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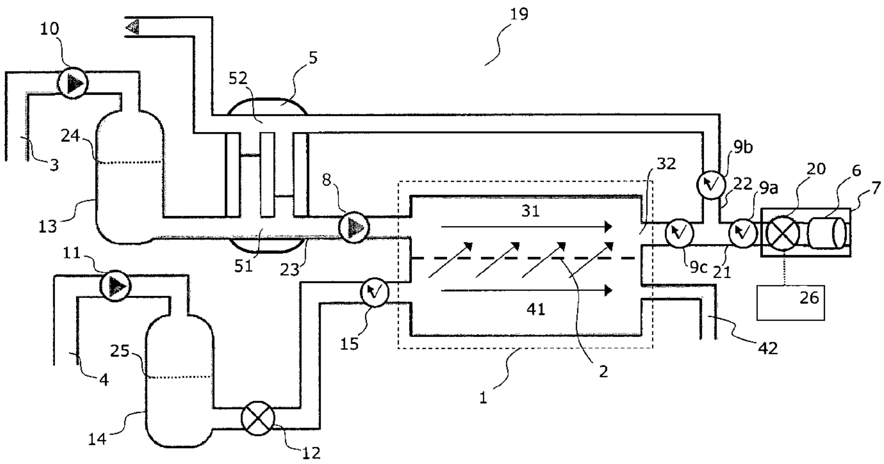

Fig. 1

(57) Abstract: The present invention relates to pressure control of draw and/or feed solutions in osmotic systems such as osmotic power plants. The pressure control according to the invention makes use of a new principle that enables a very fast and energy efficient control of pressurized solutions in osmotic systems. According to the invention the control of pressure is done by a pressure regulating unit that administers the amount of solution leaving the draw and/or feed side compartment. The regulation is done according to a measured solution pressure in the compartment from which the solution is leaving. Osmotic systems according to the invention can operate by pressure retarded osmosis (PRO) or forward osmosis (FO) also known as direct osmosis (DO).

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REGULATING PRESSURE CONDITIONS IN OSMOTIC SYSTEMS

FIELD OF THE INVENTION

The present invention relates to controlling the pressure in osmotic systems.

BACKGROUND OF THE INVENTION

For centuries it has been known that when salt water and fresh water are partitioned in two different chambers separated by a semi-permeable membrane, made for example of a biological membrane, e.g. of hog's bladder, fresh water will press itself through the membrane. The driving force is capable of elevating the salt water level above the level of the fresh water, whereby a potential energy is obtained in the form of a static water height. The phenomenon is called osmosis and can occur when two solutions with different solute concentrations are separated by a semi-permeable membrane. The energy potential can be utilized by several technical methods where the energy can be recovered. Two of the technical methods using semi-permeable membranes are reverse electro dialysis (energy potential as electrical DC voltage) and pressure retarded osmosis (PRO) where energy potential is a build up water pressure.

Osmosis may also be used in other industrial applications, where the processes of forward osmosis (FO), also referred to as direct osmosis (DO), and reverse osmosis (RO) are relevant. In FO the mass flow across a semi-permeable membrane is occurring naturally only due to the difference in osmotic pressure between each side of the membrane. In reverse osmosis, pressure is applied to force the solvent through the membrane. In pressure retarded osmosis, pressure is applied to the solution with high solute concentration to optimize conditions for the osmotic processes.

Several plant configurations using a pressure retarded energy converter have been described earlier e.g. in article "Comparative mechanical efficiency of several plant configurations using a pressure-retarded osmosis energy converter" by Loeb et al. (Journal of Membrane Science, 51 (1990) 323-335). In this reference examples of such plant configurations are continuous or alternating flow plants both terrestrial and underground.

The generating power utilizing pressure-retarded osmosis is disclosed in US 4,193,267. Herein, a concentrated solution at a high hydraulic pressure is passed along one face of a semi-permeable membrane, and a dilute solution at a low hydraulic pressure is passed along the opposite face of the membrane to effect, by PRO, the passage of at least a part of the dilute solution through the membrane forming a pressurized mixed solution. The potential energy stored in the pressurized mixed solution is converted to useful energy by depressurizing and re-pressurizing only the dilute solution. The high hydraulic pressure is achieved and maintained by osmotic permeation of dilute solution into the concentrated solution.

GB 1 343 891 describes an osmotic power plant and a process optimized for extracting the maximum amount of osmotic potential in a volume of solvent (fluid with small molecular concentration) and solution (fluid with large molecular concentration). Here, the osmotic process are operated in cycles; osmotic flow of solvent over the membrane is continued until it stops due to the pressure being build up is equal to the osmotic pressure. Then, the pressure can be stored as potential energy or released for energy production, whereafter the flow of solvent over the membrane will start again to initiate a new cycle of pressure build up. As the sultion is diluted by the in-flowing solvent, the osmotic pressure will decrease and the cycles will become shorter. At this point, additional solute can be introduced into the solution.

It is a disadvantage of GB 1 343 891 that the osmotic flow is allowed to continue until $P = P_{osmosis}$, where the flow naturally stops, whereafter it is initiated again by releasing the entire pressure ($P = 0$). While this is optimal operation for situations with limited availability of solvent and solution, the power yield is low in most of the operation cycle.

WO 2007/134226 describes a plant capable of both desalination and power production. In power production mode, the amount of flow of mixed solution from the membrane chamber that is directed to the hydroturbine is indirectly controlled by controlling the flow rate of sea water into the membrane chamber using a booster pump. Furthermore, the system is considered to be essentially self-controlling when a efficient rotary pressure transfer device is used.

It is a drawback of WO 2007/134226 that control of a booster pump to supply a defined flow rate of seawater into the membrane chamber will control the remainder amount of flow directed to the hydroturbine. This is disadvantageous as it involves operating a booster pump at different speeds, and since it provides only an indirect control of the power yield.

A disadvantage with systems using FO or PRO is related to the need for a precise control of the pressure in the draw solution (the most concentrated solution) to ensure optimum conditions for FO or PRO. Hence, an improved control of the pressure in the draw solution would be advantageous, and in particular a faster way of regulating the pressure of the draw solution would be advantageous to ensure an optimal energy output from an osmotic system during non-steady state conditions.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a system and a methodology for controlling the draw solution pressure in osmotic processes to ensure pressure conditions for FO or PRO.

