United States Patent [19]

Theeuwes

[11] **3,923,426**

[45] **Dec. 2, 1975**

[54] **ELECTROOSMOTIC PUMP AND FLUID DISPENSER INCLUDING SAME**

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[52] **U.S. Cl.**............... **417/48;** 417/389; 204/180 R; 204/301

[51] **Int. Cl.²**..................... **F04B 37/02;** F04F 11/00

[58] **Field of Search**................ 204/180 R, 299, 301; 417/48, 389

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Attorney, Agent, or Firm—Thomas E. Ciotti; Paul L. Sabatine; Edward L. Mandell

[57] **ABSTRACT**

A miniature electroosmotic pump and fluid dispenser including the pump are disclosed. The pump comprises a plexiglass housing having a fluid inlet and outlet, a pair of spaced silver-silver chloride electrodes disposed in the housing and connected to a d.c. power source, a porous ceramic plug which has a high zeta potential relative to the fluid interposed between the electrodes, a cation exchange membrane positioned on each side of the ceramic plug between it and the electrode facing it and a fluid passageway in the housing extending from the fluid inlet to one side of the plug and from the other side of the plug to the outlet. The fluid dispenser is a modularized, self-contained unit consisting of the pump and a multicavitied fluid reservoir which contains both the fluid to be pumped and the fluid to be dispensed. Fluid is pumped from a first reservior cavity into a second cavity which already is filled with fluid. The second cavity adjoins a third cavity filled with fluid, such as drug, to be dispensed and is sealingly spearated from the third cavity by a flexible partition. The increase in volume in the second cavity distends the flexible partition into the third cavity forcing fluid therefrom.

21 Claims, 9 Drawing Figures

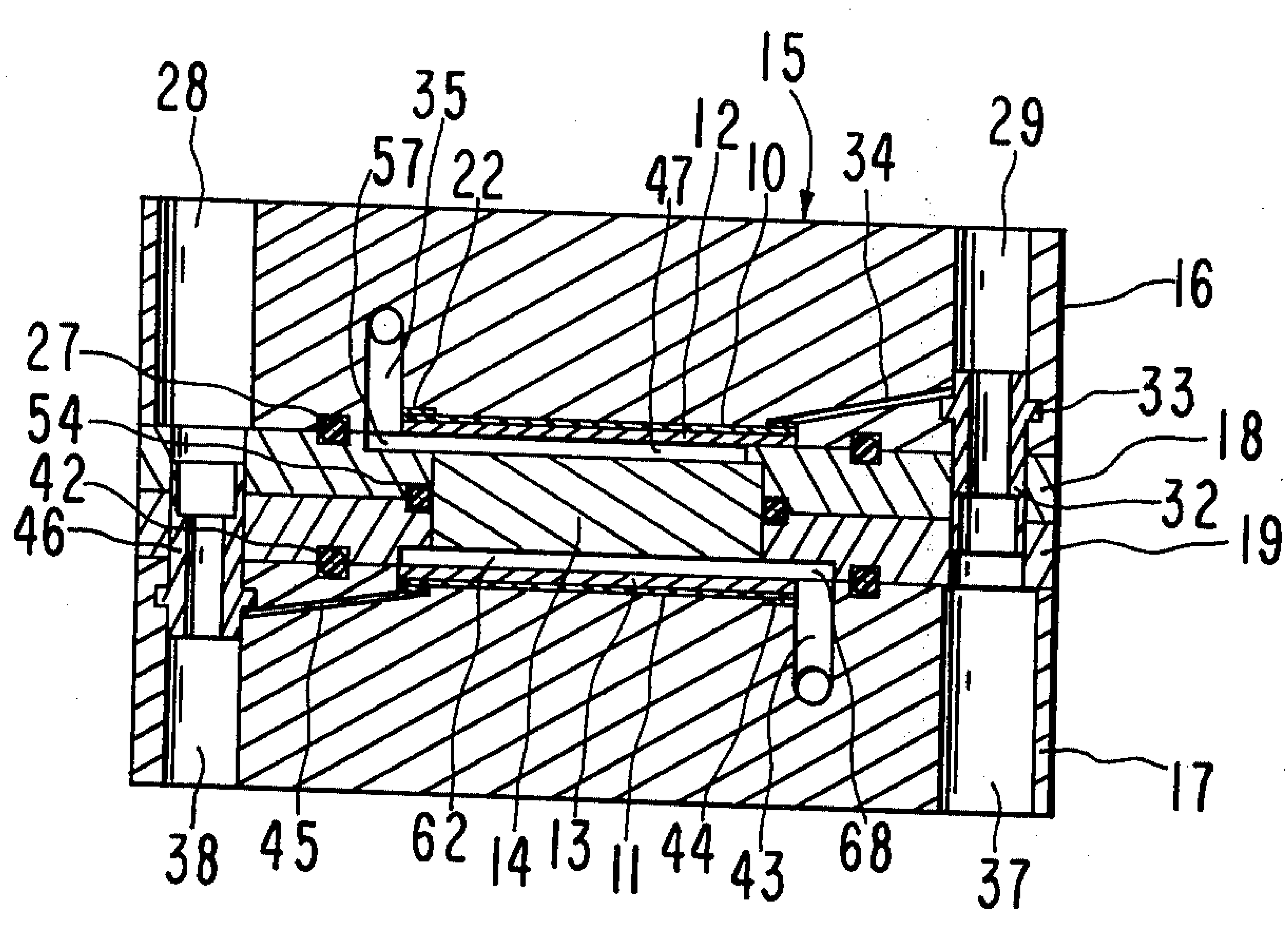

FIG. 1

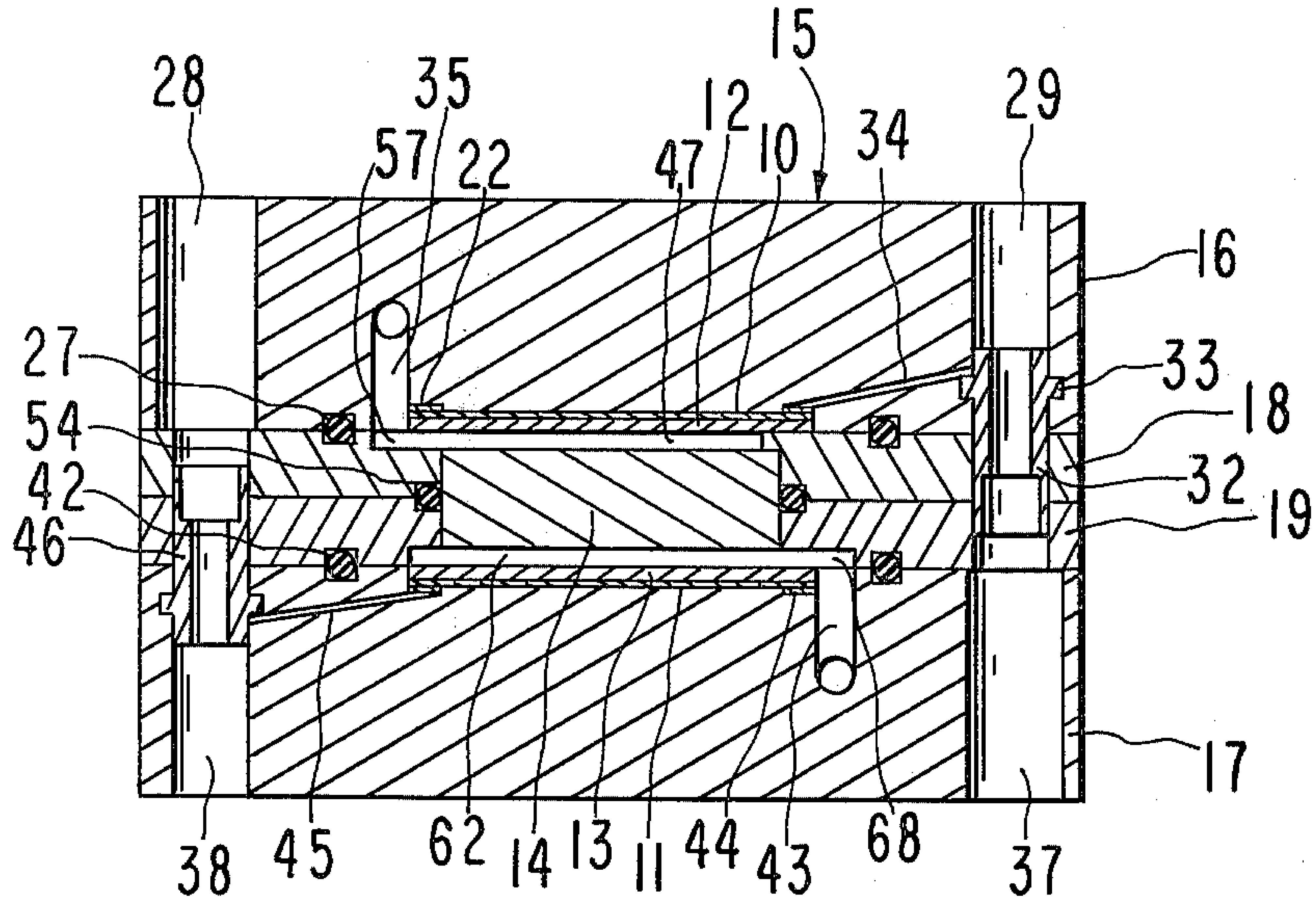
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FIG. 2

