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(54) REVERSE OSMOSIS METHOD AND APPARATUS

(71) I, BOWIE GORDON KEEFER, a Canadian Citizen, of 4324 West 11 Avenue, Vancouver, British Columbia, Canada, V6R 2M1; do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates generally to reverse osmosis and ultrafiltration fluid separation processes, and is applicable particularly to water desalination and purification by reverse osmosis.

Desalination by reverse osmosis is achieved by pumping a feed stream of saline water at an elevated working pressure into a pressure resistant vessel containing an array of semi-permeable membranes. Purified product water of greatly reduced salinity permeates across the membranes into low pressure collection channels if the working pressure exceeds feed stream osmotic pressure. Considerably excess working pressure above the feed stream osmotic pressure is required to produce sufficient product water flux across membranes of reasonable surface area, and also to ensure sufficient dilution of the small but finite salt diffusion through the membrane which always exists when there is a concentration gradient across such membranes. For sea water whose osmotic pressure is about 25 Kg/sq. cm, typical working pressure for single stage reverse osmosis is in the order of 70 Kg/sq. cm.

While some of the feed stream permeates through the membranes, the balance becomes increasingly concentrated with salt rejected by the membranes. In a continuous reverse osmosis process, a concentrate stream must be exhausted from the vessel to prevent excessive salt accumulation. In sea water desalination, this concentrate stream may be typically 70% and sometimes as much as 90% of the feed stream. The concentrate stream leaves the vessel at almost full working pressure, but before the concentrate stream is exhausted from the apparatus, it must be depressurised. In common reverse osmosis apparatus the concentrate stream is depressurised by throttling over a suitable back presure valve, for example a restrictor valve, which regulates the working pressure while dissipating all the pressure energy of the concentrate stream. It is known to recover some of the concentrate stream pressure energy using recovery turbine devices, however such energy recovery devices have mostly seemed practicable only for large stationary plants where efficiency and economy advantages of scale would apply.

Without energy recovery devices, small scale manually operated reverse osmosis desalinators for use in households, life-boats, etc. would be almost unpracticable. Similarly, using wind power for desalination is discouraged by high energy consumption.

Furthermore, for high recovery concentration polarisation must be controlled. Concentration polarisation in the feed stream is the tendency for a concentration gradient to develop in the feed stream with high salt concentration on the membrane face during reverse osmosis. This tendency results from the bulk transport of saline feed water toward the membrane face and the accumulation of salt in the boundary layer as less saline water permeates through the membrane, balanced by diffusion of salt back out of the boundary layer. Concentration polarisation is detrimental especially with feed solutions of high osmotic pressure such as sea water, because the membrane sees a higher concentration which raises the effective osmotic pressure. When concentration polarisation occurs, working pressure for given product flux must be increased, product salinity will be increased, and membrane life may be impaired.

Reverse osmosis systems are typically designed to reduce concentration polarisation effects by forced convection through the membrane array. Forced convection may be provided by circulating a low ratio of product flow to concentrate flow through suitably configured feed channels between the membrane faces, or by auxiliary recirculation or mechanical stirring devices. It is essential that continuous feed circulation be maintained through the membrane array, because even momentary stagnation of flow may cause severe concentration polarisation.

Operation at low ratios of product flow to concentrate flow is also generally favourable to the reduction of concentration polarisation effects, but of course increases the feed pumping energy expenditure for given product flow delivery.

The invention enables reverse osmosis to be reached with low energy consumption, particularly for manually operated or wind driven desalination devices. Concentration polarisation effects are reduced by providing surge reducing means to maintain the continuity of fed flow circulating past the membranes, and by enabling operation at a low ratio of product flow to concentrate flow without excessive energy consumption normally associated with large feed flows. The device provides simple and effective control of directional valve timing which facilitates recovery of fluid pressure energy from the concentrate stream. All embodiments described have dwell means to increase tolerance to valve actuation, thus simplifying manufacture and servicing.

According to the present invention there is provided membrane separation apparatus for separation of a feed fluid into permeate fluid and concentrate fluid fractions which respectively are permeated and rejected by selective membrane means, the apparatus including: reciprocating pump means having a cylinder, a movable piston means and piston rod means, the piston means dividing the cylinder into a pumping chamber for the feed fluid and an expansion chamber for the concentrate fluid fraction, the piston rod means extending through the expansion chamber, the cylinder and piston rod means having relative diameters which define cylinder/piston rod proportions to determine in part recovery ratio of permeate fluid fraction to total feed fluid flow; inlet conduit means to admit feed fluid into the pumping chamber, outfeed conduit means to conduct feed fluid from the pumping chamber to the membrane means, and return conduit means to conduct concentrate fluid fraction from the membrane means to the expansion chamber; surge reducing means connected to at least one of said conduit means to reduce fluctuations in pressure and feed fluid flow across the membrane means; first valve means communicating with the expansion chamber and having a closed intermediate position between first and second positions, and non-return second valve means communicating with the pumping chamber, the first valve means co-operating with the conduit means to direct fluid flow to and from the expansion chamber of the pump; and reciprocable mechanical drive means mechanically connected to the pump means and the first valve means to apply a reciprocatory action to the pump means and to the first valve means so that in the first position of the first valve means pressurised feed fluid from the pumping chamber is fed to the membranes through the second valve means while concentrate fluid is discharged into the expansion chamber through the first valve means, so that depressurisation of the concentrate fluid returning from the membrane means assists in pressurising of the feed fluid; and in the second position of the first valve means depressurised concentrate fluid is exhausted from the expansion chamber through the first valve means while feed fluid is inducted into the pumping chamber through the second valve means; wherein the apparatus incorporates dwell means associated with the pump means and the first valve means the dwell means being arranged so that the reciprocatory force transmitted to the pump means is reacted in part by the first valve means so that reversal of force reverses the valve means and so that a hydraulic bias effect acts on the piston means to inhibit relative motion of the piston means in one direction, as determined by the position of the first valve means, and to permit relative piston motion in the opposite direction, so that following reversal of the force applied to the pump means, the first valve shifts between the first and second position thereof prior to reversal of pumping action, to ensure that the first valve means is shifted during an interval of substantially zero fluid transfer to or from the expansion chamber.

The invention also provides a method of membrane separation of a feed fluid into permeate fluid and concentrate fluid fractions which respectively are permeated and rejected by selective membrane means, the membrane means being exposed to pressurised feed fluid supplied by a reciprocating pump means having a cylinder and piston means and co-operating with valve means in conduit means, the piston means dividing the cylinder into a pumping chamber in which feed fluid is pressurised and an expansion chamber in which the concentrate fluid is depressurised; the method including steps of: simultaneously inducting feed fluid into the pumping chamber and exhausting depressurised concentrate fluid from the expansion chamber, followed by simultaneously pressurising the feed fluid in the pumping chamber and admitting pressurised concentrate fluid into the expansion chamber to supplement energy supplied to the piston in the pumping stroke; the method being characterised by: reversing direction of force applied to the pump means and simultaneously hydraulically biasing the piston means against movement due to reversal of force so that reaction to reversal of force is transmitted to the valve means causing the valve means to shift in preference to relative piston means movement so as to mechanically shift the valve means to direct fluid flow between the pump means and the membrane means, the transfer of reaction forces causing a dwell period so that the valve means shifts across a closed intermediate position thereof during an interval of substantially zero fluid transfer in the expansion chamber thus incurring timely valve shifting.