In particular, it may be seen as an object of the present invention to provide an osmotic system that solves the above mentioned problems of the prior art with control of pressure of the draw solution.

In both PRO and FO systems, solvent is transported into a draw solution, whereby the amount of solution on the draw side continuously expand and the pressure conditions on the draw side subject to change. Hence, although the optimal pressure conditions for PRO and FO are different, there is a need for precise regulation of the pressure conditions in order to establish and maintain efficient, such as close to optimal or optimal, pressure conditions for PRO and FO.

Thus, the above described object and several other objects are intended to be obtained in a first aspect of the invention by providing an osmotic system comprising:

- a feed side compartment for receiving a feed solution;
- a draw side compartment for receiving a draw solution;
- a semi-permeable membrane separating said feed and draw side compartments and allowing feed solution from the feed side compartment to enter the draw side compartment by osmosis to form a mixed solution;
- pressure conversion means in fluid communication with a first outlet of the draw side compartment for conversion of pressure into another form of energy;
- a pressure exchanger for transferring pressure in the draw side compartment from a second outlet to an inlet of the draw side compartment, the pressure exchanger ensuring mass balance between draw solution received by the inlet and mixed solution leaving the draw side compartment through the second outlet;
- a first pressure sensor for sensing a pressure in the draw side compartment;
- adjustable flow control means for regulating a volume of mixed solution entering the pressure conversion means from the first outlet of the draw side compartment; and
- a pressure regulation unit for regulating pressure in the draw side compartment to maintain pressure conditions for PRO by regulation of the volume of mixed solution entering the pressure conversion means from the first outlet through adjustment of an opening degree of the adjustable flow control means in response to a signal from the first pressure sensor .

In a further aspect, the invention provides a method for regulating pressure conditions in an osmotic system comprising a semi-permeable membrane separating a feed side compartment holding a feed solution and a draw side compartment holding a draw solution, pressure conversion means in fluid communication with a first outlet of the draw side compartment for converting pressure generated in the draw side compartment by pressure retarded osmosis (PRO), preferably of solvent from the feed side compartment into energy, and a pressure exchanger for transferring pressure in the draw side compartment from a second outlet to an inlet of the draw side compartment, the method comprising regulating pressure in the draw side compartment to maintain pressure conditions for PRO by adjusting an opening degree of flow control means controlling a volume of mixed solution entering the pressure conversion means from the draw side compartment in response to input relating to a pressure in the draw side compartment from a first pressure sensor placed therein.

In PRO or FO depending on available resources of draw and feed solutions, one will try to optimize the volume of feed solution solvent passing over the membrane, i.e. the flow or flux through the membrane. When PRO is used in power production, the power yield is sought to be optimized, which involves a simultaneous optimization of feed solvent flux over the membrane and pressure build up in the draw compartment - this will be described in more detail later. However, a flow (volume/time) is difficult and time consuming to measure. The present invention provides the advantage of providing a fast and energy efficient regulation of pressure conditions. The pressure conditions preferably correspond to a predefined optimized pressure corresponding to optimized operation of the osmotic system. It is important to understand that osmotic systems are very complex, and that the conditions determining such predefined optimized pressure can change continuously or abruptly due to factors internal or external of the system. Examples may be internal factors such as fouling of the membrane and external factors such as changes in the feed or draw solution availability. Such changes will result in that the pressure conditions corresponding to optimized operation will change, and that fast regulation is advantageous for maintaining optimized operation also after the change.

The regulation according to the invention is fast because the regulation is made in response to a sensed pressure which is immediately affected by changes in flux over the membrane. The regulation according to the invention is energy efficient because the efficiency of the osmosis (i.e. the flux) is affected by the pressure, so that by regulating the amount of mixed solution to the pressure conversion means in response to the pressure (the cause) instead of the flux (the effect) renders it possible to maintain predefined (e.g. optimum) PRO or FO pressure conditions during fluctuations in the operation conditions. As an example, if the flow of the incoming draw solution is suddenly decreasing for some reason, the pressure drop can be determined instantly and compensated for by decreasing the volume of draw solution entering the pressure conversion means. This regulation would only lead to a decrease in energy production stemming from the decreased inflow of draw solution, and not to a decrease in the power production stemming from a decrease in osmotic membrane efficiency when the pressure is differing from optimum conditions.

Mechanical pumps for pressurizing the draw solution may only be working optimally under certain pressure differences and RPM's (revolutions per minute), and quick changes in water flow or pressure may not be accommodated by regulation using these mechanical pumps. Regulating the pressure by the volume allowed to enter the pressure conversion means provides the advantage that the pressure of the draw solution may be controlled fast and almost effortless in order to match the optimum conditions.

In the following, used terms will be explained and a number of preferred and/or optional features, elements, examples and implementations will be summarized. Features or elements described in relation to one embodiment or aspect may be combined with or applied to the other embodiments or aspects where applicable. For example, structural and functional features applied in relation to the method may also be used as features in relation to the system and vice versa. Also, explanations of underlying mechanisms of the invention as realized by the inventors are presented for explanatory purposes, and should not be used in ex post facto analysis for deducing the invention.

The principles of the invention are similarly applicable to systems using forward osmosis and pressure retarded osmosis. In the present description, the term "osmosis" is to be understood as PRO and/or FO unless otherwise specified.

The feed and draw side compartments designate fluid systems on each side of the membrane. These comprise both piping and sub-compartments which can be separated by valves, faucets, or similar. In the draw side compartment, the fluid system is limited at the entrance to the pressure exchanging means and at the exits to the flow control means of the pressure converting means and furthermoreat the exit from the pressure exchanging means (Please refer to Figure 4).

The semi-permeable membrane is a membrane that will allow certain molecules or ions to pass through it by diffusion, depending on the size, solubility, properties, or chemistry of the molecules or ions. The semi-permeable membrane designates the entire membrane in contact with the fluid systems, typically comprising a plurality of smaller pieces of semi-permeable membrane in arranged in membrane modules. An example of an applicable semi-permeable membrane is a flat sheet cellulose acetate membrane.