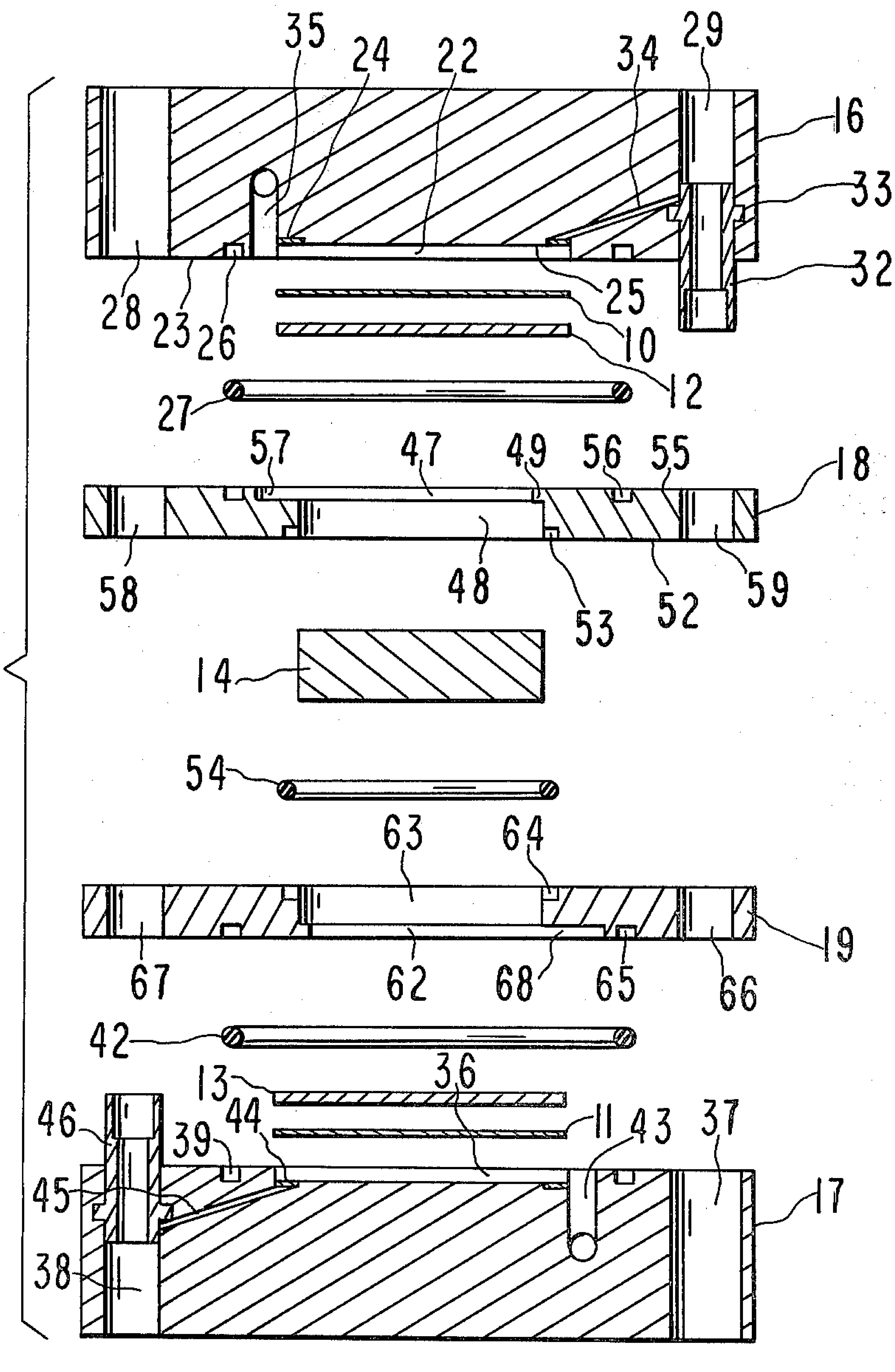
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FIG. 3

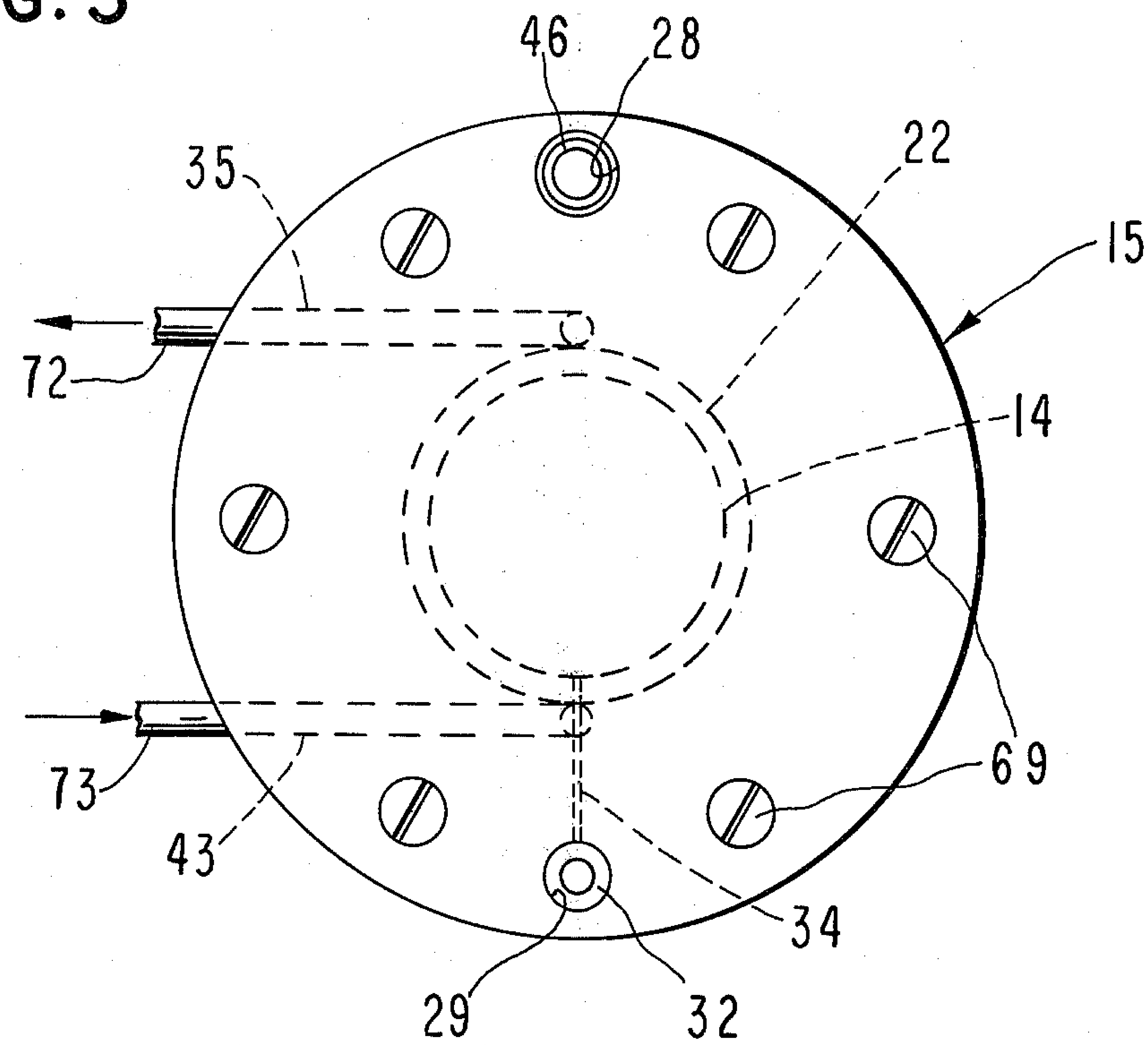
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FIG. 4

