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ION DRAG PUMPS

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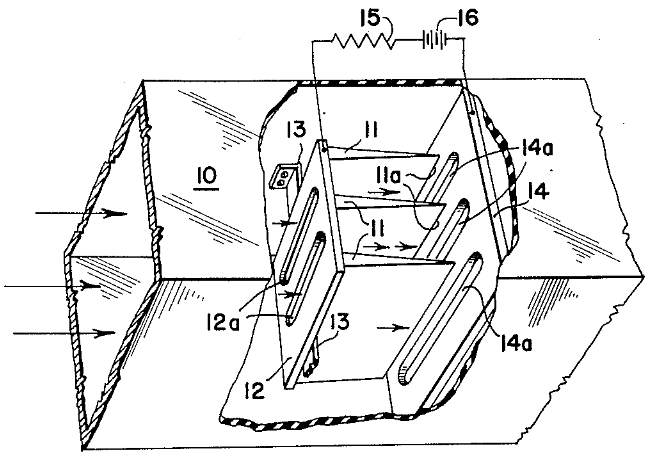

FIG. 1

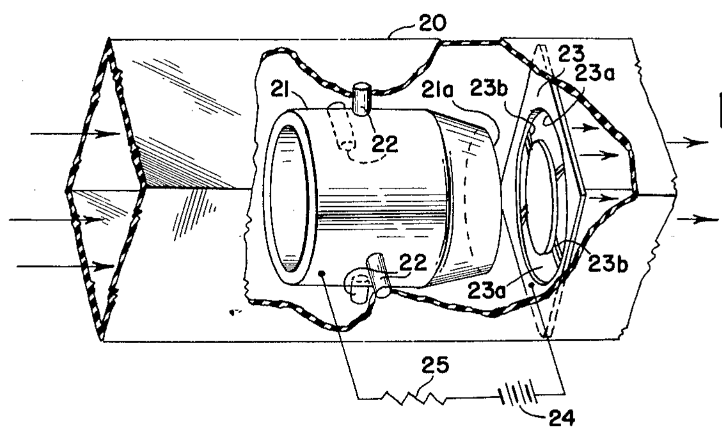

FIG. 2

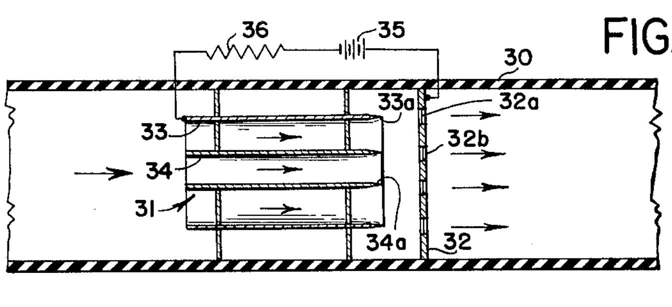

FIG. 3

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ION DRAG PUMPS

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This invention relates to pumps. More particularly, it relates to pumps having no moving parts and being especially suited for continuously pumping insulating liquids.

It is known that insulating liquids can be pumped using the principles of ion drag. One such pump is described in a paper by Otmar M. Steutzer entitled "Ion Drag Pump" published in the Journal of Applied Physics, Volume 31, Number 1, 136–146, January 1960. Ion drag pumps are based on the principle that, when ions in a perfectly ionized medium move under the influence of an electric field, friction with the carrier medium transfers momentum to the latter. If ions of only one polarity are present, appreciable pressure may be created by this means.

Applying ion drag principles to a pump for insulating liquids involves increasing the concentration of ions present in the liquid. The increased concentration of ions is accelerated by an electric field and under its effect the ions move in one relative direction. As they move, the ions frictionally engage molecules of the insulating liquid and drag them in a direction approximately parallel to the lines of force of the electric field. Thus, momentum and movement are imparted to the liquid and it is, in effect, pumped.

The means for injecting electrons into the liquid and causing them to move under the influence of an electric field generally comprises one or more emitter electrodes and one or more collector electrodes, with a source of high potential connected between the emitter and collector electrodes. The present invention is directed toward providing such an ion drag pump which embodies an improved electrode structure.