A membrane module is a compartment divided into separate feed and draw side sub-compartments by a semi-permeable membrane, the feed and draw side sub-compartments having inlets for influx of feed and draw solution, respectively. The draw side sub-compartment also comprises an outlet for outflow of solution, the inlet and outlet being arranged so that solution adjacent to the semi-permeable membrane in the draw side sub-compartment is continuously replaced by flow of draw solution into the membrane module. A plurality of membrane modules are combined so that their respective feed and draw side sub-compartments form at least part of the feed and draw side compartments of the plant.

The feed and draw solutions are any solutions that, when separated by the semi-permeable membrane, will result in diffusion of solvent from the feed solution to the draw solution via osmosis. Where feed solution diffuses through the membrane, a mixture of feed and draw solution will be formed in the draw side compartment. This mixture is referred to as mixed solution or simply solution.

The draw solution is a solution of high solute concentration, for example, but not limited to, a solution of inorganic or organic salts in water or any other electrolytic solution. Typical draw solutions may contain ions naturally occurring in seawater such as Chloride (Cl^-), Sodium (Na^+), Sulfate (SO_4^{2-}), Magnesium (Mg^{2+}), Calcium (Ca^{2+}), Potassium (K^+), Bicarbonate (HCO_3^-), Bromide (Br^-), Iodine (I^-), Borate (BO_3^{3-}), or Strontium (Sr^{2+}). Other typical draw solutions may comprise common salt-forming cations comprising Ammonium (NH_4^+), Calcium (Ca^{2+}), Iron (Fe^{2+} and Fe^{3+}), Magnesium (Mg^{2+}), Potassium (K^+), Pyridinium ($C_5H_5NH^+$), Quaternary ammonium (NR_4^+), or Sodium (Na^+) and common salt-forming anions comprising Acetate (CH_3COO^-), Carbonate (CO_3^{2-}), Chloride (Cl^-), Citrate

($HOC(COO^-)(CH_2COO^-)_2$), Cyanide ($C{\equiv}N^-$), Hydroxide (OH^-), Nitrate (NO_3^-), Nitrite (NO_2^-), Oxide (O^{2-}), Phosphate (PO_4^{3-}), or Sulfate (SO_4^{2-}). Draw solution is also sometimes referred to as the hypertonic solution.

The feed solution is a solution with lower overall solute concentration than the draw solution. It may be that the feed solution for some single solutes has a higher concentration than the draw solution (referred to as a partial concentration when only looking at the concentration of some solutes in the solutions). But overall, taking into consideration the molar concentration of all solutes in the feed and draw solution, the feed solution has a smaller concentration. Feed solution is also sometimes referred to as the hypotonic solution.

The adjustable flow control means for controlling volume entering the pressure conversion means comprise all possible ways of limiting, controlling or adjusting a liquid flow such as valves, nozzles, jets, vanes, etc.

Pressure conversion means is any type of device that will transform hydraulic pressure to another type of energy, such as kinetic energy, electric potential, potential energy, internal energy (e.g. thermal, chemical or latent energy), etc. The pressure conversion means can comprise any number of separate units which in unity enables conversion of energy. In a preferred embodiment, the flow control means may be a nozzle generating a flowing solution from the pressurized solution, converting the pressure (potential energy) into kinetic energy. The pressure conversion means may then further comprise a turbine transforming the flowing solution into mechanical rotation (linear kinetic energy into rotational kinetic energy), and finally a generator transforming rotational kinetic energy into alternating electrical potential. Pressure conversion means may also provide other functions and is not limited to converting energy.

Pressure retarded osmosis (PRO) is osmosis through a semi-permeable membrane separating a feed and a draw solution, where the draw solution is subdued to a pressure load relative to the feed solution which is larger than zero. Forward or direct osmosis is osmosis where the pressure difference between the draw and feed solution is zero or at least substantially zero, such as small in relation to the absolute pressure in the draw solution.

In the following, P_1 is the draw solution pressure, P_2 is the feed solution pressure, and the differential pressure is $\Delta P = P_1 - P_2$. Pressure of a liquid is sometimes also referred to as water potential or pressure potential designating the potential energy of the solution relative to the surroundings.

Pressure sensors are sensors capable of extracting information on the pressure in a liquid. Pressure sensors can directly measure the pressure in a liquid or indirectly measure the pressure of a liquid by directly measuring some property of an adjacent material such as a thin wall in contact with the liquid etc. Numerous types of applicable pressure sensors are known by the person skilled in the art.

As there is a continuous flow of solution through the draw side compartment, the pressure will typically vary depending on position in the draw compartment. In a preferred embodiment, the first pressure sensor for measuring P_1 is placed in the draw side compartment between the semi-permeable membrane and the flow control means, such as preferably immediately before the flow control means. Often, the pressure in the feed side compartment is kept approximately constant, in which case P_1 is proportional to the differential pressure, ΔP. In this case, the regulation of the draw side pressure can occur solely by input of P_1. In the alternative, the flow control means is operated in response to the differential pressure, ΔP, in front of and behind the semi-permeable membrane in the feed and draw side compartments, respectively, using signals P_1 and P_2 from the first pressure sensor and a second pressure sensor placed in the feed side compartment. In the following description, the term 'working pressure' is used to refer to the actual pressure conditions in the plant, P_1 or ΔP, as these may often be used interchangeably. Also, the term 'predefined pressure' is used to designate the value of P_1, ΔP, or similar that the regulation of pressure seeks to achieve.

In the present invention, the draw solution pressure is preferably regulated to establish or maintain pressure conditions for PRO or FO, i.e. so that $0 \leq \Delta P \leq P_{osmotic}$, where $P_{osmotic}$ is the osmotic pressure in the specific set-up.