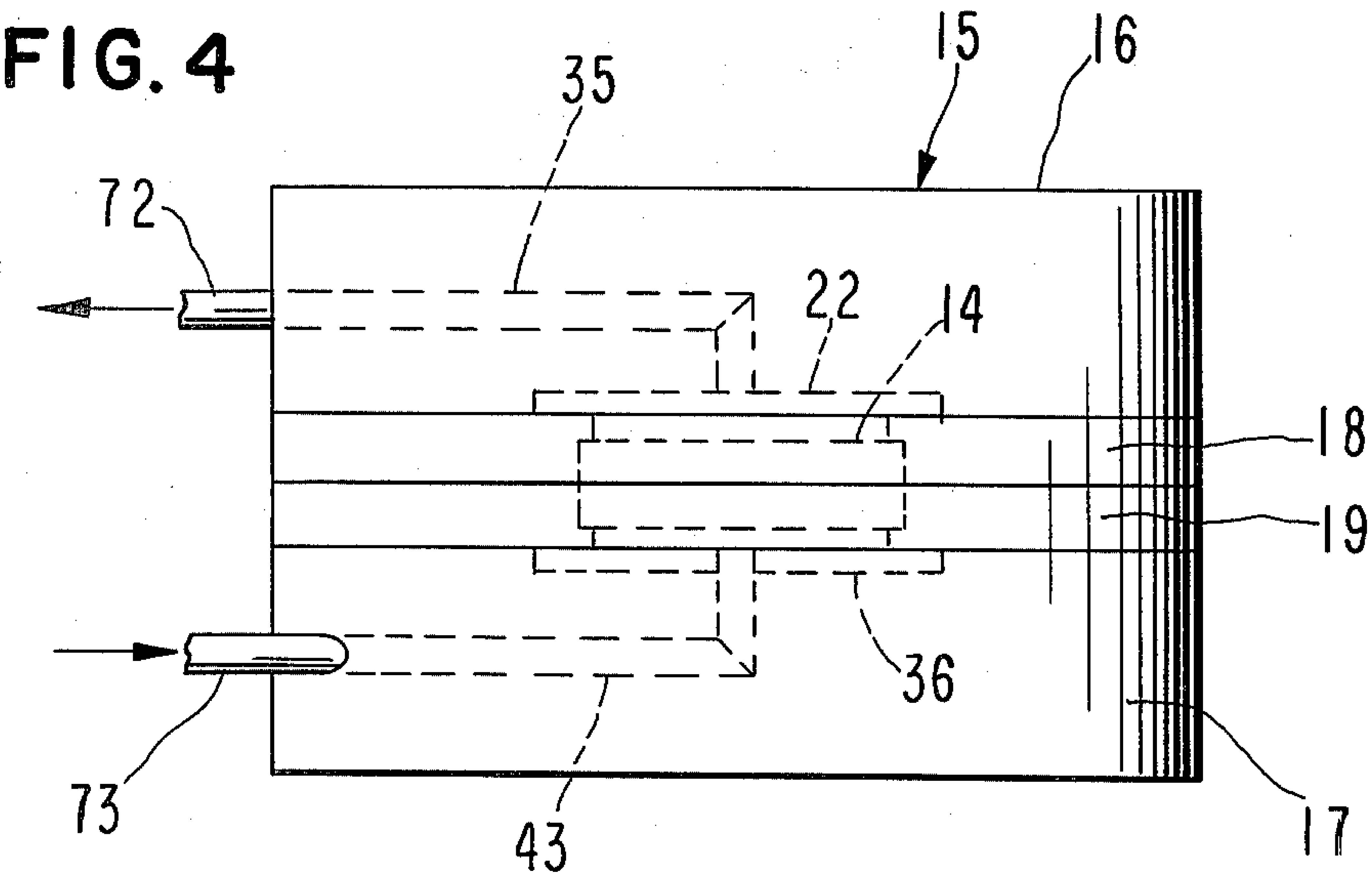
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FIG. 5

