CLAIMS

1. A system for measuring an amount of liquid in a pumping chamber of a pneumatically actuated diaphragm pump comprising:

a fluid inlet and fluid outlet valve connected to the pumping chamber;

a diaphragm separating a pneumatically actuated control chamber from the pumping chamber, the control chamber fluidly connected to a reference chamber of known volume via a conduit that includes a reference chamber valve;

the control chamber fluidly connected via one or more actuation valves to a source of positive or negative pneumatic pressure;

a controller configured to control the fluid inlet and outlet valves, the reference chamber valve, and the one or more actuation valves, and to receive pressure data from a first pressure sensor connected to the actuation chamber and a second pressure sensor connected to the reference chamber;

wherein the controller is configured to isolate the pumping chamber by closing the fluid inlet and outlet valves, charge the control chamber with a first pneumatic pressure; vent the reference chamber or fix a pneumatic pressure in the reference chamber that is different from the control chamber pneumatic pressure; measure a first control chamber pressure and a first reference chamber pressure, connect the control chamber to the reference chamber by opening the reference chamber valve, measure a third equalized pneumatic pressure in the control and reference chambers, and

compute a control chamber volume based on an ideal gas model that assumes an adiabatic pressure equalization process in the reference chamber and a polytropic pressure equalization process in the control chamber.

2. The system of claim 1, wherein the model further assumes an isothermal process in the conduit as a gas moves from the control chamber to the reference chamber during the equalization process.

3. The system of claim 1, wherein the model applied to the control chamber uses a polytropic coefficient in the ideal gas model, wherein the controller is programmed to vary the polytropic coefficient as a pre-defined function of the control chamber volume.

4. The system of claim 3, wherein the controller is programmed to compute a polytropic coefficient based on an estimated volume of the control chamber using a model that assumes an adiabatic pressure equalization process in the control chamber.

5. A system for measuring an amount of liquid in a pumping chamber of a pneumatically actuated diaphragm pump comprising:

a fluid inlet and fluid outlet valve connected to the pumping chamber;

a diaphragm separating a pneumatically actuated control chamber from the pumping chamber, the control chamber fluidly connected to a reference chamber of known volume via a conduit that includes a reference chamber valve;

the control chamber fluidly connected via one or more actuation valves to a source of positive or negative pneumatic pressure;

a controller configured to control the fluid inlet and outlet valves, the reference chamber valve, and the one or more actuation valves, and to receive pressure data from a first pressure sensor connected to the actuation chamber and a second pressure sensor connected to the reference chamber;

wherein the controller is configured to isolate the pumping chamber by closing the fluid inlet and outlet valves, charge the control chamber with a first pneumatic pressure; vent the reference chamber or fix a pneumatic pressure in the reference chamber that is different from the control chamber pneumatic pressure; measure a first control chamber pressure and a first reference chamber pressure, connect the control chamber to the reference chamber by opening the reference chamber valve and equalizing pressures between the control chamber and the reference chamber, measure a third equalized pneumatic pressure in the control and reference chambers, and

compute a control chamber volume based on an ideal gas model that assumes the presence of three closed mass systems of a gas comprising:

a first mass system that occupies the control chamber at the end of pressure equalization;

a second mass system that occupies the reference chamber before pressure equalization; and

a third mass system that occupies the conduit, a part of the control chamber and a part of the reference chamber after equalization of pressure begins between the control and reference chambers.

6. The system of claim 5, wherein the model assumes an expansion of the first mass system after pressure equalization begins, the expansion being modeled as a polytropic process.

7. The system of claim 5, wherein the model assumes a compression of the second mass system after pressure equalization begins, the compression being modeled as an adiabatic process.

8. The system of claim 5, wherein the third mass system is modeled to be subdivided into component volumes, a first component volume occupying part of the control chamber and being modeled polytropically, a second component volume occupying part of the reference chamber and being modeled adiabatically, and a third component volume occupying the conduit and being modeled isothermally.