The regulation of pressure in the draw side compartment, or the operation of the flow control means, may be carried out manually by an operator, mechanically by a mechanical or electrical connection between the first pressure sensor and the flow control means (here it is understood that 'signal' may also be a mechanical connection), or electronically by an electronic processor such as computer or a computer system. In the preferred embodiment, the osmotic system comprises a pressure regulation unit for regulating working pressure in the draw side compartment by operation of the flow control means. The pressure regulation unit may comprise an electronic processor connected to receive at least signal from the first pressure sensor, and typically forms part of an overall control system for the osmotic system. To exercise the control, the pressure regulation unit preferably involves a pressure regulation algorithm configured to generate an operation signal to the flow control means determined by the sensed working pressure and the set desired pressure. As an example, the algorithm may perform proportional-integral-differential (PID) regulation of the opening degree of the needle valve, which ensures a fast and precise control of the pressure conditions. The PID algorithm can be optimized to resist large fluctuations in working pressure, to do fast regulation on small fluctuations etc., depending on the special needs for a specific plant. As will be described later, the pressure regulation algorithm may also involve utilization of modeled or planned changes in parameters that affect optimal pressure conditions to set the desired pressure accordingly. Also, the pressure regulation unit may be manually controlled by an operator entering a desired pressure to be steered after or feeding parameter values manually to the pressure regulation algorithm.

It may be preferred that the flow control means, after start-up and establishment of stable pressure conditions for PRO or FO of the osmotic system, is operated to regulate pressure in the draw side compartment to maintain pressure conditions for PRO or FO by:

- when the input from the first pressure sensor indicate a decrease in pressure, operate the flow control means to reduce the volume of solution entering the pressure conversion means; and
- when the input from the first pressure sensor indicate an increase in pressure, operate the flow control means to increase the volume of solution entering the pressure conversion means.

Alternatively, when the differential pressure is applied in the regulation, the flow control means is operated by:

- when the input from the first and second pressure sensors indicate a decrease in differential pressure, operate the flow control means to reduce the volume of solution entering the pressure conversion means; and
- when the input from the first and second pressure sensors indicate an increase in differential pressure, operate the flow control means to increase the volume of solution entering the pressure conversion means.

In a further embodiment, the regulating of pressure conditions further comprises:

- receiving information relating to internal or external factors affecting the pressure conditions for FO or PRO;
- setting a new predefined pressure for the draw side compartment;
- using input from the first pressure sensor, regulating the pressure in the draw side compartment towards the new predefined pressure.

These steps may be carried out by a pressure regulation unit comprising electronic processor as described elsewhere.

The three regulations described above may constitute examples of pressure regulation algorithms as used by a pressure regulation unit described previously.

In a preferred embodiment, the osmotic system is an osmotic power plant operating by PRO.

In an osmotic power plant, pressure conditions for PRO designates operation under fulfilling $0 < \Delta P < P_{osmotic}$. The optimal pressure conditions are preferably those leading to the largest possible power yield. The power yield obtainable from the pressurized mixed solution is proportional to the volume of mixed solution entering the draw side compartment (i.e. the flux of feed solution solute over the membrane) and to the pressure build-up created by this flux. The more liquid and the higher its pressure build-up, the larger power yield. The power yield (W) may therefore be expressed as proportional to a product of the flux (F) over the membrane and the draw-side pressure build-up (P_1) created by this flux, $W \propto F \cdot P_1$. However, in PRO, flux and draw-side pressure is also related. The flux increases towards pressure conditions for FO, and are maximum for $\Delta P = 0$. Similarly, for ΔP approaching $P_{osmotic}$, the flux approaches zero. Hence, there is an inverse proportionality between F and ΔP, which can be taken as close to linear for gross calculations (see Thorsen et al. Journal of Membrane Science 335 (2009) 103–110), leading to $F \propto -\Delta P$. Thus, for systems with an approximately constant feed-side pressure, $F \propto -P_1$, which leads a power yield $W \propto -P_1^2 + c_P \propto -1/F^2 + c_F$, where c is a constant.

Optimal pressure conditions with respect to achieving a large power yield corresponds to the maxima of the parabola $W \propto -P_1^2$, but precise theoretical expressions for practical osmotic power plants are difficult, if not impossible to make, although boundary conditions $W = 0$ for $\Delta P = 0$ and $\Delta P = P_{osmotic}$ can be assumed. Durng normal operation several parameters might change. By way of example a change in concentration of the draw solution, limitations in the feed/draw supply, fouling of the membrane, etc. Such situation is illustrated in the graph 80 of Figure 6, showing the power yield W as a function of pressure (ΔP) and flow (F). Here, a situation with a first salt concentration in the draw solution represented by osmotic pressure OP1 and optimal pressure P1 corresponding to optimum power production is illustrated by the full curve 81. Hence, in this situation, the draw side pressure may be regulated to P1 to have pressure conditions with higest power yield. The stipled curve 82 then shows a situation where the draw solution concentration has been lowered, which leads to that the osmotic pressure (OP2) as well as the optimum pressure (P2) is shifted towards the left. Accordingly, it will be necessary to regulate the actual pressure down to maintain pressure conditions with higest power yield. If instead the supply of one of the fliuds is restricted, a simular change in situation would occur in that the flow would then be reduced. Curves 83 and 84 show the flow trough the membrane at different pressures, wherecurve 83 is related to curve 81 and curve 84 is related to curve 82. A reduction in the flow would also make a regulation ofthe pressure necessary to maintain an optimum power production.

It is an advantage of the present invention that the power yield may be controlled directly by controlling the working pressure on the draw side compartment. In the prior art, such as in WO 2007/134226, the power yield is indirectly controlled by controlling the flow of sea water into the membrane chamber. Thus, only the flow of draw fluid is controlled. This makes it difficult/impossible to adjust the optimal pressure and thereby the power production based on other parameters than the flow. Examples may be concentration variations in the draw solution, changes in membrane performance, temperature changes, membrane fouling, limitations in available fluid, etc.

Optimal pressure conditions with respect to achieving a large power yield are typically established for $\Delta P \sim \frac{1}{2} P_{osmotic}$. In a preferred embodiment, the flow control means is operated to regulate pressure in the draw side compartment to establish or maintain a predefined pressure in the draw side compartment. The predefined pressure may preferably correspond to pressure conditions $\Delta P \in [\frac{1}{8}P_{osmotic};\frac{7}{8}P_{osmotic}]$, such as preferably $\Delta P \in [\frac{3}{8}P_{osmotic};\ \frac{5}{8}P_{osmotic}]$. In another preferred embodiment, an expression of power yield as a function of pressure conditions, and possibly also as a function of time, is determined empirically for the osmotic power plant or for specific parameters of an osmotic power plant, such as membrane type. The flow control means preferably being operated to regulate pressure in the draw side compartment to establish or maintain a predefined pressure corresponding to maximum power yield as determined from such expression.

