish exhibits a roughness average of between about eight and sixteen microinches.

7. A metering pump as described in claim 5, wherein said cylindrical wall includes a surface finish exhibiting a roughness average of at least about eight microinches.

8. A metering pump as described in claim 7, wherein said cylindrical wall includes a surface finish exhibiting a roughness average of between about eight and sixteen microinches.

9. A metering pump as described in claim 7, including a seal within said pump housing and engaging said cylindrical body portion of said piston.

10. A metering pump as described in claim 9, including a ceramic liner within said housing, said ceramic liner being said chamber.

11. A metering pump for dispensing small, precise volumes of fluid, comprising:

   a piston including a substantially cylindrical outer surface having a surface finish exhibiting a roughness average of at least about four microinches and a duct formed within said outer surface;

   a housing having an inner surface defining a cylindrical chamber, said piston extending into said cylindrical chamber;

   an inlet passage extending through said housing;

   an outlet passage extending through said housing;

   means for rotating said piston about a longitudinal axis;
means for reciprocating said piston within said chamber such that fluid is drawn into said chamber through said inlet passage and expelled through said outlet passage; and

a vapor deposited polymer on said substantially cylindrical outer surface of said piston.

12. A metering pump as described in claim 1 wherein said polymer comprises polytetrafluoroethylene.

13. A metering pump as described in claim 1 wherein said polymer consists essentially of polytetrafluoroethylene.

14. A metering pump as described in claim 1 wherein the total diametrical clearance between said outer surface of said piston and said inner surface of said housing is between about 0.000050 and 0.000100 inches.

15. A metering pump as described in claim 14 wherein said surface finish of said piston exhibits a roughness average between about eight and sixteen microinches.

16. A metering pump as described in claim 14 wherein said inner surface of said housing exhibits a roughness average of at least about four microinches.

17. A metering pump as described in claim 16 wherein said inner surface of said housing and said outer surface of said piston are comprised of ceramic materials.

18. A piston and cylinder assembly for a metering pump for dispensing small, precise volumes of fluid, comprising:

a ceramic piston including a substantially cylindrical outer surface having a surface finish exhibiting a roughness average of at least about four microinches and a duct formed within said surface;

a housing having a ceramic inner surface defining a cylindrical chamber and exhibiting a roughness aver-

age of at least about four microinches, said piston extending within said chamber;

a vapor deposited polymer comprising polytetrafluoroethylene on at least one of said substantially cylindrical outer surface of said piston and said inner surface of said housing.

19. The assembly of claim 18 wherein the total diametrical clearance between said cylindrical outer surface of said piston and said inner surface of said housing is between about 0.000050 and 0.000100 inches.

20. The assembly of claim 18 including a seal mounted to said housing and engaging said cylindrical outer surface of said piston.

21. The assembly of claim 18 wherein said surface finish of said piston exhibits a roughness average of at least about eight microinches and said polymer is on said outer surface of said piston.

22. The assembly of claim 21 including an inlet passage extending through said housing and an outlet passage extending through said housing.

23. The assembly of claim 21 wherein said housing includes a ceramic liner mounted to said housing and defining said ceramic inner surface, and first and second openings in said liner communicating, respectively, with said inlet and outlet passages.

24. The assembly of claim 23 wherein said roughness averages of said outer surface of said piston and said ceramic inner surface are less than about sixteen microinches.

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