Heretofore, ion drag pumps have generally employed a pointed emitter electrode arranged opposite a small opening in the collector electrode. In a device requiring a flow rate greater than that available from a single point emitter electrode, several points have been mounted in parallel. For a multi-point stage to function well the points must be made and positioned uniformly. If a few points are sharper or duller than others, or closer to or farther from the opposing electrodes than the others, they will carry most of the current or practically none. In either case the pressure head built up by the current-carrying points causes reverse flow at the other points, thus decreasing the output power and efficiency. Even though current-limiting resistors are used, arcing will in time cause changes in the emitter electrodes which result in decrease in efficiency. Any particles which may have entered the insulating fluid from the outside or have been generated through polymerization by the high electric field strengths tend to clog the small holes in the collector electrode. The present invention provides an electrode structure wherein the aforementioned difficulties are either obviated or greatly reduced.

Broadly speaking, the present invention provides a pump for insulating liquids, comprising an emitter electrode positoned in the flow path of the liquid and having two surfaces converging in the direction of flow to a razor edge. A collector electrode is positioned in the flow path adjacent the razor edge and has an aperture substantially aligned with the edge. Of course, a potential source is

connected between the electrodes for establishing ionization and a high field strength in the insulating liquid between the electrodes.

The invention will be better understood by reference to the following description of several embodiments, taken in conjunction with the accompanying drawing, in which

FIGS. 1 and 2 are diagrammatic perspective views, with parts broken away to show the electrode structure more clearly, of two embodiments of the invention; and

FIG. 3 is a diagrammatic sectional view of another embodiment of the invention.

As used herein, the term "insulating liquid" includes both those liquids that are truly insulating and those that are poorly conducting. Examples of such liquids are lubricating oil, machine oil, silicone oil, castor oil, octane and kerosene, to name but a few.

FIG. 1 illustrates an embodiment of the invention including a duct **10** which may conveniently be made of an insulating material. Although the duct **10** is shown as being rectangular in cross section, its particular shape is of no great importance and the pump of the invention may be modified to fit into ducts of various shapes. The duct **10** defines the flow path for the insulating liquid to be dumped.

Mounted within the flow path defined by the duct **10** are a plurality of emitter electrodes **11** secured to a mounting plate **12**. Each of the emitter electrodes **11** has two surfaces which converge in the direction of flow to a razor edge **11***a*. As used herein, the term "razor edge" is taken to mean an edge having a radius of approximately one micron. In practice, it has been found that ordinary razor blades may be used quite successfully for the emitter electrodes **11**.

The bases of the emitter electrodes **11** are secured by conventional means, such as soldering or welding, to the conductive base plate **12**. The base plate **12** is provided with slits **12***a* between the emitter electrodes to permit fluids to flow easily through the plate and between the electrodes. The mounting plate **12** may be secured in the duct **10** by any suitable conventional means, such as brackets **13**.

A collector electrode **14** is mounted in the duct **10** by conventional means and is positioned in the flow path adjacent the razor edges **11***a* of the emitter electrode. The collector electrode **14** is provided with a plurality of apertures **14***a*, there being the same number of apertures as emitter electrodes. Each aperture **14***a* conforms in general shape to the razor edge **11***a* of the emitter electrode, but is wider than the razor edge to permit free flow of liquid through the aperture. In the present case, because the razor edges **11***a* are straight, the apertures **14***a* take the shape of slits, with an aperture being substantially aligned with each razor edge. The collector electrode **14** substantially completely obstructs the flow path, except for the apertures **14***a* through the electrode, this prevents reverse flow around the electrode and also builds up pressure in the liquid. Thus, the velocity of the liquid moving through the apertures is increased, which aids in flushing dirt particles out of the apertures and generally keeps the collector electrode clean.

A current-limiting resistor **15** and a direct high potential source **16** are connected in series between the emitter electrode **11** and the collector electrode **14**.

In operation, a high strength electric field is established between the electrodes **11** and **14** when they are connected to the voltage source **16**. With the formation of that electric field, electrons are injected from the cold (as opposed to thermionic) emitter electrodes into the insulating liquid in the space between the razor edges **11***a* of the emitter electrodes and the collector electrode **14**. These electrons increase the number of ions present in the liquid in that area by ionizing a small percentage of the liquid. The ions thus formed are accelerated by the electric field and under its effect move toward the collector electrode. As they move, these ions engage molecules of the insulating liquid and, due to friction between the ions and the molecules, the molecules are dragged toward the collector electrode 14. Thus, momentum and movement are imparted to the insulating liquid in the direction shown by the arrows (left to right). The theory underlying this phenomenon is explained in detail in the above-mentioned technical paper and, therefore, will not be treated here.