In practical operation of an osmotic power plant, neither $P_{osmotic}$ or the maxima of the parabola $E \propto P_1^2$ are constant over time, but are subject to almost constant minor changes. Changes and fluctuations in a large number of parameters as well as impressed restrictions will affect the pressure conditions that allows for efficient and stable power production. These may be e.g. temperature, quality and purity of feed and draw solution, feed solution availability and pressure, solute concentrations in feed and draw solutions, and membrane efficiency, such as when membrane is fouled, clogged, dirty, old, or damaged. Also the abrupt changes in flux when membrane modules are coupled in/out for maintenance purposes impresses similarly sudden changes in the working pressure. All of these are parameters and events that can be fed to the pressure regulation algorithm in the pressure control unit to allow fast and energy efficient control of the working pressure. The change in some of the parameters can be modeled or simulated and some events can be planned so that the algorithm can automatically adjust the desired pressure over time. Others will occur sporadically and may require operator input to the pressure regulation unit. The present invention thereby provides the advantage of fast and energy efficient control of the working pressure to ensure optimal pressure conditions for PRO during operation.

It is foreseen that the feed solution availability may be restricted in some seasons. In a preferred embodiment, the pressure regulation algorithm of the pressure regulation unit is configured to receive an input related to the feed solution availability and: in case of a decrease in the availability, increase the desired pressure; and in case of an increase in the availability, decrease the desired pressure. Based on the newly set desired pressure and the sensed working pressure, the algorithm causes the pressure regulation unit to adjust the flow control means accordingly. Such adjustment will ensure a that flux of feed solution over the membrane is reduced in case of lower feed solution availability, while the power yield is kept high.

In a preferred embodiment, the flow of mixed solution entering the pressure conversion means is adjusted, using the flow control means, to at least substantially correspond to the flow, $F_{osmosis}$, of feed solution over the semi-permeable membrane. Here as well, the flow control means is operated in response to a pressure in the draw compartment and not in reponse to a determination or estimation of the flow over the membrane. In order to do this, the pressure at which the condition is fulfilled may be estimated so that it can be used to control the flow control means. It may be estimated by the module characteristics (determined before the modules are insertes into the plant) such as the response to salt concentration, temperature and cross flow consitions on both sides. During power production the pressure might then be changed depending on the above parameters so that the flow of mixed solution entering the pressure conversion means correspond to the flow, $F_{osmosis}$, of feed solution over the semi-permeable membrane which will in this case give optimal pressure conditions and thus power yield.

In an osmotic power plant, the pressure is preferably built up by osmosis during start-up. The draw-side compartment is filled with draw solution and a flow through the compartment is generated from an inlet, past the semi-permeable membrane to the first outlet connected to the pressure conversion means and/or a second outlet for discharging solution. At the same time, the feed-side compartment is filled with feed solution. Permeation of feed solution through the membrane caused by osmosis will initiate irrespective of the pressure on the draw-side (as long as the pressure is not larger than osmotic pressure), and this will build up pressure in the draw side compartment.

Hence, special conditions are present during start-up of the osmotic system where flow and pressure are generated in the compartments. Here, the flow control means are preferably operated to regulate pressure in the draw side compartment to establish pressure conditions for PRO by:

- when the input from the first pressure sensor indicate a pressure outside a predefined pressure or pressure range, set the flow control means to allow little or no solution to enter the pressure conversion means;
- when the input from the first pressure sensor indicate a pressure within the predefined pressure or pressure range, operate the flow control means to regulate pressure in the draw side compartment by allowing solution to enter the pressure conversion means.

The osmotic power plant preferably further comprises one or more of:

- means for generating a flow of draw solution through the draw side compartment (and thereby replacement of mixed solution at membrane with fresh draw solution), for example a connection to draw solution from a position higher than the draw side compartment (such as a tank, a lake or a sea), a draw solution supply pump, or any a device used to move the draw solution.
- means for generating a flow of feed solution through the feed side compartment, for example a connection to feed solution from a position higher than the draw side compartment (such as a tank, a lake, or a river), a draw solution supply pump, or any device used to move the draw solution.

In a preferred embodiment, the means for generating a flow is provided by a draw solution supply pump in connection with an inlet of the draw side compartment for providing draw solution to the draw side compartment in a continuous manner, the semi-permeable membrane being arranged so that solution in front of the semi-permeable membrane in the draw side compartment is continuously replaced by the flow generated by the draw solution supply pump.

BRIEF DESCRIPTION OF THE FIGURES

Embodiments of the methods and systems according to the invention will now be described with references to the accompanying figures. The figures show one way of implementing the present invention and is not to be construed as being limiting to other possible embodiments falling within the scope of the attached claim set.

Figure 1 describes an exemplary PRO plant serving to describing the preferred features of the invention relating to the regulation of pressure and flow. In this plant, fresh water as well as sea water is fed into separate water filters prior to the streams are passing by one another on each side of a semi-permeable membrane. A portion of the mixture of permeate and salt water with elevated pressure is passed to a turbine for the production of electric power. The balance of the permeate stream is passed to a pressure exchanger where incoming sea water is pressurized. The pressurized sea water is then fed into the membrane module.

Figure 2 shows an enlarged portion of Figure 1, with further details and data flows related to the pressure regulation unit 26.

Figure 3 is an embodiment according to the invention, where the pressure conversion means is a long tube reaching into a water tower. The osmotic pressure from the osmotic membrane module is converted to potential energy of the fluid. The potential energy of the liquid can then subsequently be utilized for convenient purposes.

Figure 4 is an embodiment according to the invention, where the pressure conversion means comprises a pressure exchanger. The osmotic pressure from the osmotic membrane module is converted to potential energy of a second fluid. Compared to the embodiment in Figure 3 the potential energy can in this embodiment be stored in a different liquid such as drinking water.