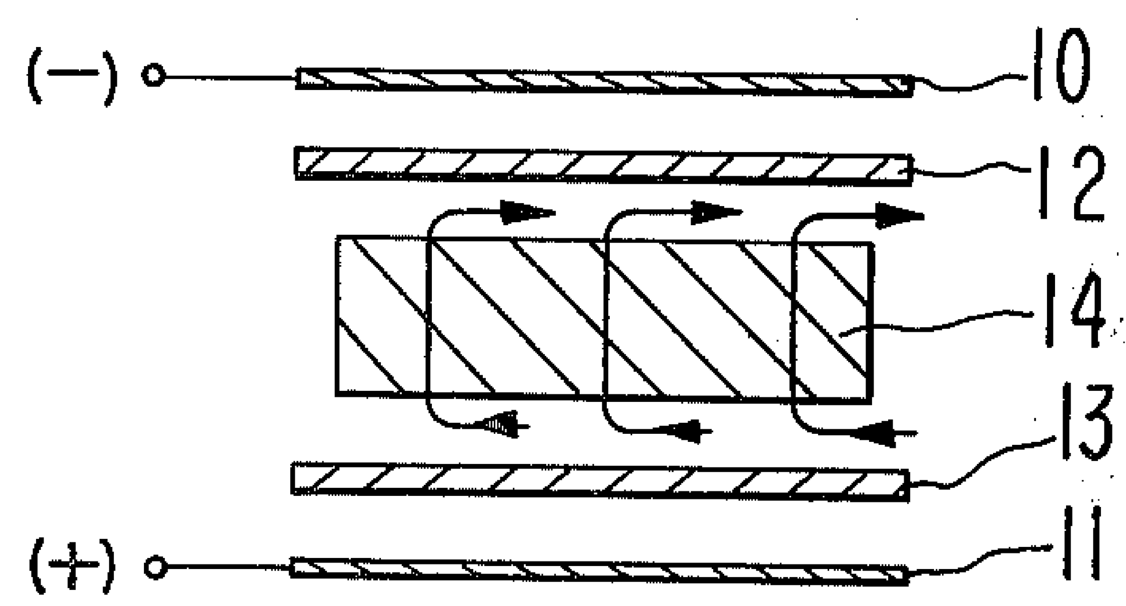


FIG. 6

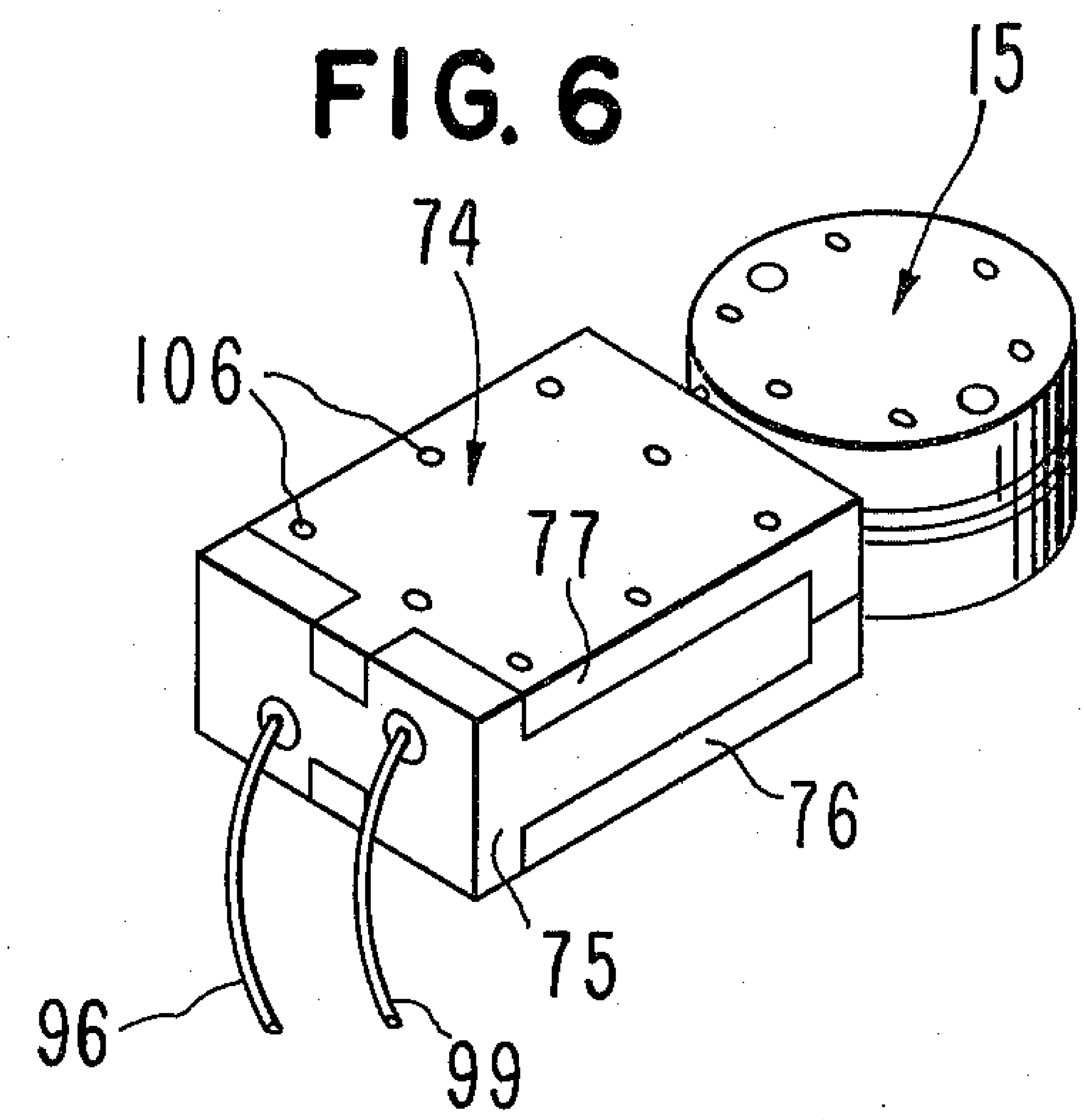
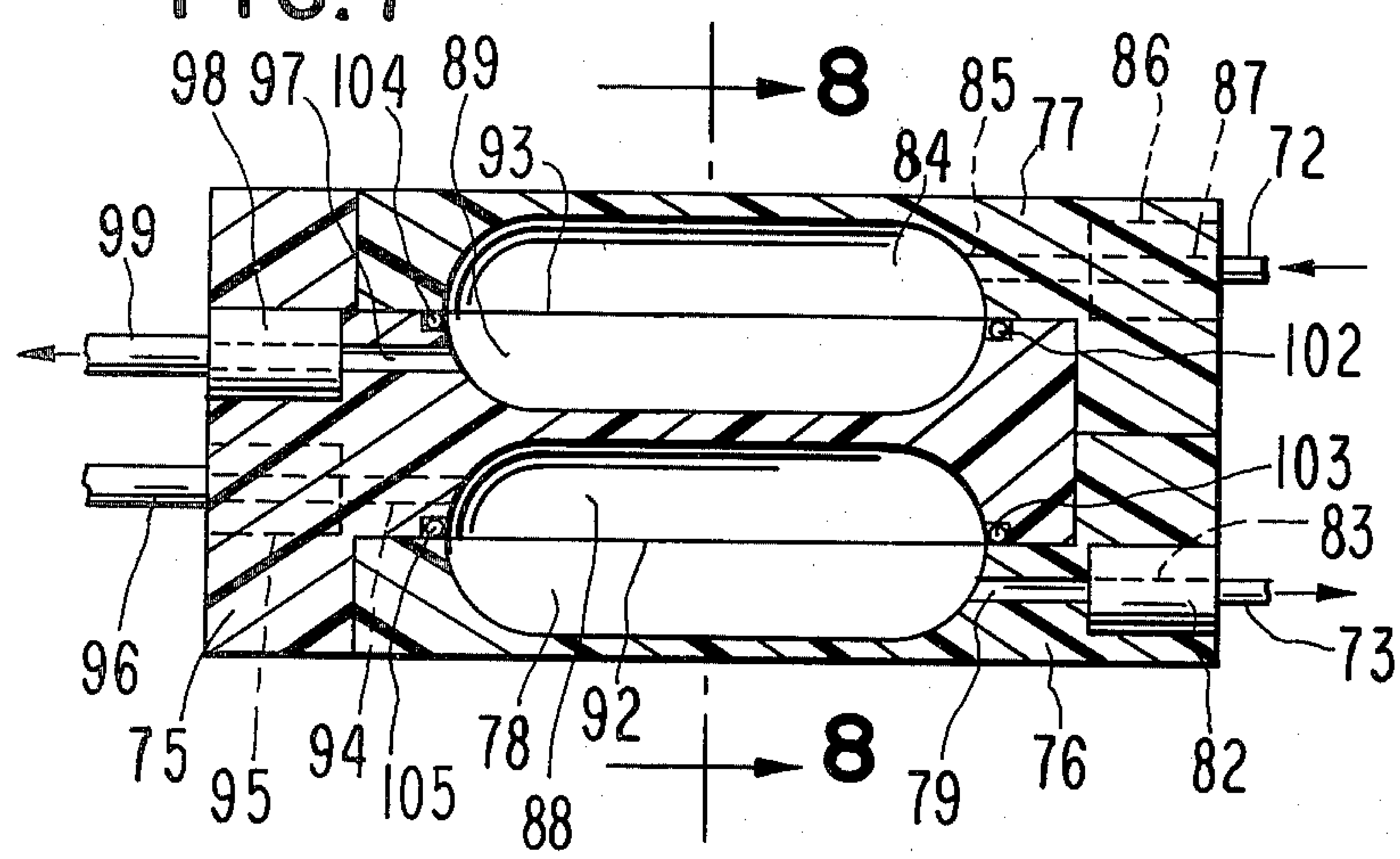