The term "piston means" is used herein as a general term for a piston or diaphragm, and in one embodiment the piston means comprises a diaphragm.

The invention will be described further, by way of example, with reference to the accompanying drawings, wherein:

Figure 1 is a simplified section through a manually powered embodiment of a lever actuated reverse osmosis apparatus according to the invention;

Figure 2 is a fragmented section of an alternative valve means for the apparatus;

Figure 3 is a fragmented section of a second form of piston means for use in the apparatus shown in Figure 1;

Figure 4 is a detailed fragmented section of an alternative differential surge absorber for use in the apparatus shown in Figure 1;

Figure 5 is a simplified fragmented section of a third embodiment of a piston means with dwell means incorporated therein;

Figure 6 is a simplified section showing a fourth embodiment of a piston means with dwell means incorporated therein;

Figure 7 is a simplified elevation, partially in section, of a wind powered embodiment of the apparatus of Figure 1; and

Figure 8 is a schematic of a lever actuated apparatus of the invention having two cylinders.

The directions "upwards" and "downwards" refer to the figures as drawn, but clearly the apparatus could be in other orientations.

A first embodiment 10 of a lever actuated membrane separation apparatus, shown in Figure 1, includes a reciprocating pump means 12, a directional three-way valve means 13, a drive means 14 mechanically connected to the pump means and valve means, and a differential surge absorber 15. The apparatus further includes a membrane vessel 16 containing semi-permeable membrane means 17, and optional low and high pressure filters 18 and 19. Feed fluid 21 is separated into a permeate fluid fraction 22 and a concentrate fluid fraction 23 which are respectively permeated and rejected by the membrane means.

The reciprocating pump means 12 has a pump cylinder 24 and a movable piston means 25, the piston means dividing the cylinder into a pumping chamber 27 in which the feed fluid is pressurised, and an expansion chamber 28 in which the concentrate fluid is depressurised. The piston means co-operates with a piston rod means 32 extending through the expansion chamber, and sealing means 30 and 33 prevent mixing and leakage of fluid. The cylinder 24 and thus the piston means 25, and the piston rod means 32 have relative diameters which define piston rod/cylinder proportions such that a ratio of the swept volume of piston rod means to swept volume of the piston means determines recovery ratio of the permeate fluid fraction to the total fluid fraction. Alternatively, the recovery ratio can be defined in terms of displacement ratio of the piston rod means to the piston means. Inlet conduit means 36 admits feed fluid 21 to the pumping chamber 27 from a conduit portion 35 immersed in feed fluid, *via* a non-return check valve 37 and the filter 18, whilst the valve 37 prevents return flow from the chamber imto the conduit portion 35. Outfeed conduit means 39 connects the pumping chamber with the membrane 17 via the differential surge absorber 15 and filter 19 to conduct pressurised feed fluid from the pumping chamber to the membrane means, a non-return check valve 40 preventing return flow of fluid into the pumping chamber.

The outfeed conduit means 39 consists of a conduit portion 41 extending between the differential surge absorber 15 and the pumping chamber, a conduit portion 42 extending between the differential surge absorber and the filter 19, and a conduit portion 43 extending from the filter 19 to the membrane vessel means. A return conduit means 44 connects the membrane means with the expansion chamber 28 to conduct the concentrate fluid fraction from the membrane means to the expansion chamber 28. The means 44 has a conduit portion 45 extending between the differential surge absorber 15 and the membrane vessel 16, and a conduit portion

46 extending between the directional valve means 13 and the differential surge absorber 15. The valve means 13 has a vent conduit 47 to conduct the concentrate fluid fraction 23, usually to waste, and a connecting conduit 48 communicating with the expansion chamber 28.

The valve means 13 is a three-way directional control valve and has a sliding valve spool 49 having linear travel limited by lower and upper stops 50 and 51 which determine upper and lower limits of travel of the spool respectively, the spool being shown in the upper limit of travel in which the conduit portion 46 is connected with the connecting conduit 48 to conduct the concentrate fluid fraction from the membranes to the expansion chamber. In a lower limit of travel, not shown, the connecting conduit 48 is connected to the vent conduit 47 as will be described. Because water has low viscosity and lubricity, the spool 49 is fitted with dynamic sealing rings 52 of suitable composition, for example glass-filled fluorocarbon polymeric compounds to minimise leakage and prevent spool seizure. Thus, the valve assembly 13 is a two-position, centre-closed, three-way valve having a movable spool, the spool having travel between two positions through a closed intermediate position to interchange conduit connections, the travel being limited by stops. The valve means 13 directs fluid to or from particular conduits communicating with the expansion chamber 28, and is termed a first valve means. The non-return valves 37 and 40 control flow in conduits communicating with the pumping chamber 27 and are termed second valve means. As will be described, the first and second valve means co-operate with the conduit means so as to direct fluid flow from the fluid source and to and from the membrane means, and clearly alternative first and second valve means can be substituted.

The drive means 14 includes a manually operated lever 54 having an inner end hinged on a hinge pin 55 which is carried at an outer end of the piston rod means 32. A link 57 is pinned at one end with a pin 58 to the lever 54 and at an opposite end with a pin 59 to an outer end of the spool 49. It can be seen that reciprocation action applied to the lever 54 in an arc shown by a double headed arrow 61 results in corresponding linear movement of the piston rod means 32 and the spool 49, relative shifting of the spool and piston rod being dependent on leverage and resistance to motion of the piston means and the spool. The position of the spool 49 determines a hydraulic bias effect on the piston means 25 such that the spool 49 must shift before the piston can reverse. The hydraulic bias inhibits piston movement in one direction and permits the piston means to move relatively easily in the opposite direction, the direction being determined by the spool 49 as follows. When the conduits 46 and 48 are connected, upwards movement of the piston means is resisted by concentrate fluid in the chamber 28 which pressure assists in downwards movement of the piston. When the conduits 47 and 48 are connected, downwards movement of the piston is resisted by the check valves 37 and 40, whereas upwards movement is relatively easy due to vent pressure in the chamber 28. Thus, when the spool is in the upper position as shown in Figure 1, swinging the lever 54 downwards shifts the spool to the lower position before the piston moves within the cylinder, and vice versa for opposite swinging of the lever. The hydraulic bias causes the piston rod to serve as a temporary fulcrum for the lever, and thus provides dwell, which is of major importance to operation of the invention because the valve spool must shift between its two limits when the piston is stationary because the fluid is essentially incompressible and damage would likely result if the piston shifted before the spool had interchanged connections.