Figure 5 is a schematic drawing with emphasis on the extent of the draw side compartment and the feed side compartment.

Figure 6 is a graph 80 of the power yield W as a function of pressure (ΔP) and flow (F).

Figure reference numbers

1. Osmotic membrane module
2. Semi-permeable membrane
3. Draw solution/Seawater; of high solute concentration
    31. Draw side compartment/Seawater side compartment
    32. Mixed solution/Brackish water
4. Feed solution/Freshwater; of low solute concentration
    41. Feed side compartment/Freshwater side compartment
    42. Feed solution concentrate/Freshwater concentrate
5. Pressure exchanging means
    51. Draw solution/Seawater side of the pressure exchanging means
    52. Mixed solution/Brackish water side of the pressure exchanging means
6. Turbine
    61. Piping/tubing
    62. Tower
    63. Top tank
    64. Pressure exchanger
    65. Tank
    66. Liquid
    67. Process
7. Pressure conversion means
    71. Pressure converting means (Alternative embodiment)
    72. Pressure converting means (Alternative embodiment)
8. Pressure increasing pump
9. Pressure gauges (9a-c)
10. Draw solution/Seawater supply pump
11. Feed solution/Freshwater supply pump
12. Adjustable feed solution/freshwater supply valve
13. Draw solution/Seawater supply tank
14. Feed solution/Freshwater supply tank
15. Feed solution/Fresh water pressure gauge

19. Osmotic system
20. Adjustable flow control means
21. First outlet of draw side/seawater side compartment
22. Second outlet of draw side/seawater side compartment
23. Inlet of the draw side/seawater side compartment
24. Draw solution/Seawater filter
25. Feed solution/Freshwater filter
26. Pressure regulation unit/Computer
27. Electronic processor/CPU
28. Memory/storage
53. Sensed pressure
54. Internal parameters/restrictions influencing pressure conditions
55. External parameters/restrictions influencing pressure conditions
56. Flow regulation signal
80. Graph of the power yield W as a function of pressure (ΔP) and flow (F)
81. Curve of power yield as a function of pressure and flow.
82. Curve of power yield as a function of pressure and flow.
83. Flow through the membrane as function of pressure.
84. Flow through the membrane as function of pressure.

DETAILED DESCRIPTION OF EMBODIMENTS

In the following, various embodiment of the invention will be described. These embodiments describe only examples of implementing the aspects and embodiments described in the summary of the invention and are not to be construed as being limiting the scope of the attached claim set.

One embodiment of the present invention is an osmotic power plant using the difference in salinity between seawater (draw solution) and freshwater (feed solution) to produce electrical energy by a turbine. A prototype example of such a plant which is to be opened in Tofte, Norway, will be described in detail below with reference to Figure 1.

The osmotic power plant 19 utilizes a semi-permeable membrane 2 separating the seawater 3 from the freshwater 4 to create energy.

The feed side compartment 41 comprises the fluid system below the membrane 2 in Figure 1, and the draw side compartment 31 comprises the fluid system above the membrane 2.

Incoming fresh- and seawater is filtered through automatic filters 24 and 25 of 50 µm mesh size or smaller. The seawater 3 is pumped onto the filter using a seawater supply pump 10. A seawater supply tank 13 is acting as buffer by accumulating the filtered seawater so the supply for the pressure exchanger and following process steps can be steady and furthermore to give sufficient volume to smoothen out differences in pump capacity. The seawater supply tank has a volume of 1.4 m^3 i.e. 1 minute retention time at water flow of 20 l/s. The freshwater supply has the same arrangement with a freshwater supply tank 14, filter 25, and, if necessary, a freshwater supply pump 11 on its inlet side if it is not possible to place the membrane modules below the water surface, typically a river or a lake.

A further use of these buffer tanks can be to enable to run continuously on the supply pumps during cleaning of the osmotic membrane module 1. If the plant stops running or if parts of the membrane area are sealed off during cleaning, but the rest of the membrane area continues to be utilized. No flow or flow through a limited membrane area would therefore require limited flow to the membrane module, which can be accommodated by pumping less water into the system. However since the supply pumps are optimized to a certain flow it is more energy efficient to let the water level build up in the buffer tank and keep the supply pumps running on optimum flow.

Extra measures can be taken to filter the incoming water by placing further filtering means upstream of the osmotic membrane module such as nanofiltering devices. Recurrent chlorination of the membrane can help to avoid fouling i.e. that the membrane gets clogged up with particles or other impurities in the water. Chlorine is oxidizing natural organic material (NOM) clogged up in the membrane, and the NOM can after chlorination more easily be removed. No exact number for the frequency of chlorination can be given, but in a plant dimensioned similar to this one, the experience is that 2 times a day is appropriate using a solution of 5-10 ppm chlorine.

The volume of freshwater 4 through the membrane 2 is determined by the membrane characteristics. Given a working pressure of the draw solution 3, determined by the pressure conversion means 7 and the temperature of the solution, the volume of freshwater through the osmotic membrane module 1 (or flux, l /m^2×h) is determined by the membrane characteristics. The water surface of the freshwater supply tank is higher than the membrane modules and the freshwater 4 will therefore flow towards the membrane due to gravity. Osmosis will draw the freshwater 4 through the membrane to the seawater 3 on the other side of the membrane 2. The volume of freshwater not entering the membrane is called the feed solution concentrate 42, and this volume is preferably in the vicinity of 25% of the incoming feed solution 4, which is controlled by an adjustable nozzle 12.

The freshwater 4 is pumped into the feed side compartment 41 from the freshwater supply tank 14/filter 25 by the pump 11, which seeks to keep the pressure constant. The pump may be placed on either side of the freshwater supply tank 14/filter 25 and starts when the freshwater concentrate 42 volume exceeds a certain level and stops when it goes below the certain level.

The osmotic power plant is build with a total membrane area of 2000 m^2, distributed in 66 modules (only one shown) of 30 m^2 each. From 6 lines (not shown) of 11 modules 5 lines of modules will always be in use i.e. 1650 m^2 membrane area. In theory this gives a permeating volume of $Q_{freshwater}$ = 7,5 l/s at a working pressure of 12 bar on the draw side of the membrane 2.