FIG. 7



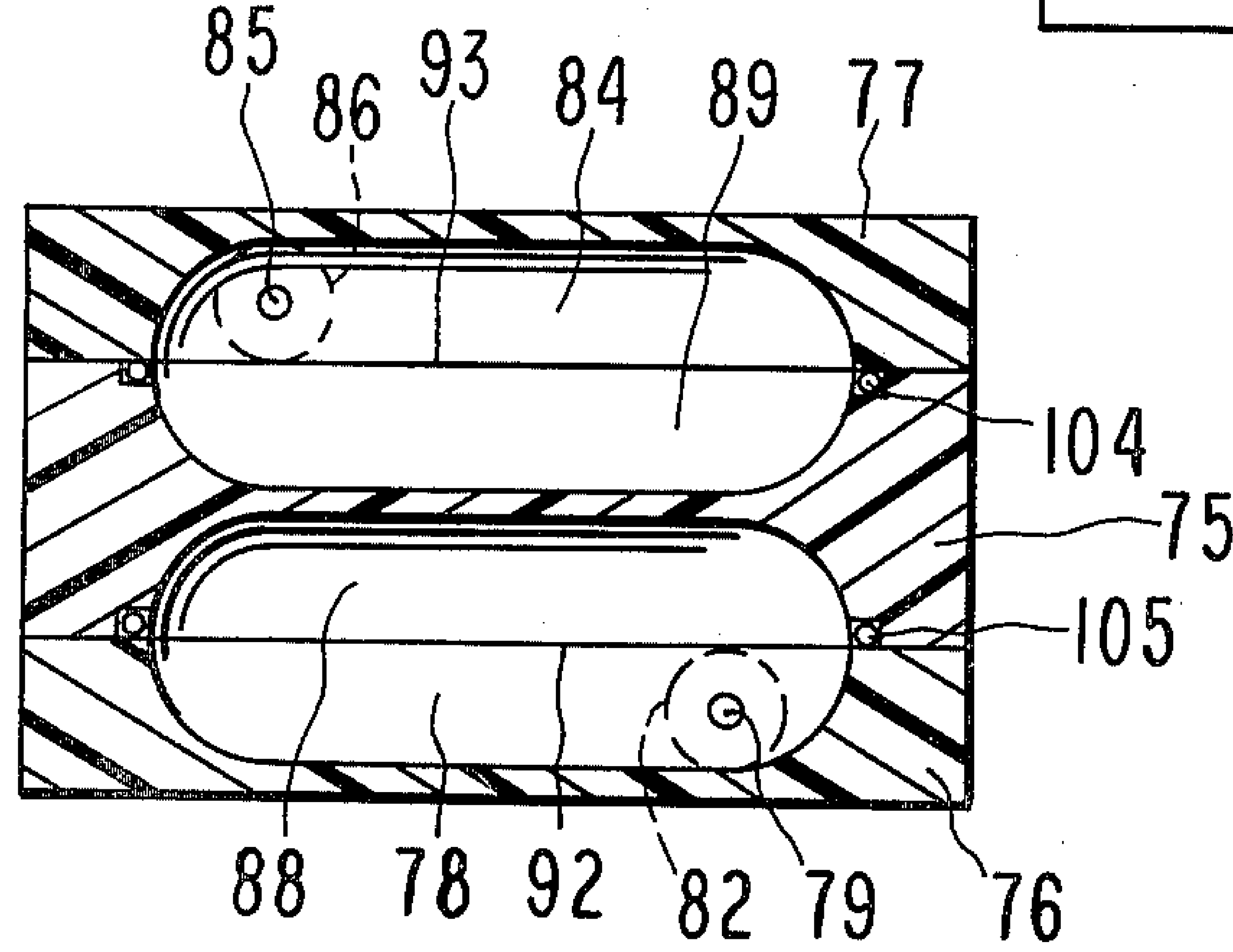


FIG. 8

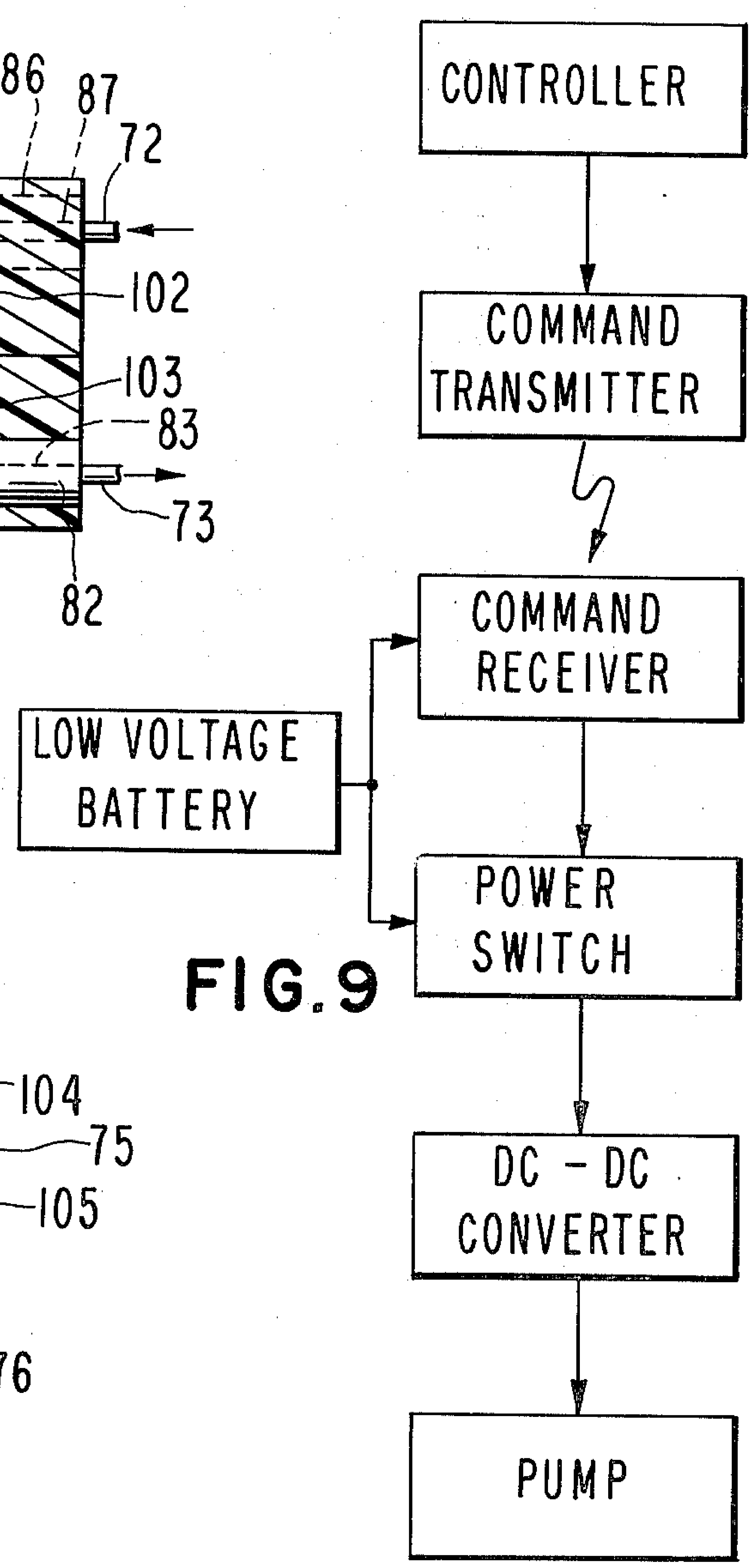


FIG. 9

ELECTROOSMOTIC PUMP AND FLUID DISPENSER INCLUDING SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an electroosmotic pump and a fluid dispenser incorporating an electroosmotic pump.

2. Description of the Prior Art

The electroosmotic phenomenon and the physics and mathematics defining it have been known for many years. Perhaps the best review of electroosmosis in the *Electrokinetic Phenomenon and Their Application to Biology and Medicine*, H.A. Abramson, American Chemical Society Monograph Series, the Chemical Catalog Company, Inc., N.Y. (1934). Electroosmosis is the opposite of electrophoresis. Generally, in electroosmosis a stationary solid body through which a fluid will pass, such as a porous body, has a matrix of fixed electrical charges and a fluid carries mobile electrical charges of opposite polarity relative to the fixed charges of the body. By applying a sufficient potential difference to the system one can cause the fluid to move through the body and exit therefrom at a predetermined positive pressure. Electrophoresis, on the other hand, involves the movement of charged particles through a stationary body of fluid.

While many practical applications of electrophoresis have been made in the separation and purification arts, little practical use of the electroosmotic phenomenon has been reported. "Irreversible Thermodynamics of Electro-osmotic Effects", R.P. Rastogi, *J. Scient. Ind. Res.*, Vol. 28, pp. 284–292 (August, 1969) says applications of electroosmosis to pump fluids, generate electricity and measure pressure or flow have been proposed and investigated. And *Colloid Science I*, H.R. Kruyt, Elsevier Pub. Co., (1952) p. 234 reports that several vintage German patents exist on the removal of water from porous substances by electroosmosis.

STATEMENT OF THE INVENTION

This invention is an electroosmotic pump and a fluid dispenser including the pump. The pump pumps a fluid susceptible to electroosmotic transport and comprises: a housing having an inlet for the fluid and an outlet for the fluid; a pair of spaced electrodes within the housing; a d.c. electrical power source connected to the electrodes; a porous body interposed between the electrodes in spaced relationship thereto, the porous body having a fluid entrance surface and a fluid exit surface and being capable of carrying a surface charge of opposite polarity relative to the surface charge of the fluid; a cation exchange membrane interposed between the porous body and the electrode on the fluid exit surface side of the porous body; and a fluid passageway in the housing extending from the inlet to the fluid entrance surface of the body and from the fluid exit surface of the body to the outlet.

In a preferred embodiment the pump is structured symmetrically so that the fluid flow therethrough may be reversed by reversing the electrode polarity. In such an embodiment a cation exchange membrane is interposed between the porous body and both of the electrodes.

The dispenser is a self-contained unit and in addition to the pump comprises: a source of the fluid pumped by the pump connected to the pump inlet; and a vessel having a first chamber for containing the fluid to be dispensed, the first chamber having an outlet port, a second chamber for receiving the fluid pumped by the pump connected to the pump outlet and a movable barrier sealingly separating the first chamber from the second chamber. Fluid is dispensed from the first chamber as fluid is pumped into the second chamber from the pump causing the fluid volume in the second chamber to increase and move the barrier into the first chamber thereby forcing a corresponding volume of fluid from the first chamber therefrom via the outlet port.

The above described pump and dispenser have several very advantageous features. The pump has no moving parts and thus is not susceptible to frictional wear. The elements of the pump which are the limiting elements in the pump's lifetime, namely the electrodes, membranes and porus body, may be modularized for easy replacement. The dispenser is readily miniaturized and is thus capable of being used as a portable unit which may be strapped or otherwise affixed to the desired dispensing site. Since the pump is driven electrically and has no moving parts it may be instantaneously turned on and off and therefore may be programmed to dispense fluid in an infinite variety of time patterns. The flow rate and output pressure may be varied by varying the electrical input to the pump. And, the dispenser is capable of being controlled remotely if desired.