The differential surge absorber 15 has a cylinder 65 and a piston means 64, the piston means dividing the cylinder 65 into a concentrate surge absorber chamber 66 and a feed surge absorber chamber 67. The piston means co-operates with a piston rod means 69 extending through the concentrate surge absorber chamber 66 and has sealing means 70 and 71 to prevent mixing and leakage of fluid. For smooth operation of the surge absorber the seals are selected for low friction characteristics. A compression coil spring 72 encloses the piston rod means and extends between the piston means 64 and the chamber so that the piston means is effectively spring-loaded and double-acting and reciprocable within the cylinder. Thus, the spring means co-operates with the piston means to force the piston means in a direction to exhaust the feed surge absorber chamber. The feed surge absorber chamber 67 is exposed to pressurised feed fluid in the portion 41 of the outfeed conduit 39 and also communicates with the membrane vessel 16 through the conduit portions 42 and 43. The concentrate surge absorber chamber 66 is exposed to the concentrate fluid fraction in the conduit portion 45 of the return conduit means 44 and also communicates with the valve assembly 13 through the portion 46.

The piston rod means 69 and the cylinder 65 of the surge absorber 15 have relative diameters similar to the piston rod/cylinder proportions of the pump means, but have a displacement several times greater and thus can accommodate the recovery ratio of the permeate fluid fraction to the total fluid fraction. The key feature of the differential surge absorber is rigid coupling of the concentrate and feed surge absorber chambers 66 and 67 with a ratio similar to that of the pump means 12, i.e. a similar displacement ratio so as to serve as a load leveller for the pump means. The spring 72 is relatively small and the piston rod means 69 is of relatively small area when compared with the piston means 64, and the differential surge absorber is charged to full effectiveness within a few pump strokes when starting up. It should be noted that extension of the piston rod means 69 from the surge absorber provides a visual indication of hydrostatic pressure of the system by its position at any instant. Piston rod/cylinder area proportions or displacement volumes can be within the range of 1:10 and 1:2 for practical recovery ratios.

The membrane means 17 are housed in the membrane vessel 16 in suitable arrays known in the art and a low pressure product channel 76 receives product water from the membranes which is discharged through product conduit 77. The geometry of the membrane arrays in the membrane container vessel is designed to ensure sufficient forced convection of the feed fluid to prevent excessive concentration polarisation effects. If the feed fluid flow velocity is dropped too low, concentration polarisation effects can become severe.

Referring to Figure 1, as the lever 54 is swung manually upwards about the hinge pin 55, the valve spool 49 is held in its uppermost position against the lower stop 50, closing the vent conduit 47 and connecting the conduit portion 46 with the connecting conduit 48 so as to pass the pressurised concentrate fluid fraction from the membrane vessel 16, through the chamber 66 of the differential surge absorber, through the valve assembly 13 into the expansion chamber 28 to act on a rear face of the piston means 25. The force from the concentrate fluid in the chamber 28 augments force from the lever 54 and the piston means simultaneously travels downwards in the pump cylinder 24 in direction of arrow 74 to pressurise feed fluid in the chamber 27. The check valve 37 is held closed by the feed fluid pressure and the check valve 40 is open to transmit pressurised feed fluid from the pumping chamber 27 through the conduit portion 41 into the feed surge absorber chamber 67 of the differential surge absorber 15. Pressurised feed fluid from the chamber 67 passes through the conduit portion 42, through the high pressure filter 19 and the conduit portion 43 into the membrane vessel 16. The permeate fluid fraction is permeated by the membrane means and passes into the low pressure product channels 76 to be collected from the product conduit 77. The concentrate fluid fraction is rejected by the membrane means and passes through the conduit portion 45 into the concentrate surge absorber chamber 66, through the conduit portion 46 and the valve assembly 13 into the expansion chamber 28. The concentrate fluid pressure acts on the rear face of the piston means 25 and hydrostatic pressure energy of the concentrate fluid can be utilised, permitting recovery of a substantial portion of the energy in the feed fluid. Pressure of the concentrate fluid in the expansion chamber 28 is only slightly less than pressure of feed fluid in the pumping chamber 27 and thus, taking into consideration the reduced area of the rear face of the piston upon which pressure of the concentrate fluid acts, an operator has to supply only a fraction of the power that would have been required without energy recovery.

Reversing the reciprocation action manually applied to the lever 54, that is pushing the lever downwards, swings the lever about the hinge pin 55 of the piston rod means which serves a fulcrum because the hydraulic bias on the piston means prevents initial upwards movement of the piston means, so that the initial downwards movement of the lever causes the valve spool 49 to move downwards until the downwards movement is limited by the stop 51. In this position, the conduit portion 46 is closed, thus isolating the valve from the surge absorber 15, and the vent conduit 47 is open and communicates with the connecting conduit 48, and is thus exposed to fluid in the expansion chamber 28. When the spool stops, the hydraulic bias is now reversed and the piston means 25 can move upwards on a return stroke, that is opposite to direction of the arrow 74, as the lever is pushed further downwards, and the check valve 37 opens to induct feed fluid into the pumping chamber 27 and the check valve 40 closes preventing return flow of fluid from the differential surge absorber. It can be seen that the first valve means is responsive to force applying the reciprocation action to the pump means in such a manner that the reciprocating force transmitted to the pump means is reacted in part by the first valve means. Upwards movement of the piston means also forces concentrate fluid from the expansion chamber through the valve assembly and the vent conduit 47, usually to waste.

As pressure in the feed surge absorber chamber 67 drops slightly as a result of continuing permeation of product water through the membrane means 17, the spring 72 forces the differential surge absorber piston means 64 downwards towards the conduit portions 41 and 42. Force from the spring 72 is augmented by pressure of concentrate fluid from the membrane means flowing into the concentrate surge absorber chamber 66 and acting on the rear face of the piston means 64. Downwards movement of the piston means 64 of the differential surge absorber maintains a flow of feed fluid into the membrane vessel and across the membrane means, thus tending to reduce concentration polarisation effects that would otherwise occur. Thus, stagnant flow conditions on the concentrate fluid side of the membrane means during the return stroke of the pump means are reduced and there is sufficient displacement of the piston means 64 to maintain adequate flow through the membrane vessel throughout the return stroke. It can be seen that the differential surge absorber 15 serves as a means communicating with the membrane means to provide essentially uniform pressure and feed fluid flow across the membranes during operation of the apparatus. The differential surge absorber communicates with the outfeed and return conduit means and is interposed between the membrane means and the first and second valve means to absorb pressure fluctuations while providing essentially uniform feed fluid flow across the membranes.