To provide sufficient difference in salinity between the seawater and the freshwater, a flow of 10 l/s of freshwater and 20 l/s seawater is needed. The volume of the freshwater through the membrane is controlled by the pressure difference over the membrane, which is controlled by the pressure conversion means 7 connected to a first outlet 21 of the draw side compartment, more specifically by the flow control means 20 controlling the volume of mixed solution (brackish water 32) that enters a turbine 6. In this embodiment with the above prescribed volume flows and dimensions the pressure is in the vicinity of 12 bars.

As previously mentioned, the optimal pressure conditions are established for $\Delta P \sim$ ½ $P_{osmotic}$, and for typical fresh-saltwater systems $P_{osmotic} \sim$ 26 bar. In the plant described here, the feed solution pressure is close to 1 bar, so that the draw solution pressure, also referred to as the working pressure, is around 12-14 bar. The working pressure determines the efficiency of the PRO, and thereby the flow of freshwater through the membrane. Applicable volume of freshwater may be restricted by water level e.g. in a river. Typically the volume of needed fresh water will be much less than the accessible amount so the plant always is able work on the maximum possible load.

Pressure exchanging means 5 is provided for transferring pressure from the second outlet 22 to the inlet 23 of the draw side compartment in order to pressurize the saltwater. In addition, a pressure increasing pump 8 can be provided and dimensioned so as to accommodate the pressure difference between the second outlet 22 and the inlet 23, i.e. the loss in the pressure exchanger. There is mass-balance in the pressure exchanger so that the flow of brackish water at outlet 22 is equal to the flow of seawater at the inlet 23, here approximately 20 l/s.

The pressure increasing pump 8 is steered according to a flow measurement, e.g. before the second outlet of the draw side, and determines how efficiently the membrane is utilized. With the right flow, the membrane will be less clogged and concentration gradient better etc. During normal operation salts, particles, etc. tend to get consentrated in the membrane area of the feed side, and on the draw side a decrase in salt concentration may occure unless the fluids flow with a certain speed and thus reduce the concentration polarization.

In the present example, the pressure exchanging means 5 is a purely mechanical component ensuring energy transfer from the low pressure seawater 3 to the high pressure brackish water 32. The pressure exchanging means 5 comprise a rotating cylinder with a number of cylindrical channels connecting the seawater side 51 of the pressure exchanging means with the brackish water side 52. The energy transfer is conducted like this:

1. Low pressure (e.g. 1.6 bar) seawater (LP in), is pushed into one of the channels. The water pushes out brackish water with a lower pressure (LP out) which leaves the pressure exchanger. The difference in pressure between the LP in and LP out depends on the characteristic of the pressure exchanger and is a function of water volume through the pressure exchanger. Increasing volume results in increasing difference in pressure.

2. The cylinder rotates and the cylindrical channel now being filled with seawater is closed in both ends.

3. Now the cylindrical channel is exposed to the high pressure side, high pressure (e.g 12 bar) brackish water (HP in) is therefore entering the cylindrical channel. The water in the cylindrical channel now pushes out the seawater (HP out) with a lower pressure (e.g. 11.8 bar). Also here the difference in pressure will depend on the type and characteristic of the pressure exchanger and is a function of water volume through the pressure exchanger.

The pressure increasing pump 8 receives seawater 3 from the pressure exchanging means 5 after the seawater 3 has been pressurized in the pressure exchanging means 5 by the outgoing brackish water 32. A normal working pressure on the seawater side of the membrane is 12 bar. After the pressure exchanging means the seawater only has a pressure of 11.5 bar and the pressure increasing pump then further pressurizes the seawater to the aimed pressure e.g. 12 bar.

The value from a first pressure sensor in the draw side compartment is used for monitoring the draw side working pressure, P_1, of the brackish water. Reference numerals 9a, 9b and 9c indicate different possible positions of the first pressure sensor. The pressure signal from this is used for regulating the pressure in the draw side compartment in accordance with the invention.

As mentioned, the feed pressure is preferably held approximately constant. Therefore, the pressure P_1 from the first pressure sensor in the draw side compartment is most often also proportional to the differential pressure ΔP over the membrane. However, to control this the system also comprises a pressure sensor 15 in the feed side compartment for measuring a feed side pressure, P_2.

The task of the pressure conversion means 7 is to transform hydraulic pressure produced in the membrane to electrical energy, and furthermore to regulate the pressure on the seawater side of the membrane.

The pressure conversion means 7 is equipped with adjustable flow control means 20, in this embodiment comprising a needle valve or a nozzle on the intake of a hydroelectric turbine or Pelton device 6, which functions as a pressure regulator on the seawater side of the membrane. In an alternative embodiment, the flow control means 20 and the turbine 6 are combined into one unit, e.g. a turbine with adjustable blades which can be used to regulate the flow therethrough (turbine turning or standing still). A certain opening degree of the flow control means 20 corresponds to a certain volume of brackish water 32 entering the turbine 6, which again corresponds to a certain change in the draw side working pressure as well as a certain effect produced by the turbine. In general it can be said that high water volume through the turbine corresponds to a high water volume through the membrane, when the pressure is kept constant.

In a preferred embodiment, a pressure regulation unit 26 operates the flow control means 20, so as to determine the flow to the turbine and to regulate the draw side pressure. The operation of the pressure regulation unit 26 is described in more detail in relation to Figure 2.

The pressure regulation unit 26 is preferably a computer or part of a computer system, typically forming part of an overall control system of the plant. The pressure regulation unit 26 thereby involves an electronic processor 27, such as CPU, and memory 28 used to store data and software applications to be executed bu the processor 27.

The pressure regulation unit holds a preset desired pressure and receives the sensed working pressure 53 from at least a pressure sensor on the draw side. A pressure control software application which can be stored in the memory 28 is used to control the flow control means with the object of regulating the working pressure towards the preset desired pressure. This can involve a pressure regulation algorithm to generate an operation signal 56 to the flow control means 20 to regulate, adjust or set the opening degree of this. For this purpose, i.e. to determine the operation signal 56 from the difference between the sensed pressure 53 and the preset desired pressure, the pressure regulation algorithm can comprise a regulation sub-algorithm such as proportional-integral-differential (PID) regulation.