Embodiments of the pump/dispenser in which the electrode polarity may be reversed have the additional advantage of being long-lived.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawings illustrate a small electroosmotic pump and a fluid dispenser including the pump such as might be used as a portable unit for dispensing drugs to patients. In the drawings:

FIG. **1** is an enlarged, sectional view of the pump;

FIG. **2** is an enlarged, exploded view of the pump of FIG. **1**;

FIG. **3** is an enlarged plan view of the pump of FIG. **1**;

FIG. **4** is an enlarged side elevational view of the pump of FIG. **1**;

FIG. **5** is a partly schematic, sectional view of the basic elements of the pump of FIG. **1**;

FIG. **6** is a perspective view, in actual scale, of the fluid dispenser. The cylindrical member is the pump of FIG. **1** and the parallelipiped member is a reservoir module which contains the fluid to be pumped (transport fluid) and the fluid to be dispensed;

FIG. **7** is an enlarged, longitudinal sectional view of the reservoir module of the dispenser of FIG. **6**;

FIG. **8** is a sectional view taken along line **8-8** of FIG. **7**; and

FIG. **9** is a schematic view illustrating the power and control elements for activating and driving the pump and dispenser.

DETAILED DESCRIPTION OF PUMP AND DISPENSER OF DRAWINGS

The basic innards of the electroosmotic pump are shown in FIG. **5**. They are a cathode **10** connected to the negative pole of a d.c. power source, an anode **11** connected to the positive pole of the d.c. power source, a pair of cation exchange membranes **12, 13** interposed between cathode **10** and anode **11** and a porous plug **14** interposed between membranes **12, 13**. Briefly this pump transports a transport fluid (indicated by arrows in FIG. 3) by the phenomenon of electroosmosis. Porous plug **14** carries a negative surface charge relative to the transport fluid and the transport fluid carries a positive surface charge relative to the porous plug **14**. When a voltage difference is applied across anode **11** and cathode **10** the transport fluid will flow through porous plug **14** generally in the direction from anode to cathode as shown by the arrows. The transport fluid flow may be reversed by simply reversing the polarity of the electrodes. Membranes **12, 13** inhibit dendrite growth of electrode material and thus increase the pump's lifetime.

Cathode **10** and anode **11** may be made of conventionally used metal electrode materials such as silver, platinum, copper and the like. Electrodes should be selected which do not produce appreciable amounts of gas through electrolysis and which do not polarize.

The cation exchange materials from which membranes **12, 13** may be made are well known in the art and do not require extensive elaboration. In brief these materials are cross-linked polymer resins of the strong acid type. Preferred resins are the sulfonated cross-linked polystyrene variety which have a high selectivity for ions of the metal forming the electrodes. For instance, if the electrodes are silver, the resin preferably has a high selectivity for silver. It is also desirable that the ion exchange resin be in a salt form corresponding to the metal forming the electrodes, e.g. in the case of silver, in the silver salt form. Commercial resins are normally supplied in an alkali metal salt form and may be transformed to other salt forms by treatment with solutions of such salts, e.g. aqueous silver nitrate in the case of silver.

The composition, porosity, pore size and the thickness of porous plug **14** significantly affect the operation of the pump, namely the potential required to drive the pump, the flow rate and output pressure. A composition which exhibits a high zeta potential relative to the transport fluid is desired. Generally speaking, the higher the zeta potential between the plug and transport fluid the lesser the potential required to produce a given pressure and flow rate. Quartz, glass, ceramics and sulfur are suitable materials for making the plug when used with the transport fluids described below.

Plugs of such materials may be in the form of an integral, interconnected porous network, a porous walled container packed with particles of such materials, a porous matrix in which particles of such materials are dispersed, such as beads of the material in a porous polymer matrix, and the like.

The pore size of the plug will usually be between about 0.004 μ and about 1 μ. The porosity of the plug is not critical and will usually be between about 10 and about 70 percent.

The transport fluid should have a high zeta potential with respect to the plug, high dielectric constant, low viscosity and high specific resistance. The conductivity of the fluid has an inverse relationship to the specific resistance. For this reason the conductivity should be low, that is, less than about 1 millimho/cm, preferably less than 25 micromho/cm. It follows that the transport fluid should be essentially free of even small concentrations of conducting species such as various ions. It is desirable that the zeta potential between the fluid and plug be in the range of about 1 to 100 millivolts, the dielectric constant be between about 10 and 90, the viscosity between about 0.5 and 10 centipoises and the specific resistance about 10^3 to 10^7 ohm cm. Examples of fluids which may be used are distilled water, 1,2-propanediol cyclic carbonate, ethyl alcohol and ethyl alcohol-water mixtures, formamide, furfuraldehyde, nitrobenzene, o-nitrotoluene, acetone, n-propyl alcohol, n-butyl alcohol, benzaldehyde, aniline, propionic acid, chloroform, ether, methyl alcohol, iso-butyl alcohol, methyl ethyl ketone, methyl propyl ketone, methyl acetate, ethylene bromide, benzene, glycerine, allyl alcohol, amyl alcohol, ethyl acetate, ethyl butyrate, amyl acetate, carbon tetrachloride, xylene and turpentine oil.

Once the electrodes, transport fluid and porous plug have been selected, they together with the voltage applied across the electrodes determine the flow rate and the electroosmotic pressure (the actual output pressure of the pump or dispenser is equal to the electroosmotic pressure less any back pressure inherent in the pump or dispenser). The flow rate and osmotic pressure for any given system may be calculated from the basic linear electroosmotic phenomenological equations defining the volume flow of fluid and electrical current through the porus plug **14**, the Onsager relations, the Helmholz-Smoluchowski theorems, Poisseuille's Law, Ohm's Law, the characteristics of the porous plug **14** and the characteristics of the transport fluid. For an embodiment such as the one illustrated in the drawings a flow rate of 0.001 to 1.0 ml/hr at an actual output pressure on the order of at least one atmosphere is desired. The voltage required to produce such flow rates and pressures may also be calculated from the above listed equations, etc. Voltages in the range of 1 to 100 volts will normally be sufficient to generate the above flow rates and pressures.

FIGS. **1–4** show an entire pump unit, generally designated **15**, which embodies the basic elements shown in FIG. **5**. The housing of pump **15** consists of two cylindrical electrode/membrane housing members **16, 17** which are identical in structure and a pair of cylindrical porous plug housing members **18, 19** which are also identical in structure (FIG. 2). All of these housing members should be made of materials from which the transport fluid cannot leach conducting species. Various plastics from which ionic species have been preleached, such as preleached plexiglass, or metals such as stainless steel may be used. conducting metal

Housing member **16** has a cylindrical recess **22** in its inner face **23** into which disc-shaped cathode **10** and disc-shaped membrane **12** snugly fit face-to-face (FIGS. **1** and **2**). A thin ring **24** of a conducting metal such as silver is permanently imbedded in housing member **16** at the periphery of the bottom surface **25** of recess **22** such that ring **24** contacts the entire periphery of cathode **10** when the latter is fit into recess **22**. Inner face **23** is also provided with an O-ring slot **26** for receiving an O-ring **27**. Housing member **16** also has a pair of axial, diametrically opposed bores **28, 29** extending through it. A hollow sleeve **32** made of a conducting metal such as silver, platinum or gold is press fit partially into bore **29**. Sleeve **32** has an integral radial collar **33** which is pressed into contact with a lead wire **34**, also formed of a conductingmetal such as platinum or silver, which is permanently imbedded in member **16** and extends therein from bore **29** to contact with ring **24**. The hollow of sleeve **32** is adapted to receive a lead wire (not shown) from the negative pole of a d.c. power source (also not shown in FIGS. **1–4**). Sleeve **32**, lead wire **34** and ring **24** interconnect cathode **10** with the negative pole of the d.c. power source.

Housing member **16** is further provided with an L-shaped transport fluid flow channel **35** which extends axially into member **16** from face **23** and then radially outwardly therein opening at the radial surface thereof (FIGS. **3, 4**).

As indicated previously housing member **17** is identical in structure to member **16.** Member **17** has a cylindrical recess **36** for receiving anode **11** and membrane **13,** a pair of axial bores **37, 38** which register with bores **29, 28** respectively, an O-ring slot **39** for receiving an O-ring **42** and an L-shaped transport fluid flow channel **43.** Likewise it is provided with an imbedded anode contacting ring **44,** an imbedded lead wire **45** and a metal sleeve **46** within bore **38** for interconnecting anode **11** with the positive pole of the d.c. power source.

Housing members **18, 19** (FIGS. **1** and **2**) hold porous plug **14.** Member **18** has a cylindrical central axial bore **47** extending through it and an inner counterbore **48** thereto. As shown in FIG. **1** one side of the porous plug fits within counterbore **48** and is seated against a shoulder **49** which defines the transition between bore **47** and counterbore **48.** The inner face **52** of member **18** is provided with an O-ring slot **53** for receiving O-ring **54** and the outer face **55** thereof is provided with an O-ring slot **56** for receiving O-ring **27.** Outer face **55** also has a slot at **57** which opens through shoulder **49** into bore **47** and extends radially therefrom into registry (FIG. **1**) with the axial portion of fluid flow channel **35** in housing member **16.** Said slot at **57** and bore **47** are part of the fluid flow passageway through the pump and provide a flow path for fluid exiting from plug **14** to channel **35.** Housing member **18** also has a pair of axial, diametrically opposed bores **58, 59** extending through it which align with bores **28, 29** respectively in member **16** and receive portions of metal sleeves **32, 46** when the pump is assembled (FIG. **1**).