Upon reversal of the reciprocation action again, the valve assembly shifts before the piston means changes direction and the operation as previously described will be repeated. Note that the piston means 25 of the pump chamber does not have to travel full stroke of the pump cylinder 24 prior to reversal of piston action, i.e. reversal of pump stroke can occur anywhere in the cylinder 24. Thus, the operator may reverse the lever stroke at any point in its arc of travel as the apparatus is insensitive to the positional limits of lever travel. Because the valve means 13 shifts as a direct result of reversal of reciprocating action applied to the lever, and it always shifts before reversal of pump action because of hydraulic bias which causes the spool 49 to be moved more easily in a particular direction than the piston means 25, the first valve means always shifts in a period when the piston rod means is stationary and there is therefore zero displacement of fluid from the expansion chamber. This is essential for operation of the device as premature displacement of fluid from the expansion chamber before the valve spool has shifted completely would likely result in damage to the apparatus. Thus, it can be seen that as the direction of reciprocation action applied to the lever means is reversed, the piston rod means serves as a fulcrum for the lever to shift the first valve means initially between the two positions thereof. When stopped in either of the two position, the first valve means then provides a fulcrum for the lever means. in the Figure 1 embodiment, the three-way valve assembly 13 has a closed centre or intermediate position in which all first valve conduits are closed to provide a temporary hydraulic lock for the piston means between the two valve positions. Thus, the lever 54 and the link 57 serve as mechanical linkage means co-operating with the first valve means and the pump means so that reversal of reciprocation action applied to the pump means shifts the first valve means between the first and second positions thereof.

There is thus a time delay or dwell between actuation of the first valve means and transfer of fluid relative to the expansion chamber, and this is attained by interposing a dwell means between the pump means and the first valve means. In the Figure 1 embodiment, the dwell means is the linkage means and selection of force difference required to shift the valve spool before movement of the piston rod means. Alternative dwell means can be substituted so as to be, in effect, interposed between the pump means and the first valve means. The dwell means determines that reversal of force applying reciprocating action to the pump means shifts the valve means between the first and second positions thereof prior to reversal of pump action in the expansion chamber, i.e. displacement or transfer of fluid. Further dwell means are described hereinafter with reference to Figures 3, 5 and 6 and all such dwell means permit actuation of the first valve means during an interval of zero fluid transfer in the expansion chamber which follows completion of a piston stroke. The dwell means accommodates the hydraulic lock of the piston means without destructive shocks.

Thus, in summary, the method if characterised by steps as follows. The feed fluid is inducted into the pumping chamber 27 by the induction stroke of the piston means 25, and simultaneously concentrate fluid is exhausted from the expansion chamber 28. Direction of force applied to the pump means is reversed and the piston is hydraulically biased against movement so that reaction to the reversal of force is transmitted to the valve means, so as to mechanically shift the first valve means to direct fluid flow between the pump means and the membrane means, the dwell means causing the valve means to shift across a closed intermediate position thereof during an interval of zero fluid transfer in the expansion chamber, this incurring timely valve shifting. The feed fluid in the pumping chamber is pressurised by a compression stroke of the piston means which forces pressurised feed fluid to the membrane means and simultaneously admits the concentrate fluid fraction from the membrane means into the expansion chamber to supplement energy supplied to the piston in the compression stroke by using pressure of the concentrate fluid. The feed fluid is separated by the membrane means into a permeate fluid which passes through the membrane means and a concentrate fluid fraction which is returned from the membrane means to the expansion chamber to recover some pressure energy for pressurising the feed fluid.

The first valve means is shown displaced laterally relative to the piston means, however other relative positions can be devised to be within the scope of the invention. If desired, alternative first valve means can be substituted, however an intermediate closed position between the two valve positions is required to hydraulically lock the piston means for a finite period between the two valve positions.

An alternative first valve means 81, for use with the embodiment 10 of Figure 1 and equivalents, is shown in Figure 2, which valve means is in the form of a three-way valve having a spool or sliding cam 82 having spaced stops 83 and 84 limiting movement of the spool. The cam 82 actuates two two-way poppet valves 85 and 86 having complementary seat 87 and 88 connected to conduits as follows. A return conduit portion 89 connects valve 85 with the differential surge absorber, not shown, a connecting conduit 90 connects both valves with the expansion chamber of the pump means, not shown, and a vent conduit 91 connects the valve 86 with a concentrate fluid outlet, not shown. The valve 85 and 86 have respective springs 93 and 94 which initiate closure of the valve with fluid pressure differences augmenting sealing of the valve. Seals 96 and 97 mounted in stem guides prevents fluid leakage past the stems of the poppet valves, and hardened steel balls 98 and 99 protect the stems against lateral forces. It is mandatory that profile of sliding cam 82 can be such that at least one of the poppet valve will remain seated at all times. If both poppet valves were lifted at once, even momentarily, the conduits 89 and 90 would be connected to vent pressure and the apparatus would be inoperative. The spool 82 is connected to the link 57 of Figure 1, and the means 81 can be directly substituted for the valve means 13 and functions similarly.

In operation, the valve is shown in a fully raised position limited by the stop 84, in which position the cam 82 lifts the valve 85 off the seat 87 so that conduits 89 and 90 are connected to admit pressurised concentrate fluid from the membrane means into the expansion chamber. The valve 86 is seated by the spring 94 and unbalanced hydrostatic pressure. On the pump return stroke, the valve 86 is lifted off the seat 88 so as to vent the expansion chamber into the vent conduit 91, and the valve 85 is closed by the spring 93 and hydrostatic pressure, thus preventing concentrate fluid flow from the membrane means.

Figure 3 shows an alternative pump means having a cylinder 105 to which the inlet conduit 36, the outfeed conduit 39 and the connecting conduit 48, are connected as previously described with reference to Figure 1. The pump cylinder 105 has an alternative piston rod means 106 which cooperates with piston means comprising a flexible diaphragm 108 of bellows form which is secured to the pump cylinder 105 by a static seal 110 at one end thereof and at an opposite end thereof to the piston rod means. The diaphragm thus divides the pumping cylinder into a pumping chamber 109 on one side of the diaphragm and an expansion chamber 111 on an opposite side of the diaphragm and thus separates feed and concentrate fluid fractions and serves as substitution for the piston means of the Figure 1 embodiment. The flexible diaphragm is feasible because only small differences in hydrostatic pressure normally exists between the pump chamber 109 and the expansion chamber 111. The flexible diaphragm or bellows eliminates the friction losses of the sealing means 30 of the piston means 25 of Figure 1 and also may simplify manufacturing since tolerances may be less critical. Preferably the diaphragm should be elastically relatively stiff to prevent collapse under pressure differences, because if collapse occurs, its displacement will be reduced and it will not function satisfactorily. Alternatively, the feed fluid can be supplied to the inlet conduit 36 at a boost pressure exceeding exhaust pressure in connecting conduit 48. The diaphragm does not provide rigid boundaries between the feed and concentrate fluids and it can be seen that motion of the piston rod means can cause fluid displacement in the pumping chamber 109 with zero fluid displacement in the expansion chamber 111. Thus the diaphragm is yieldable to fluid pressure as a result of piston motion and thus is compliant upon reversal of reciprocation action applied to the lever means. Thus it can be seen that resilience of the diaphragm provides a means to attain dwell to permit timely valve shifting without fluid transfer in the expansion chamber, and thus serves as an alternative dwell means which can be used in combination the dwell means associated with force differences in shifting the valve assembly.