9. A system for measuring an amount of liquid in a pumping chamber of a pneumatically actuated diaphragm pump comprising:

a fluid inlet and fluid outlet valve connected to the pumping chamber;

a diaphragm separating a pneumatically actuated control chamber from the pumping chamber, the control chamber fluidly connected to a reference chamber of known volume via a conduit that includes a reference chamber valve;

the control chamber fluidly connected via one or more actuation valves to a source of positive or negative pneumatic pressure;

a controller configured to control the fluid inlet and outlet valves, the reference chamber valve, and the one or more actuation valves, and to receive pressure data from a first pressure sensor connected to the actuation chamber and a second pressure sensor connected to the reference chamber;

wherein the controller is configured to isolate the pumping chamber by closing the fluid inlet and outlet valves, charge the control chamber with a first pneumatic pressure; vent the reference chamber or fix a pneumatic pressure in the reference chamber that is different from the control chamber pneumatic pressure; measure a first control chamber pressure and a first reference chamber pressure, connect the control chamber to the reference chamber by opening the reference chamber valve and equalizing pressures between the control chamber and the reference chamber, measure a third equalized pneumatic pressure in the control and reference chambers, and

compute the control chamber volume based on an ideal gas model that assumes the presence of three closed mass systems of a gas comprising:

a first mass system that occupies the control chamber before pressure equalization;

a second mass system that occupies the reference chamber at the end of pressure equalization; and

a third mass system that occupies the conduit, a part of the control chamber and a part of the reference chamber after equalization of pressure begins between the control and reference chambers.

10. The system of claim 9, wherein the model assumes a compression of the first mass system after pressure equalization begins, the compression being modeled as a polytropic process.

11. The system of claim 9, wherein the model assumes an expansion of the second mass system after pressure equalization begins, the expansion being modeled as an adiabatic process.

12. The system of claim 9, wherein the third mass system is modeled to be subdivided into component volumes, a first component volume occupying part of the control chamber being modeled polytropically, a second component volume occupying part of the reference chamber being modeled adiabatically, and a third component volume occupying the conduit being modeled isothermally.

13. A system for measuring an amount of liquid in a pumping chamber of a pneumatically actuated diaphragm pump comprising:

a fluid inlet and fluid outlet valve connected to the pumping chamber;

a diaphragm separating a pneumatically actuated control chamber from the pumping chamber, the control chamber fluidly connected to a reference chamber of known volume via a conduit that includes a reference chamber valve;

the control chamber fluidly connected via one or more actuation valves to a source of positive or negative pneumatic pressure;

a controller configured to control the fluid inlet and outlet valves, the reference chamber valve, and the one or more actuation valves, and to receive pressure data from a

first pressure sensor connected to the actuation chamber and a second pressure sensor connected to the reference chamber;

wherein the controller is configured to isolate the pumping chamber by closing the fluid inlet and outlet valves, charge the control chamber with a first pneumatic pressure; vent the reference chamber or fix a pneumatic pressure in the reference chamber that is different from the control chamber pneumatic pressure; measure a first control chamber pressure and a first reference chamber pressure, connect the control chamber to the reference chamber by opening the reference chamber valve and equalizing pressures between the control chamber and the reference chamber, measure a third equalized pneumatic pressure in the control and reference chambers, and

compute a control chamber volume based on an ideal gas model under a polytropic process, wherein the controller is configured to select a polytropic coefficient for the model using a pre-determined function in which the value of the polytropic coefficient depends on and varies with the control chamber volume.

14. The system of claim 13, wherein the pre-determined function is determined by fixing the control chamber volume at a known volume, and calculating a polytropic coefficient corresponding to the known volumes of the control and reference chambers, and the measured first, second and third pressures before and after equalization of pressures; wherein said calculation is repeated a plurality of times, each said time corresponding to fixing the control chamber volume at a different known volume.

15. The system of claim 14, wherein the function corresponds to a stored look-up table from which the controller selects a polytropic coefficient corresponding to the volume of the control chamber being computed.

16. The system of claim 14, wherein the function corresponds to an equation that has been fitted to a plurality of calculated polytropic coefficients corresponding to a series of known control chamber volumes.

17. A system for calculating a change in fluid volume in a pumping chamber of a pneumatically actuated diaphragm pump using a gas having a heat capacity ratio of n, the system comprising:

a control chamber separated from the pumping chamber by a flexible diaphragm;

a fluid inlet or outlet of the pumping chamber;

a valve connecting the control chamber to a pressurized source of the gas;

a pressure sensor fluidly connected to the control chamber;

a controller that receives pressure data from the pressure sensor, that controls the valve, and that is configured to regulate pressure in the control chamber by opening or closing the valve;

wherein the controller is configured to compute a change in volume of the control chamber as fluid enters or leaves the pumping chamber by monitoring a pressure change in the control chamber when the valve is closed;

said computation assigning a first chamber volume to a first measured pressure, and calculating a second chamber volume based on a second later measured pressure using an equation in which a ratio of the second measured pressure to the first measured pressure is assumed to be equal to a ratio of the first chamber volume to the second chamber volume, raised to a power between 1 and n.