As indicated previously the structure of housing member **19** is identical to that of member **18.** Thus it too has a central axial bore **62** and counterbore **63** thereto which receive the other side of porous plug **14.** Likewise, it is provided with an O-ring slot **64** for O-ring **54,** an O-ring slot **65** for O-ring **42** and a pair of diametrically opposed axial bores **66, 67.** It also has a slot at **68** which opens into bore **62** and extends radially therefrom into registry with the axial portion of fluid flow channel **43** to provide a flow path therefrom to the entrance side of porous plug **14.**

As seen in FIG. **3** pump **15** is assembled and held together in fluid tight engagement by means of six stainless steel bolts **69** (the corresponding nuts are not shown) which are spaced circumferentially about the edge of pump **15** and extend axially therethrough from one side of pump **15** through to its other side. Also as seen in FIGS. **3** and **4** pump **15** is fitted with a pair of stainless steel transport fluid conduits **72, 73** which are received in the other ends of fluid flow channels **35, 43** respectively, in fluid tight engagement therewith and extend outwardly from the pump.

FIG. **6** shows pump **15** connected to a fluid reservoir, generally designated **74.** Conduits **72, 73** interconnect reservoir **74** and pump **15.** The housing of reservoir **74** consists of three housing members **75, 76, 77** the latter two of which are identical in structure. Members **76, 77** hold the transport fluid which is pumped by pump **15** and member **75** holds the fluid to be dispensed. All three members may be made from the same materials as the housing members of the pump.

As seen in FIGS. **7** and **8** member **76** has an elongated, bowl-shaped cavity **78** formed in its inner surface which contains the transport fluid to be pumped by pump **15.** A flow passageway **79** extends from cavity **78** to a fitting **82** which is adapted to receive an end of conduit **73** in fluid tight engagement. Fitting **82** has a channel **83** which interconnects passageway **79** and conduit **73.** Similarly member **77** is provided with an elongated, bowl-shaped cavity **84** which is filled with transport fluid and a flow passageway **85** extending from cavity **84** to a fitting **86** which receives an end of conduit **72** in fluid tight engagement. Fitting **86** has a channel **87** which interconnects passageway **85** and conduit **72.**

Member **75** has a pair of cavities **88, 89** which are identical in shape and volume to cavities **78, 84,** respectively, and which adjoin therewith. The two sets of adjoined cavities (**78/88** and **84/89**) are separated by a pair of fluid impermeable, fliud tight, flexible partitions **92, 93** respectively. Partitions **92, 93** should be made from materials which are compatible with and do not contaminate the transport fluid or the fluid to be dispensed. These partitions may be flexible by virtue of their composition (e.g. the use of deformable or elastomeric polymers such as natural rubber, polyisoprene, polyethylene, vinyl chloride/vinylidene chloride copolymers and the like) and/or their mechanical design (e.g. the use of bellows structures and other conventional mechanically flexible configurations). A fluid passageway **94** leads from cavity **88** to a channeled fitting **95** adapted to receive a dispensing conduit **96.** Likewise a fluid passageway **97** leads from cavity **89** to a channeled fitting **98** adapted to receive a dispensing conduit **99.**

The outer surfaces of member **75** which face members **76, 77** are provided with seal channels **102, 103** which hold seals **104, 105** respectively. The reservoir **74** is assembled and held tightly together by eight stainless steel bolts **106** (and nuts not shown) (FIG. **6**) which extend transversely through elements **77, 75, 76** from one side of reservoir **74** to the opposite side thereof.

Dispensing conduits **96, 99** may be fitted with conventional administration means such as valves, needles, nozzles, catheters and the like.

FIG. **9** illustrates power and control elements which may be used to run the dispenser of FIG. **4.** Everything illustrated with the exceptions of the pump and controller are electronic elements of the type well known or readily designed by persons skilled in the art. The controller may be a human being or a machine which functions to activate the command transmitter. The command transmitter is simply a signal generator which responds to the input from the controller and generates a signal, usually electrical, which is capable of being received by the command receiver. The command transmitter may be integral with the command receiver or remote therefrom (indicated by a curvilinear arrow in FIG. **9**). A remote element might be analogized to the commonly used manually operated remote controls used with television receivers.

The command receiver is powered by the same low voltage d.c. battery which serves as the power source for the pump. (A low voltage battery is employed merely to conserve space.) Both the battery and command receiver are connected to a power (off/on) switch. The command receiver activates the power switch in response to the signal transmitted to it by the command transmitter. The signal may of course be continuous or intermittent with the pattern of intermittency being infinitely variable. With such variety the dispenser may be made to dispense in an infinite variety of patterns.

A d.c.-d.c. converter is interposed between the power switch and the pump. The function of that converter is to take the low voltage power it receives from the low voltage battery via the switch and convert it to a higher voltage. It does this by converting the low voltage d.c. to a.c., transforming the a.c. up to a higher voltage and converting the higher voltage a.c. to d.c. The low voltage battery/d.c. d.c. converter combination is employed rather than a higher voltage battery because it is easier to make a small version of that combination than to make a small version of a higher voltage battery. The output from the converter is transmitted to the pump by appropriate wiring which is engaged by the metal sleeves **32, 46.**

By way of example a pump and dispenser as shown in the drawings were constructed according to the following specifications:

Item	Description
pump housing	preleached lexan
porous plug	porcelain, 0.1 μ pore diameter, 21% porosity, 0.2 cm thick
electrodes	silver-silver chloride
electrode backing ring	silver
lead wire	platinum
metal sleeves (battery contact)	gold plated
cation exchange membrane	sulfonated polystyrene (IONAC MC 3470) treated with $AgNO_3$ 13.5 mils thick
membrane-plug spacing	0.5 mm
reservoir housing	preleached lexan
reservoir cavity volumes (individual)	3 ml
reservoir membranes	vinylchloride/vinylidene chloride copolymer (Saran)
transport fluid	distilled water
fluid dispensed	water
applied potential	50 volts
flow rate	0.3 ml/hr
output pressure	0.7 atm

Once a sufficient potential drop is applied across the electrodes, pumping of transport fluid will begin by the electroosmotic phenomenon described above. Specifically transport fluid will be pumped from cavity **78** via passage **79,** channel **83** and conduit **73** (FIG. **7**) into flow passageway **43** in pump **15** (FIG. **3, 4**). From passageway **43** it flows through the slot at **68** into bore **62,** through plug **14** and into bore **47** (FIG. **1**). It then flows out of bore **47** via the slot at **57** into flow passageway **35.** It exits from the pump via passageway **35** into conduit **72** (FIGS. **3** and **4**) then into cavity **84** in reservoir **74** by way of channel **87** and passage **85** (FIG. **7**). Since cavity **84** is already filled with fluid, the fluid being pumped into it causes flexible partition **93** to deform and displace into adjacent cavity **89** which is filled with the fluid (drug) to be dispensed. Such displacement squeezes the fluid in cavity **89** out of the reservoir via passage **99,** channeled fitting **98** and dispensing conduit **99.** From there it may be administered to a patient or other administration site using well known administration means and techniques.

Because of its symmetry pump **15** may be used to pump transport fluid in a direction reverse to that shown in FIG. **5.** This may be done by simply reversing the polarity of the electrodes, i.e., making cathode **10** an anode and anode **11** a cathode. It is solely for this reason that pump **15** is provided with membrane **13.** Membrane **13** inhibits dendrite growth from electrode **11** towards electrode **10** when the electrode polarity and transport fluid flow are reversed. Otherwise it serves no function and could be eliminated if the pump was intended to pump in one direction only. When the electrode polarity is reversed transport fluid is pumped from cavity **84** of reservoir **74** via passageway **85,** channel **87** and conduit **72** into fluid flow channel **35.** It then passes through the slot at **57** into bore **47** and through plug **14,** exiting into bore **62** on the opposite side of the plug. From bore **62** it flows through the slot at **68** into flow channel **43** and out of pump **15** by way of conduit **73.** Conduit **73** carries it to reservoir **74** where it flows into cavity **78** via channel **83** and passageway **79.** The increase in fluid volume in cavity **78** will ultimately cause partition **92** to distend and displace into cavity **88** thereby displacing fluid (drug) contained therein out of the reservoir by way of passage **94,** channeled fitting **95** and dispensing conduit **96.** Thus, by reversing the electrode polarity the entire charge, that is the contents of both of cavities **88, 89,** may be dispensed.