An alternative differential surge absorber 118 is shown in Figure 4 for the differential surge absorber 15 of Figure 1. The absorber 118 has an alternative cylinder 119 communicating with conduit portions 41 and 42 of the outfeed conduit means 39, and with conduit portions 45 and 46 of the return conduit means 44. The surge absorber 118 has an alternative piston rod means 121 which co-operates with a flexible diaphragm or bellows 123 which is secured to the cylinder by a static seal 125 at one end thereof, and at an opposite end thereof to the piston rod means. The diaphragm divides the cylinder 119 into a concentrate surge absorber chamber 129 and a feed surge absorber chamber 130. A coil spring 131 encircles the piston rod means 121 and functions similarly to the spring 72 of Figure 1. Consideration relating to the substitution of the rigid piston means 25 of Figure 1 for the diaphragm means 108 of Figure 3, apply also to the structure of Figure 4.

Figures 5 and 6 show third and fourth forms of pump means, which can be substituted for the pump means in Figure 1. Referring to Figure 6, the fourth embodiment 136 of a pump means has an alternative piston rod means comprising a piston rod 146 which reciprocates within a pump cylinder 150 generally similar to the cylinder 24 of Figure 1, having the inlet and outfeed conduits 36 and 39, and the connecting conduit 48 to the first valve means.

The pump means 136 has as an alternative piston means 154 mounted on the rod means 146, the means 154 dividing the pump cylinder into an expansion chamber 156 and a pumping chamber 157. The piston rod means 146 has a pair of spaced stops 159 and 160 fitted with oppositely facing resilient pads 158. The alternative piston means 154 includes a piston disc 161 with a bore 162 accepted as a sliding fit on the piston rod means, the disc being interposed between the pads 158 of the spaced stops and being free to slide between the stops, the pads reducing shock loads when the disc 161 contacts the stops. A dynamic seal 163 surrounds an outer periphery of the piston disc to prevent leakage of fluid past the outer periphery and the cylinder wall. Spacing 164 between the pads 158 of the stops and thickness of the disc are such that the piston rod means 146 can move axially through the disc 161 with negligible movement of the disc between approximately 10 and 20 percent of total piston stroke. Hence the piston disc 161 floats on the piston rod means and the reciprocating stroke of the piston disc 161 will be less than that of the piston rod means 146. Unlike the first embodiment, the ratio of permeate flow to feed flow is no longer given by the simple ratio of piston rod section area to piston area, because the strokes of piston rod and piston are inequal.

Operation of the fourth embodiment 136 follows closely that of the first, but it is noted that upon reversal of piston rod movement there is relative movement, i.e. axial sliding, between the disc 161 and the piston rod means 146 which results in lost motion or dwell of the piston disc, following the piston rod reversal, the piston disc reciprocating between the pads 158 on the stops.

The third embodiment of pump means shown in Figure 5 comprises piston means 168 which is shown in the pumping cylinder, 150 of the fourth embodiment, and an alternative piston rod means 169. The piston rod means has a pair of spaced supports 171 and 172 having partially spherical surfaces 173 and 174 disposed oppositely to each other. A flexible disc 176 has a central bore to accept the rod means 169 and has shallowly, convexly curved opposite faces 177 and 178 when in an undeformed state, not shown, and has an outer periphery 179 of slightly larger diameter than bore of the cylinder. The periphery carries a hard wearing, low friction sealing ring 180 which projects from the periphery sufficiently to be in sliding and sealing engagement with cylinder walls. The disc is fitted between the supports and is thus deformed into a saucer-like shape by the cylinder. The disc is sufficiently flexible so that as the piston rod reverses its axial motion, inner portions of the disc flex to follow the rod movement whilst outer portions of the disc remain in static contact with the cylinder walls until limit of deformation of the disc is reached, at which time the periphery of piston disc slides on the cylinder walls. The piston is thus sufficiently compliant to permit, upon reversal of piston rod movement, movement of the piston rod means and adjacent portions of the disc a relatively small amount, typically between about 10 and 20 percent of total piston rod stroke, with negligible sliding of the sealing ring on the cylinder wall. It can be seen that the piston disc deforms from an upwardly convex shape as shown when the piston travels downwards to a downwardly convex shape, shown in broken outline at 176.1, upon reversal of piston rod movement. This deformation of the disc occurs with negligible slippage of the disc relative to the walls. Thus, it can be seen that such a piston disc 176 serves in effect as a resilient, essentially plane diaphragm carried on the piston rod means and has sufficient resilience to permit piston rod movement with negligible piston disc movement and thus can provide dwell.

It can be seen that the flexible piston disc 176 of Figure 5, the floating piston disc 161 of Figure 6 and the diaphragm 108 of Figure 3 are generally equivalent and can be defined as yieldable means associated with the piston means and the piston rod means to permit relative axial movement between a portion of the piston means and the piston rod means in response to reversal of pump action. The yieldable means provide a positive dwell which can be selected for a desired value and is particularly important when the apparatus is used for desalination of brine which has harsh properties of low viscosity, poor lubricity and corrosiveness. Other yieldable means can be substituted to co-operate with piston means and can be used with alternative drive means, a further example of which is described as follows.

The embodiment 181 of apparatus of the invention, shown in Figure 7, is adapted for wind power and has a supporting frame 183 and a mechanical drive means 182 which utilises power from a horizontal axis wind turbine 184 which drives a crank shaft 185. The shaft 185 has a connecting rod 186 and is journalled in a yoke 188 which is journalled for rotation about a vertical axis 189 relative to the frame 183 to permit the turbine to operate in all wind directions. Aligned shafts 191 and 192 are carried in bushings 193 and 194 mounted in the frame 183, and a swivel coupling 196 connects the shafts to permit relative rotation therebetween with negligible axial relative movement. The shaft 191 is hinged to the connecting rod 186 and the shaft 192 is hinged to a link 198. The link 198 is hinged to a coupling 199 secured to the lever 54 of the first embodiment 10 of the apparatus. The lever 54 co-operates with the piston rod means 32 and the valve spool 49 as previously described, and it can be seen that the coupling 199 can be shifted axially along the lever 54 end thus adjust pump stroke with a corresponding change in average torque requirement for the crank shaft 185. When used with a wind turbine, axial adjustment of the coupling can be useful to adjust pump delivery to prevailing wind speed and also to unload the wind turbine for easier starting.

Clearly, the mechanical drive means 182 of Figure 7 can be applied to drive the lever 54 from any low speed rotating shaft powered by any prime mover. If the orientation of the shaft is fixed in such applications, the swivel 196 and the aligned shafts 191 and 192 can be eliminated and a single connecting shaft substituted. It may be convenient in some installations to connect the connecting rod 186 directly to the coupling 199 without intervening linkage.

An alternative multi-cylinder embodiment 201 of the invention is shown in Figure 8, and has a first pump means and first valve means 203 and 204 having piston rod means and valve actuating means 205 and 206 respectively. The valve actuator can be an outer portion of the valve spool or equivalent means to shift the three-way directional valve. The embodiment 201 has a similar second pump means 208 with respective first valve means 209, piston rod means 210 and valve actuating means 211, the pump cylinders and first valve means being directly opposed to each other to minimise side loads on the piston rod means and the valve actuators. A piston rod connecting means 213 aligns and connects the piston rod means 205 and 210 of the first and second pump means, and an articulated valve actuator connecting means 214 connects the valve actuators 206 and 211 of the first valve means of the first and second pump means. A lever means 216 serving as a drive means for both pumps is hinged to the piston rod connector means and the valve actuator connecting means of both the first and second pump means, so that reciprocation of the lever means simultaneously actuates the piston means of both pump means so as to actuate the pump means in reverse phase to each other. Respective first valve means of each pump means are actuated essentially simultaneously shortly after reversal of the piston stroke.