18. The system of claim 17, wherein the assigned first chamber volume is derived from an initial condition in which the control chamber is pressurized with air, the pumping chamber and control chamber are isolated, a measurement of control chamber pressure is taken, the control chamber is connected to a reference chamber having a known volume and measured pressure, and the controller derives an initial volume of the control chamber using a model based on an ideal gas equation.

19. The system of claim 17, wherein the controller calculates a third chamber volume as fluid continues to enter or leave the pumping chamber by assigning the second chamber volume to the second measured pressure and calculating a third chamber volume based on a third measured pressure using an equation in which a ratio of the third measured pressure to the second measured pressure is assumed to be equal to a ratio of the second chamber volume to the third chamber volume, raised to a power between 1 and n.

20. The system of claim 19, wherein the controller calculates a fluid flow into or out of the pumping chamber based on a difference between the first, second and third chamber volumes.

21. The system of claim 20, wherein the controller repeats said calculations periodically during a time period in which fluid continues to enter or leave the pumping chamber, and suspends said calculations during a time period in which the valve is opened to connect the control chamber with the pressurized source of the gas.

22. The system of claim 21, wherein the pressurized source of the gas is a positively pressurized source or a negatively pressurized source.

23. The system of claim 22, wherein the gas is air.

24. The system of claim 22, wherein the value of n is approximately 1.4.

25. The system of claim 24, wherein the value of n is adjusted by the controller by comparing a cumulative calculated volume of fluid moved into or out of the pumping chamber during a pump stroke to a volume change in the pumping chamber calculated from an initial volume determination at a beginning of the pump stroke and a final volume determination at an end of the pump stroke.

26. A method for determining an amount of fluid delivered by a diaphragm pump having a pumping chamber separated from a pneumatically actuated control chamber by a diaphragm, and having pneumatically actuated inlet and outlet valves, the method comprising having a controller:

close the outlet valve, open the inlet valve, and connect the control chamber to a negative pressure source to apply negative pneumatic pressure to the diaphragm pump to draw fluid into the pumping chamber;

close the inlet valve, connect the control chamber to the positive pressure source, isolate the control chamber, measure a first control chamber pressure, measure a first reference chamber pressure in a reference chamber having a known volume, connect the control chamber to the reference chamber, and calculate a first volume of the control chamber;

open the outlet valve, and connect the control chamber to a positive pressure source to apply a positive pneumatic pressure to the diaphragm pump to expel fluid from the pumping chamber;

close the outlet valve;

vent the control chamber to reduce pressure in the control chamber toward atmospheric pressure;

connect the control chamber to the positive pressure source, isolate the control chamber, measure a second control chamber pressure, measure a second reference chamber pressure, connect the control chamber to the reference chamber, and calculate a second volume of the control chamber; and

determine the amount of fluid delivered by the diaphragm pump based on the first and second volumes of the control chamber.

27. A method for determining an amount of fluid delivered by a pumping cassette comprising a first and a second diaphragm pump each said diaphragm pump having a pumping chamber separated from a pneumatically actuated control chamber by a diaphragm, and each having pneumatically actuated inlet and outlet valves, the method comprising having a controller perform for each said diaphragm pump the steps of:

closing the outlet valve, opening the inlet valve, and connecting the control chamber to a negative pressure source to apply negative pneumatic pressure to the diaphragm pump to draw fluid into the pumping chamber;

closing the inlet valve, connecting the control chamber to the positive pressure source, isolating the control chamber, measuring a first control chamber pressure, measuring a first reference chamber pressure in a reference chamber having a known volume, connecting the control chamber to the reference chamber, and calculating a first volume of the control chamber;

opening the outlet valve, and connecting the control chamber to a positive pressure source to apply a positive pneumatic pressure to the diaphragm pump to expel fluid from the pumping chamber;

closing the outlet valve;

venting the control chamber to reduce pressure in the control chamber toward atmospheric pressure;

connecting the control chamber to the positive pressure source, isolating the contol chamber, measuring a second control chamber pressure, measuring a second reference chamber pressure, connecting the control chamber to the reference chamber, and calculating a second volume of the control chamber; and

determining the amount of fluid delivered by the diaphragm pump based on the first and second volumes of the control chamber; wherein

expelling fluid from the pumping chamber of the second diaphragm pump is performed after the control chamber of the first diaphragm pump is vented, and expelling fluid from the pumping chamber of the first diaphragm pump is performed after the control chamber of the second diaphragm pump is vented.