As mentioned briefly above membrane **12** (and membrane **13** when polarity is reversed) inhibits electrode dendrite growth and prolongs and pump's lifetime. In the system metal from the anode deposits on the cathode. In a low conductivity fluid current distribution on the cathode is not uniform but is localized in spots on the cathode surface. Metal deposits more rapidly on these spots of higher current density to form the needle like dendrites. Dendrite growth occurs in the direction of least resistance between the electrodes and if left unhindered initially occurs axially between the cathode **10** and plug **11.** At the plug the dendrite growth is through the plug's pores—which of course blocks the pores making the plug less porous and less efficient. The dendrite will grow entirely through the plug and then axially therefrom into contact with the anode—which of course short circuits the pump and renders it inoperable.

By placing a cation exchange membrane between cathode **10** and plug **14** the dendrite growth is substantially inhibited. Generally it was found that an increase in membrane thickness increased the inhibition and pump lifetime. The thickness of the membrane in pump embodiments such as for use in the drug dispenser of the drawings will usually be between about 200 microns and 2,000 microns.

It was also found that dendrite growth may be controlled by periodically reversing the electrode polarity in the manner described above. Such reversal also effects a reversal of dendrite growth, thereby shrinking and eroding the dendrites formed during operation of the pump with the original electrode polarity and vice versa. Accordingly it is desirable to periodically reverse the electrode potential if such operation is compatible with other aspects of the pump operation and use.

Denorite growth also may be controlled by operating the pump in an on/off mode. Such control may be effected by limiting the "on" mode to approximately the time it takes the current distribution to localize sufficiently to initiate dendrite growth (this time may be determined empirically for any given system) and maintaining the off mode for a time sufficient to permit ion concentration gradients at the electrodes to randomize to a significant extent.

In the above described dispenser the nature of the fluid being dispensed is not critical. Any flowable liquid, gas or slurry may be charged to the reservoir and dispensed therefrom by the pump **15** as described above. As indicated previously the device illustrated in the drawings was designed particularly for dispensing liquid drugs, solutions of drugs or dispersions of drugs.

Various modifications of the specific embodiments of the invention described above will be obvious to those of skill in the art. For instance other porous plug materials and/or other cation exchange membranes might be employed. Also, the flexible membranes **92, 93** might be replaced with other types of movable barriers such as pistons. Or the pump may be used as a suction pump such as in a fluid sampling device. In such a device the pump is used to create a pressure differential across a moveable barrier contained within a sampling vessel, the differential being employed to suck the desired sample into the vessel. These and other obvious variations are intended to be within the scope and spirit of the following claims.

I claim:

1. An electroosmotic pump for pumping a fluid susceptible to electroosmotic transport comprising:

a. a housing having an inlet for the fluid and an outlet for the fluid;

b. a pair of spaced electrodes disposed within the housing;

c. a d.c. electrical power source connected to the electrodes;

d. a porous body interposed between the electrodes in spaced relationship thereto, the porous body having a fluid entrance surface and a fluid exit surface and being capable of carrying a surface charge of opposite polarity relative to the surface charge of the fluid;

e. a cation exchange membrane interposed between the porous body and the electrode on the fluid exit surface side of said porous body; and

f. a fluid passageway in the housing extending from the inlet to said fluid entrance surface and from said fluid exit surface to the outlet.

2. The electroosmotic pump of claim **1** wherein the pore size of the porous body is between about 0.004μ and about 1μ.

3. The electroosmotic pump of claim **2** wherein the zeta potential between the porous body and the fluid is in the range of about 1 millivolt to 100 millivolts.

4. The electroosmotic pump of claim **2** wherein the porous body is made from quartz, glass, ceramic or sulfur.

5. The electroosmotic pump of claim **1** wherein the cation exchange membrane is made of a cross-linked polymer resin of the strong acid type.

6. The electroosmotic pump of claim **5** wherein the cross-linked polymer resin is a sulfonated cross-linked polystyrene which has a high selectivity for ions of the metal forming the electrodes.

7. The electroosmotic pump of claim **6** wherein the resin is in a salt form corresponding to the metal forming the electrodes.

8. The electroosmotic pump of claim **1** including:

g. a cation exchange membrane interposed between the porous body and the electrode on the fluid exit surface side of the porous body.

9. The electroosmotic pump of claim **8** wherein the pump is generally symmetrical about the porous body whereby the fluid flow through the pump may be reversed by reversing the electrode polarity.

10. The electroosmotic pump of claim **1** including:

g. means connected to said power source for switching said power source on and off in a predetermined sequence.

11. The electroosmotic pump of claim **1** wherein the potential applied across the electrodes from the power source is in the range of 1 volt to 100 volts and the flow rate of fluid through the pump is in the range of about 0.001 ml/hr to about 1.0 ml/hr.

12. The electroosmotic pump of claim **9** including:

h. means connected to said power source for switching said power source on and off in a predetermined sequence and wherein the pore size of the porous body is between about 0.004μ and about 1μ, the zeta potential between the porous body and the fluid is in the range of 1 millivolt to 100 millivolts, the ion exchange membrane is a sulfonated cross-linked polystyrene which has a high selectivity for ions of the metal forming the electrodes and the potential applied across the electrodes from the power source is in the range of 1 volt to 100 volts and the flow rate of fluid through the pump is in the range of about 0.001 ml/hr to about 1.0 ml/hr.

13. A dispenser for dispensing a fluid comprising:

A. an electroosmotic pump for pumping a fluid susceptible to electroosmotic transport comprising:

a. a housing having an inlet for the fluid and an outlet for the fluid;

b. a pair of spaced electrodes disposed within the housing;

c. a d.c. electrical power source connected to the electrodes;

d. a porous body interposed between the electrodes in spaced relationship thereto, the porous body having a fluid entrance surface and a fluid exit surface and being capable of carrying a surface charge of opposite polarity relative to the surface charge of the fluid;

e. a cation exchange membrane interposed between the porous body and the electrode on the fluid exit surface side of said porous body; and

f. a fluid passageway in the housing extending from the inlet of said fluid entrance surface and from said fluid exit surface to the outlet;

B. a source of the fluid to be pumped by the electroosmotic pump connected to said inlet; and

C. a vessel having

a. a first chamber for containing the fluid to be dispensed having an outlet port therefor;

b. a second chamber for receiving the fluid to be pumped by the electroosmotic pump connected to the outlet of the pump housing, and

c. a movable barrier sealingly separating the first chamber from the second chamber and adapted to move in response to an increase in the volume of fluid received in the first chamber so as to dispense a correspoding volume of fluid contained in the second chamber therefrom via the outlet port.

14. The dispenser of claim **13** wherein the movable barrier is a flexible partition.

15. The dispenser of claim **13** wherein the fluid to be dispensed is a drug.

16. The dispenser of claim 13 wherein the pore size of the porous body is between about 0.004μ and about 1μ.

17. The dispenser of claim 16 wherein the zeta potential between the porous body and the fluid is in the range of about 1 millivolt to 100 millivolts.

18. The dispenser of claim 13 wherein the cation exchange membrane is made of sulfonated cross-linked polystyrene which has a high selectivity for ions of the metal forming the electrodes.

19. The dispenser of claim 13 wherein the electroosmotic pump includes:

g. means connected to said power source for switching said power source on and off in a predetermined sequence.

20. The dispenser of claim 13 wherein the potential applied across the electrodes from the power source is in the range of 1 volt to 100 volts and the flow rate of fluid through the pump is in the range of about 0.001 ml/hr to about 1.0 ml/hr.

21. The dispenser of claim 13 wherein the pump is generally symmetrical about the porous body whereby the fluid flow through the pump may be reversed by reversing the electrode polarity, and pore size of the porous body is between about 0.004μ and about 1μ, the zeta potential between the porous body and the fluid is in the range of 1 millivolt to 100 millivolts, the cation ion exchange membrane is made of a sulfonated cross-linked polystyrene which has a high selectivity for ions of the metal forming the electrodes and the potential applied across the electrodes from the power source is in the range of 1 volt to 100 volts and the flow rate of fluid through the pump is in the range of about 0.001 ml/hr to about 1.0 ml/hr and the pump includes:

g. a cation exchange membrane interposed between the porous body and the electrode on the fluid exit surface side of the porous body; and

h. means connected to said power source for switching said power source on and off in predetermined sequence.

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