A feed fluid source 218 communicates with inlet conduits 219 and 220 of the first and second pump means, and a conventional independent surge absorber 222 communicates with outfeed conduit means 223 and 224 extending from the first and second pump means. An independent conventional concentrate surge absorber 226 communicates with return conduit means 227 and 228 communicating with the first valve means 204 and 209 of the first and second pump means respectively. Vent conduits 230 and 231 extend from the first valve means 204 and 209 to dump concentrate fluid fractions and a membrane vessel 234 and high pressure filter 235 in conduit 236 communicates with the return conduit means 228 and the outfeed conduit means as shown. When two or more pump cylinders are provided phased equally apart, feed flow fluctuations across the membrane means are reduced thus permitting reduction of differential surge absorber displacement, or use of conventional accumulators as disclosed above.

In operation, it can be seen that pumping chamber and expansion chamber of the first pump means, not shown, feed fluid to the membrane means and receive fluid from the membrane means respectively, whilst the pumping chamber and expansion chamber of the second pump means admits feed fluid from the fluid source and discharges concentrate fluid respectively so as to reduce fluid flow variations across the membranes.

Thus, the two cylinder arrangement with the conventional accumulators serves as means to provide essentially uniform pressure and feed fluid flow across the membranes. Thus, multiple pump means in combination with accumulators can be considered equivalent to the differential surge absorber of Figure 1. The surge absorbers can be spring-loaded pistons or diaphragms as shown for the differential surge absorbers, or alternatively other types of surge absorbers known in the art, including pneumatic bladder accumulators or weight-loaded piston accumulators can be used.

Clearly, one of the first valve means can be eliminated by combining in one valve assembly a spool which has a function of a four-way valve to open respective chambers of one pump means whilst closing chambers of the remaining pump means. Other variations are envisaged, such as providing mechanical actuation of the non-return check valves in the inlet and outfeed conduits.

A further variation in the method of operating the invention is applicable when two or more pumps phased equally apart are used. Some or all of the energy required to power the pump may be provided by pressurising the feed fluid by a relatively low powered external feed pump means to a pressure below the membrane working pressure. A feed pump 238 is shown in broken outline in the inlet conduit extending from the feed fluid source 218, so as to pressurise the inlet conduits 219 and 220. If the feed fluid has a sufficiently high pressure prior to entry into pump means, no further mechanical energy need be supplied to drive the system by the lever. The lever 216 of Figure 9 would then provide only a valve timing function.

It will be readily appreciated that there is generally provided, according to the present invention, reverse osmosis apparatus comprising semi-permeable membrane means which selectively permeate purified water from a feed solution pressurised by reciprocating piston or diaphragm pump means; wherein pump action is assisted by returning pressurised concentrate fluid acting on reverse side of the pump piston or diaphragm; and comprising directional valves controlling alternating admission and venting of concentrate fluid to and from pump means are actuated mechanically by reversal of force applied to the pump means; and wherein mechanical dwell is provided in the piston or diaphragm motion during directional valve actuation. The pump means may be operated by a manual lever. An optional differential surge absorber may be included to provide continuity of feed solution circulation past membrane surfaces during the return pump stroke, thus minimising detrimental salt concentration build-up on the membranes.

WHAT I CLAIM IS:—

1. Membrane separation apparatus for separation of a feed fluid into permeate fluid and concentrate fluid fractions which respectively are permeated and rejected by selective membrane means, the apparatus including: reciprocating pump means having a cylinder, a movable piston means and piston rod means, the piston means dividing the cylinder into a pumping chamber for the feed fluid and an expansion chamber for the concentrate fluid fraction, the piston rod means extending through the expansion chamber, the cylinder and piston rod means having relative diameters which define cylinder/piston rod proportions to determine in part recovery ratio of permeate fluid fraction to total feed fluid flow; inlet conduit means to admit feed fluid into the pumping chamber, outfeed conduit means to conduct feed fluid from the pumping chamber to the membrane means, and return conduit means to conduct concentrate fluid fraction from the membrane means to the expansion chamber; surge reducing means connected to at least one of said conduit means to reduce fluctuations in pressure and feed fluid flow across the membrane means; first valve means communicating with the expansion chamber and having a closed intermediate position between first and second position, and non-return second valve means communicating with the pumping chamber, the first valve means co-operating with the conduit means to direct fluid flow to and from the expansion chamber of the pump; and reciprocable mechanical drive means mechanically connected to the pump means and the first valve means to apply a reciprocatory action to the pump means and to the first valve means so that in the first position of the first valve means pressurised feed fluid from the pumping chamber is fed to the membranes through the second valve means while concentrate fluid is discharged into the expansion chamber through the first valve means, so that depressurisation of the concentrate fluid returning from the membrane means assists in pressurising of the feed fluid, and in the second position of the first valve means depressurised

concentrate fluid is exhausted from the expansion chamber through the first valve means while feed fluid is inducted into the pumping chamber through the second valve means; wherein the apparatus incorporates dwell means associated with the pump means and the first valve means the dwell means being arranged so that the reciprocatory force transmitted to the pump means is reacted in part by the first valve means so that reversal of force reverses the valve means and so that a hydraulic bias effect acts on the piston means to inhibit relative motion of the piston means in one direction, as determined by the position of the first valve means, and to permit relative piston motion in the opposite direction, so that following reversal of the force applied to the pump means, the first valve shifts between the first and second positions thereof prior to reversal of pumping action, to ensure that the first valve means is shifted during an interval of substantially zero fluid transfer to or from the expansion chamber.

2. Apparatus as claimed in Claim 1 in which the reciprocable drive means and dwell means comprise a reciprocatory lever connected to the piston rod means and the first valve means, so that the first valve means shifts between the first and second positions thereof as direction of reciprocation of the lever is reversed, the hydraulically biased piston causing the piston rod means to serve as a fulcrum for the lever during said shifting.

3. Apparatus as claimed in any preceding claim in which the dwell means incorporates yieldable means associated with the piston means and the piston rod means to permit, upon reversal of pump action, relative axial movement between a portion of the piston means and the piston rod means permitting the piston rod means to commence a stroke prior to displacement of fluid from the expansion chamber by the piston means, so that fluid pressures across the conduits of the first valve means that are about to be connected are approximately equalised prior to actuation of the first valve means.

4. Apparatus as claimed in Claim 3, in which the yieldable means comprises a pair of spaced stops on the piston rod means, and wherein the piston means has a disc with a bore accepted as a sliding fit on the piston rod means, the disc being interposed between the stop means, spacing between the stops and thickness of the disc permitting relative axial sliding between the disc and the piston rod limited by the stop means so that piston stroke is less than piston rod stroke.