28. A system for measuring a volume of liquid in a pumping chamber of a peritoneal dialysis pump cassette comprising:

a base unit in which the pump cassette can be installed, the base unit including a control block having a control chamber depression configured to mate with the pumping chamber of the pumping cassette, and to move a flexible diaphragm between the pumping chamber and the control chamber under positive or negative pneumatic pressure;

the control chamber depression being in communication via one or more pump actuation valves in the base unit with a source of positive or negative pressure, and in communication via a vent valve in the base unit with a vent connected to atmospheric pressure;

a controller configured to control the one or more pump actuation valves to operate the pumping cassette to fill the pumping chamber with liquid and to deliver liquid from the pumping chamber;

the controller configured to control one or more pneumatically actuated membrane inlet and outlet valves in the pump cassette via one or more inlet and outlet actuation valves in the base unit connected to the source of positive or negative pneumatic pressure;

the controller also configured to measure pneumatic pressure in the control chamber via a pressure sensor, and to calculate a volume of liquid in the pumping chamber, the calculation involving pneumatically pressurizing the control chamber before taking a pressure measurement;

wherein the controller is configured to connect the control chamber with the vent after commanding a liquid delivery stroke of the pump cassette and before pneumatically pressurizing the control chamber to perform a pumping chamber liquid volume calculation.

29. A system for adjusting negative pressure used to withdraw fluid from a cavity of a patient, the system comprising:

a pump configured to provide negative pressure to a fluid line connected to the cavity;

a controller configured to measure and control the negative pressure provided by the pump;

the controller also configured to measure a rate of flow of fluid from the fluid line to the pump;

wherein the controller is arranged to control the pump by providing a first negative pressure to the fluid line, measuring the rate of fluid flow, and control the pump by providing a second negative pressure to the fluid line that is greater in magnitude than the first negative pressure if the measured rate of fluid flow exceeds a pre-determined value.

30. A system for adjusting negative pressure used to withdraw fluid from a cavity of a patient, the system comprising:

a pump configured to provide negative or positive pressure to a fluid line connected to the cavity;

a controller configured to measure and control the pressure provided by the pump;

the controller also configured to measure a rate of flow of fluid from the fluid line to the pump;

wherein the controller is arranged to control the pump by providing negative pressure to the fluid line, measuring the rate of fluid flow, and control the pump by providing a positive pressure to the fluid line if the measured rate of fluid flow is less than a pre-determined value;

and wherein the controller is arranged to re-apply negative pressure to the fluid line if a measured fluid flow upon application of the positive pressure is greater than a pre-determined amount.

31. A system for adjusting negative pressure used to withdraw fluid from a cavity of a patient, the system comprising:

a pump configured to provide negative pressure to a fluid line connected to the cavity;

a controller configured to measure and control the pressure provided by the pump;

the controller also configured to measure a flow rate of fluid from the fluid line to the pump;

wherein the controller is arranged to control the pump by providing negative pressure in an amount that varies continuously as a function of the measured flow rate of the fluid;

wherein the variation in negative pressure applied by the pump is limited to within a pre-determined range of negative pressures.

32. A system for adjusting negative pressure used to withdraw fluid from a cavity of a patient, the system comprising:

a pump configured to provide negative pressure to a fluid line connected to the cavity;
a controller configured to measure and control the pressure provided by the pump;
the controller also configured to measure a flow rate of fluid from the fluid line to the pump;
a user interface configured to provide a user a measure of the negative pressure applied by the pump, and configured to receive input from the user to adjust the amount of negative pressure applied by the pump;
wherein the controller is arranged to receive via the user interface a command from the user to adjust the negative pressure applied by the pump, and to effectuate the adjustment.

33. A system for adjusting negative pressure used to withdraw fluid from a cavity of a patient, the system comprising:
a pump configured to provide negative pressure to a fluid line connected to the cavity;
a controller configured to measure and control the pressure provided by the pump;
the controller also configured to measure a flow rate of fluid from the fluid line to the pump, and to compute a pumping duration based on the measured flow rate;
a user interface configured to provide a user a measure of the negative pressure applied by the pump, and configured to receive input from the user to adjust the amount of negative pressure applied by the pump;
wherein the controller is arranged to receive via the user interface a command from the user to adjust the negative pressure applied by the pump, to compute a change in the pumping duration resulting from the adjustment, to display information about the change in pumping duration on the user interface, and to receive from the user a command to proceed or not proceed with the adjustment.