In a particular example, the emitter electrodes might be of the order of 20 millimeters long, the slits 14*a* in the collector electrode might be of the order of 1 millimeter wide or less, and the razor edges spaced from the slits by a distance about equal to twice the slit width or less. The voltage applied between the electrodes should be sufficient to induce corona discharge there between, but be less than that which would cause a spark to appear in the particular insulating liquid. In practice, it has been found that 5–15 kv. are generally required to accomplish the desired results. The current-limiting resistor should be of a value to limit current flow to the order of 1000 microamperes or less.

Although an arrangement utilizing three emitter electrodes is illustrated, the invention is not limited to any particular number of electrodes. Flow rate requirements will generally dictate the number of electrodes used.

FIG. 2 illustrates an embodiment of the invention which differs from that shown in FIG. 1 in that the straight emitter electrode having a straight razor edge has been replaced by a cylindrical emitter electrode having a circular razor edge. The flow path for the insulating liquid to be pumped is defined by a rectangular duct 20. Again, as in the embodiment previously described, the duct may be made of an insulating material and its cross-sectional shape is of no particular importance.

A cylindrical emitter electrode 21 is mounted within the duct 20 by means of supports 22. The cylindrical emitter electrode 21 has two surfaces which converge in the direction of flow to a circular razor edge 21*a*. Arranged adjacent the razor edge 21*a* in the flow path is a collector electrode 23, which substantially completely obstructs the flow path except for a circular aperture 23*a* therein. The circular aperture 23*a* is substantially aligned with the circular razor edge 21*a*, but, of course, is wider than the razor edge to permit the flow of liquids through the aperture. In order to support the central portion of the collector electrode 23, several narrow strips 23*b* may be soldered across the aperture to the backs of the central and outer portions of the collector electrode.

A direct high potential source 24 and a current-limiting resistor 25 are connected in series between the emitter electrode 21 and the collector electrode 23. If desired, one side of the high potential source 24 may be grounded.

The operation of the pump shown in FIG. 2 is very similar to that of the pump shown in FIG. 1. Electrons are emitted from the cold emitter electrode 21 and ionize a portion of the insulating liquid between the emitter electrode 21 and the collector electrode 23. The ions of the liquid, under the influence of the high electric field existing between the electrodes, travel toward the collector electrode 23. Those ions frictionally engage molecules of the insulating liquid and carry the liquid along the flow path and through the aperture 23*a* in the collector electrode 23. Thus, the insulating liquid is pumped along the flow path in the direction shown by the arrows.

In the event that a greater rate of flow is required than can be provided by the single-electrode pump shown in FIG. 2, the modification shown in FIG. 3 may be utilized. In that embodiment, a duct 30 contains an emitter electrode structure, indicated generally by the numeral 31, and a collector electrode 32. The emitter electrode structure 31 comprises a plurality of concentrically arranged cylindrical emitter electrodes 33 and 34. Each of the concentric electrodes 33 and 34 may be like the electrode 21 described with reference to FIG. 2, and they are provided with circular razor edges 33*a* and 34*a*, respectively, by two surfaces that converge in the direction of flow.

The collector electrode 32 is positioned adjacent the razor edges 33*a*, 34*a*, and is provided with a plurality of concentric circular apertures 32*a* and 32*b*, an aperture being substantially aligned with each circular razor edge of the emitter electrode. The collector electrode again substantially completely obstructs the flow path except for the apertures 32*a*, 32*b*. Although two emitter electrodes and two circular apertures in the collector electrode are shown, the invention is in no way limited to any particular number of concentric emitter electrodes and the number may be increased as the required rate of flow necessitates.

Again, as in the previously described embodiments, a direct high potential source 35 and a current-limiting resistor 36 are connected in series between the emitter electrode structure 31 and the collector electrode 32.

The operation of the embodiment of the pump shown in FIG. 3 is very similar to that shown in FIG. 2. It differs primarily in that a higher rate of flow may be obtained from the parallel pump section shown in FIG. 3 than from the single section shown in FIG. 2.

The particular advantage of the embodiments of the pump shown in FIGS. 2 and 3 over that shown in FIG. 1 is in ease of manufacture. The cylindrical and concentric arrangements shown in the latter two figures are inherently easier to manufacture than is the linear arrangement shown in FIG. 1. Otherwise, there is little difference between the various embodiments; they all require approximately the same value of high potential and the same value of current-limiting resistor for their satisfactory operation.