5. Apparatus as claimed in Claim 3, in which the piston means comprises a flexible diaphragm attached to said piston rod means and separating the pump chamber from expansion chamber, which diaphragm serves as the yieldable means so that resilience of the diaphragm permits the piston rod means to move without fluid transfer in the expansion chamber so as to essentially equalise fluid pressures across conduits to be connected prior to shifting of the first valve means.

6. Apparatus as claimed in Claim 3, in which the piston means comprises a flexible disc mounted on the piston rod means having a periphery in sliding sealing contact with the pump cylinder; wherein the flexible disc serves as the yieldable means, the flexibility of the disc permitting, upon reversal of piston means stroke, movement of the rod relative to the piston means with negligible movement of the periphery relative to the cylinder.

7. Apparatus as claimed in any preceding claim, wherein said pump means constitutes first pump means, and further including a second pump means having a respective cylinder, piston rod means and first valve means, the piston rod connecting means connecting the piston rod means of the first and second pump means, and valve actuator connecting means connecting valve actuators of the first valve means of the first and second pump means; wherein the drive means comprises a lever hinged to the piston rod connecting means and to the valve actuator connecting means, so that reciprocation of the lever simultaneously actuates the piston rod means of both the pump means so as to actuate the pump means in reverse phase to each other, and actuates both first valve means of the pump means substantially simultaneously shortly after reversal of piston rod means stroke so that the pumping chamber and expansion chamber of the first pump means feed fluid to the membrane means and receives fluid from the membrane means respectively, whilst the pumping chamber and expansion chamber of the second pump means admits feed fluid from the fluid source and discharges concentrate fluid respectively so as to reduce fluid flow variations across the membranes.

8. Apparatus as claimed in any preceding claim, in which the surge reducing means includes a differential surge absorber communicating with the outfeed and return conduit means and interposed between the membrane means and the first and second valve means to absorb pressure fluctuations thus providing essentially uniform feed fluid flow.

9. Apparatus as claimed in Claim 8, as appended to Claim 1 or 2, wherein the cylinder and piston rod means of the pump means have relative diameters which define cylinder/piston rod proportions such that

ratio of swept volume of piston rod means to swept volume of the piston means determines recovery ratio of permeate fluid fraction to total feed fluid flow; and wherein the differential surge absorber comprises a cylinder and a piston means, which piston means is spring-loaded and double-acting and reciprocable with the cylinder, the cylinder and piston means of the differential surge absorber having a displacement several times greater than the displacement of the piston means of the pump means.

10. Apparatus as claimed in Claim 8, wherein the differential surge absorber comprises a cylinder and a piston means, which piston means divides the cylinder into a concentrate surge absorber chamber and a feed surge absorber chamber, the feed surge absorber chamber being exposed to pressurised feed fluid in the outfeed conduit means and the concentrate surge absorber chamber being exposed to the concentrate fluid fraction in the return conduit means; wherein the piston means of the surge absorber co-operates with piston rod means extending through the concentrate surge absorber chamber with sealing means to seal the surge absorber against leakage; and wherein spring means co-operates with the piston to force the piston in a direction to exhaust the feed surge absorber chamber.

11. Apparatus as claimed in Claim 10, in which the piston means of the differential surge absorber comprises a flexible diaphragm attached to the piston rod means and separating the feed surge absorber chamber from the concentrate surge absorber chamber.

12. Apparatus as claimed in any preceding claims, as appended to Claim 2, wherein the first valve means has a spool means reciprocable between the first and second positions; wherein a link connects the lever to the spool means; and wherein the lever is hinged to the piston rod means, so that as the direction of the reciprocating action applied to the lever means is reversed, the piston rod means provides a fulcrum for the lever means to shift the first valve means initially between the two positions thereof, and when stopped in either of the two positions thereof, the first valve means provides a fulcrum for the lever means to apply the reversed force to the pump means.

13. Apparatus as claimed in claim 12, wherein the spool means is a movable spool having travel between two positions limited by stops on the spool.

14. Apparatus as claimed in any one of claims 1 to 11, wherein the first valve means is a two-position, centre-closed, three-way valve having a movable spool, the spool having travel between the two positions limited by stops.

15. Apparatus as claimed in Claim 14, wherein the spool serves as a cam means, and wherein the first valve means includes a pair of normally-closed, two-way poppet valves to close respective conduit means, the poppet valves being unseated and opened by the cam means, the cam means being adapted to unseat and open one poppet valve whilst leaving the remaining poppet valve seated and closed, so that both poppet valves are never open simultaneously.

16. Membrane separation apparatus substantially as hereinbefore described with reference to Figure 1 or Figure 1 as amended by any of Figures 2 to 7 of the accompanying drawings.

17. A method of membrane separation of a feed fluid into permeate fluid and concentrate fluid fractions which respectively are permeated and rejected by selective membrane means, the membrane means being exposed to pressurised feed fluid supplied by a reciprocating pump means having a cylinder and piston means and co-operating with valve means in conduit means, the piston means dividing the cylinder into a pumping chamber in which feed fluid is pressurised and an expansion chamber in which the concentrate fluid is depressurised; the method including steps of: simultaneously inducting feed fluid into the pumping chamber and exhausting depressurised concentrate fluid from the expansion chamber, followed by simultaneously pressurising the feed fluid in the pumping chamber and admitting pressurised concentrate fluid into the expansion chamber to supplement energy supplied to the piston in the pumping stroke; the method being characterised by: reversing direction of force applied to the pump means and simultaneously hydraulically biasing the piston means against movement due to reversal of force so that reaction to reversal of force is transmitted to the valve means causing the valve means to shift in preference to relative piston means movement so as to mechanically shift the valve means to direct fluid flow between the pump means and the membrane means, the transfer of reaction forces causing a dwell period so that the valve means shifts across a closed intermediate position thereof during an interval of substantially zero fluid transfer in the expansion chamber thus incurring timely valve shifting.

18. A method as claimed in Claim 17 further characterised by pressurising the feed fluid by external means to provide additional energy to supplement energy provided by the drive means.

19. A method as claimed in Claim 17 or 18 further characterised by storing a volume of

feed fluid under a pressure sufficient to maintain adequate flow over the membrane means during reversal of the stroke of the piston means, so as to maintain essentially uniform feed fluid pressure and flow across the membranes to reduce concentrate polarisation effects.

20. A method as claimed in Claim 17, 18 or 19 further characterised by permitting yielding between the piston means and the piston rod means so that there is relative movement therebetween to provide the dwell interval between valve shift and reversal of pumping action.

21. A method as claimed in Claim 17, 18, 19 or 20 further characterised by: upon reversal of the reciprocating force, using a first portion of a following reciprocating stroke to shift the valve means, and a remaining portion of the stroke to cause relative piston means movement.

22. A method of membranes separation of a feed fluid into permeate fluid and concentrate fluid fractions, substantially as hereinbefore described with reference to Figure 1 or Figure 1 as amended by any of Figures 2 to 7 of the accompanying drawings.

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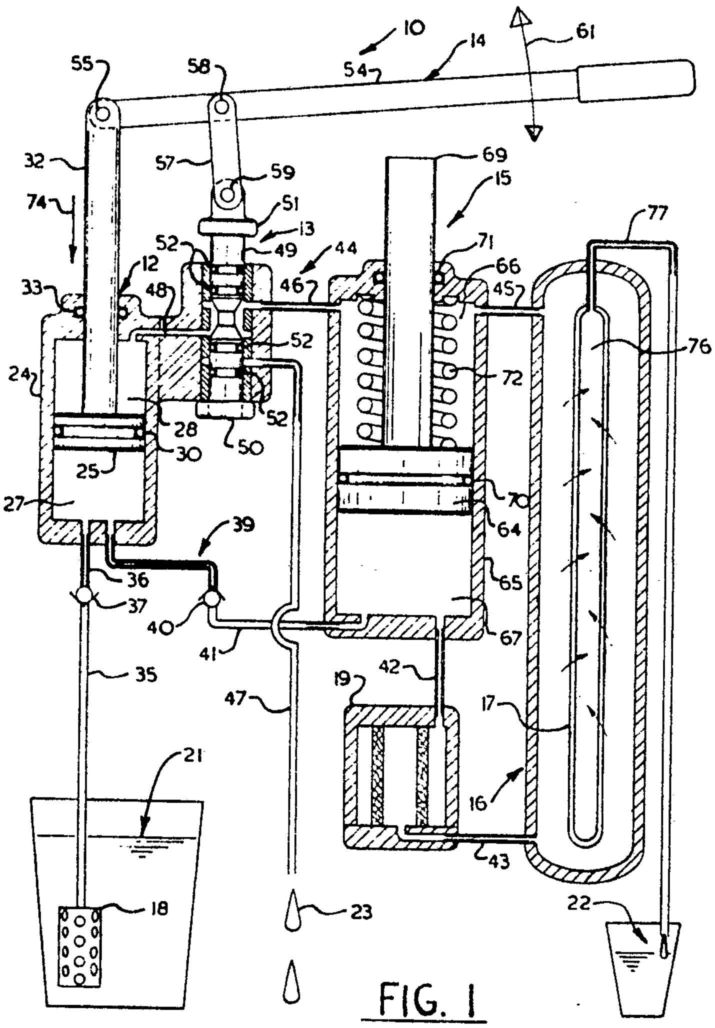
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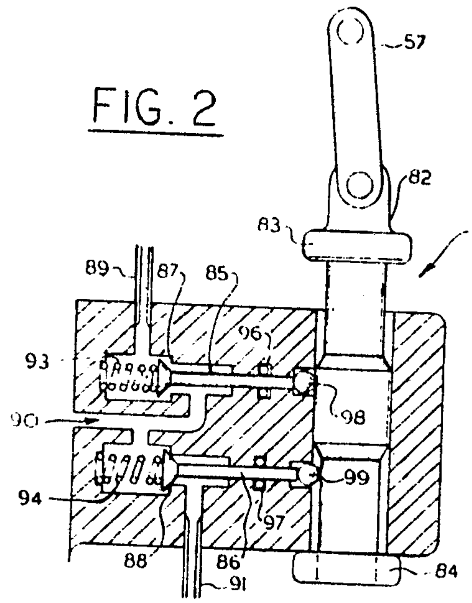
FIG. 1

1601518 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

FIG. 2



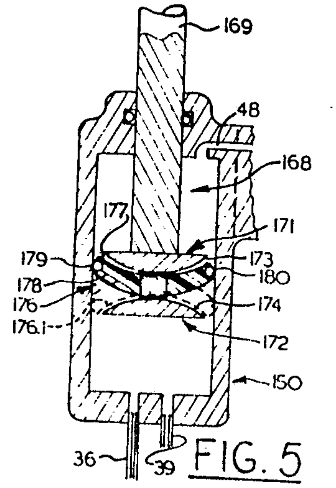
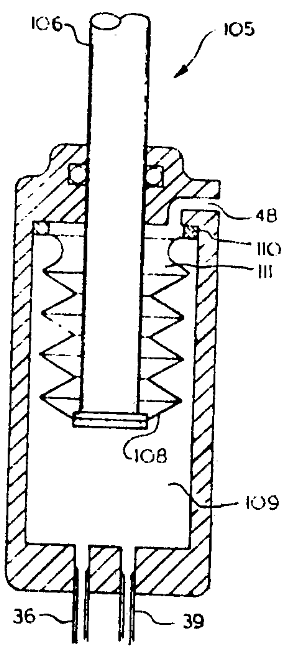


FIG. 5

FIG. 3



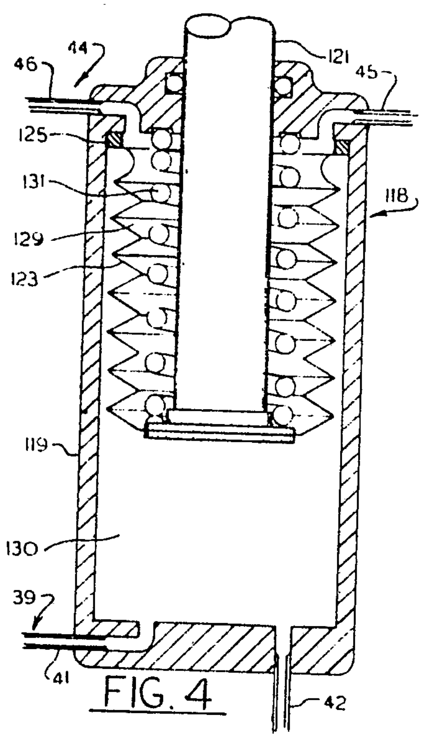


FIG. 4

FIG. 6

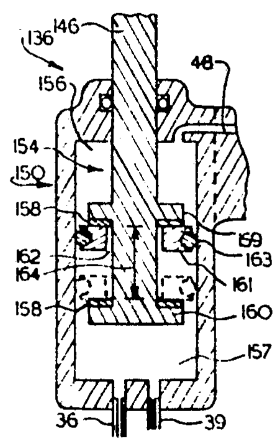


FIG. 7

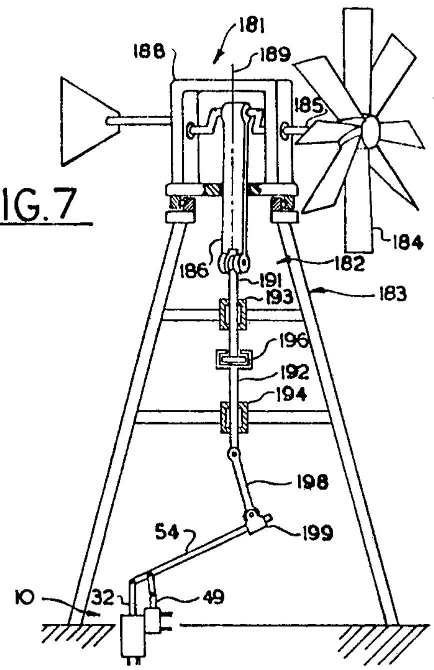


FIG. 8