If it is desired to increase the rate of flow of the liquid, more sections may be arranged in parallel in the fashion shown in FIGS. 1 and 3. Similarly, if it is desired to build up more pressure without increasing the flow rate, several sections may be arranged in series in the flow path.

It has been found in practice that it is relatively easy to position the uniformly sharpened edge emitters accurately enough so the current is quite evenly distributed over the length of the edge. Also it has been found that the razor edge emitter electrodes are less susceptible to damage from arcing than are the point electrodes heretofore used. The apertures in the collector electrodes may be made sufficiently large that any particles that might tend to be caught in the collector electrodes are flushed out very quickly by the fluid flow past them on either side.

Although several embodiments of the invention have been described, it is apparent that many modifications may be made by one skilled in the art that will fall within the true scope and spirit of the invention.

What is claimed is:

1. Apparatus for continuously pumping an insulating liquid comprising means defining a flow path for the liquid, a cold emitter electrode positioned in said flow path, said emitter electrode consisting of a thin blade having two surfaces converging in the direction of flow to a razor edge, a collector electrode positioned in and substantially coextensive with said flow path adjacent said razor edge and provided with an aperture having a configuration corresponding to said razor edge and substantially aligned with said razor edge, and means connected between said electrodes for establishing ionization and a high field strength in the insulating liquid between said electrodes.

2. The apparatus defined by claim 1, wherein said razor edge is circular in shape.

3. The apparatus defined by claim 1, wherein said razor edge and said aperture are circular in shape with said aperture being wider than said edge to permit the flow of liquid through said aperture.

4. The apparatus defined by claim 3, wherein said collector electrode substantially completely obstructs said flow path except for said aperture in said electrode.

5. Apparatus for continuously pumping an insulating liquid comprising means defining a flow path for the liquid, a plurality of cold emitter electrodes positioned in said flow path, each said emitter electrode consisting of a blade having two surfaces converging in the direction of flow to a razor edge, a collector electrode positioned in and substantially coextensive with said flow path adjacent said razor edges and having a plurality of apertures, an aperture being substantially aligned with each said razor edge and having a configuration corresponding to said razor edge, and means connected between said emitting electrodes and said collector electrode for establishing ionization and a high field strength in the insulating liquid between said electrodes.

6. Apparatus for continuously pumping an insulating liquid comprising means defining a flow path for the liquid, a plurality of cylindrical cold emitter electrodes concentrically arranged and positioned in said flow path, each said emitter electrode having two surfaces converging in the direction of flow to a circular razor edge, a collector electrode positioned in said flow path adjacent said razor edge and having a plurality of circular concentric apertures, one said circular aperture being substantially aligned with each said circular razor edge, and means connected between said emitting electrodes and said collector electrodes for establishing ionization and a high field strength in the insulating liquid between said electrodes.

7. The apparatus defined by claim 6, wherein said collector electrode substantially completely obstructs said flow path except for said apertures in said electrode.

8. Apparatus for continuously pumping an insulating liquid which comprises:

means defining a flow path for the liquid;

a cold emitter electrode positioned in said flow path, said emitter electrode comprising a thin blade having two surfaces converging in the direction of flow to a straight razor edge;

a collector electrode positioned in said flow path adjacent said razor edge, said collector electrode comprising a solid plate for substantially completely obstructing said flow path, said plate having a slit formed therethrough substantially aligned with said razor edge, said slit being wider than said razor edge to permit passage of said liquid in said flow path; and

means connected between said electrodes for establishing ionization and a high field strength in the insulating liquid between said electrodes.

9. Apparatus for continuously pumping an insulating liquid, which comprises:

conduit means defining a flow path for said liquid;

a plurality of cold emitter electrodes positioned in said flow path, each of said emitter electrodes including a thin blade having two surfaces converging in the direction of flow to a straight razor edge, said straight razor edges being aligned in a common plane extending transversely across said flow path;

a collector electrode including a plate having a flat surface positioned parallel to said plane for substantially obstructing said flow path, said plate having an elongated slit therethrough opposite to each of said razor edges; and

means connected between said emitter electrodes and said collector electrode for establishing ionization and a high field strength in said insulating liquid between said razor edges and said collector electrode to produce substantially equal pressure across each of said slits.

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