The desired pressure, towards which the working pressure is regulated, can be determined and preset in different ways. It may be entered manually (e.g. via keyboard) by an operator, which can be advantageous when unusual or highly fluctuating pressure conditions are present. During normal operation, the pressure conditions are influenced by a large number of internal and external parameters and restrictions (54, 55) as described previously. This means that the desired pressure is subject to frequent change, and based on the relevant input (54, 55), the pressure control software application of the pressure regulation unit 26 can determine the desired pressure from a table or formula, typically developed during previous extensive testing and calibration of the plant. It should be noted that the absolute values depends to a large degree of the detailed layout of the individual plant, as well as the characteristics of the sensed pressure to which it is compared (if it is P_1 or ΔP and where in the system it is measured).

Some changes and fluctuations in internal and external parameters and restrictions (54, 55) can be foreseen or planned. For this purpose, the pressure control software application can also comprise the possibility of adjusting the desired pressure based on planned or anticipated changes in the pressure conditions.

Start up procedure

The following describes the start up procedure for the osmotic power plant of the example, during which pressure conditions for PRO are established.

1. When the seawater supply tank 13 and freshwater supply tank 14 reaches a sufficient level, the start up procedure can be started.
2. The air in the system is evacuated.
3. The pressure increasing pump 8 starts to fill the draw side compartment; the pressure will not build up only using the pressure increasing pump 8. While filling the draw side compartment with seawater the cylinder of the pressure exchanger will start to rotate.
4. The adjustable valve 12 is opened to let freshwater 4 enter the feed side compartment. When the feed side compartment is filled with freshwater 4, the freshwater 4 will slowly start to penetrate the membrane 2.
5. When the freshwater 4 has penetrated the membrane, the pressure will begin to build up on the seawater side of the membrane.
6. When a certain threshold pressure is reached, the needle valve 20 will open and the turbine 6 will start to generate power. Alternatively, needle valve 20 will be slightly open from the beginning (e.g. 10% or 20%), and will gradually be opened more and more as pressure builds up due to increased osmosis through membrane.
7. After a certain transient period the pressure reaches a constant and optimum pressure according to the set point and the plant will now run in continuous mode.

Maintaining pressure conditions

The following describes how the pressure conditions are regulated during PRO operation.

The working pressure of the process is controlled by the opening degree of the needle valve and by the characteristics of the membrane. After start up, the working pressure is regulated according to the invention pressure to be close to or equal to a predefined pressure for maintaining pressure conditions for PRO. When the membrane is delivered and installed in a plant, it is advantageous to use only the flow control means to control the working pressure of the process.

The needle valve and nozzle must at any time ensure that the working pressure on the seawater side of the membrane is at a predefined pressure point, measured by the pressure sensors 9a/9b. The regulation of pressure by the needle valve is carried out by the pressure regulation unit using the difference between measured working pressure and the desired pressure to do a proportional-integral-differential (PID) regulation of the opening degree of the needle valve, which ensures a fast and precise control of the pressure conditions. The PID algorithm can be optimized to resist large fluctuations in pressure, to do fast regulation on small fluctuations etc., depending on the special needs for a specific plant.

Osmotic power plants are very complex fluidic systems, and optimal or preferred working pressures is in general not known before the plant is operational, even though large efforts have been put into dimensioning the plant. Moreover, as previously mentioned, the osmotic pressure of the system may change over time which again changes the optimal working pressure. Therefore, the predefined pressure may not be known on beforehand, but may result from initial and /or regular empirical testing of different working pressures to determine working pressures or working pressure ranges which gives the largest power yield or which results in the largest product of the flux (F) over the membrane and the draw-side pressure build-up (P_1) created by the flux, $F{\cdot}P_1$. Optimal pressure conditions as a function of time after changing or cleaning of membranes may be determined, so that the predefined pressure may vary over time. The PID regulation of the needle valve 20 will ensure that the pressure is kept close or equal to the predetermined pressure during fluctuations of conditions.

Figure 3 and 4 illustrates embodiments of osmotic power plants with alternative pressure converting means. Here, the power plant 19 is similar to the one described in relation to Figure 1, except for the pressure converting means 7.

In Figure 3, the pressure converting means 71 comprises flow control means 20 connected to piping or tubing 61 leading to a top tank 63 of a tower 62. The top tank is elevated in relation to the first outlet 21 of the draw side compartment, the elevation being smaller than the absolute water potential at the first outlet 21.

The flow control means 20 can be a valve or nozzle, converting the pressure in the draw side compartment to linear kinetic energy by creating a flow of mixed solution 32 through piping 61. Upon arriving in top tank 63, the kinetic energy of the mixed solution is converted to potential energy. Again, the operation of the flow control means can be used to regulate the pressure in the draw side compartment to establish of maintain PRO pressure conditions in the plant 19.

In Figure 4, the pressure converting means 72 comprises flow control means 20 and a pressure exchanger 64. The pressure exchanger receives the pressurized mixed solution 32 and another liquid 66 from a tank 65 to transfer the hydraulic pressure from the mixed solution 32 to the liquid 66. The mixed solution is thereafter discharged. The pressurized liquid 66 can then be used in another process 67 requiring pressurized liquid. Examples could be applying pressure water to be distributed to households, such as drinking water or heated water, or liquids for used in industrial processes.

In another embodiment (not shown) of the invention an osmotic system based on the forward osmosis principle is used for concentration of dilute, possibly pressurized industrial wastewater. Problems with dilute wastewaters containing heavy metals etc are well-known in modern society. Osmotic systems can be used to concentrate dilute solutions of wastewater using forward osmosis. The diluted wastewater is concentrated by entering the feed side compartment of the osmotic membrane module 1 of Figure 1. An appropriate draw solution with a higher osmotic pressure than the dilute wastewater is supplied in the draw side compartment and pure water is extracted from the wastewater before it leaves the feed side compartment in concentrated form. In order not to pollute the draw solution the membrane must be designed to match the specific pollutant. In such system, one is interested in maximizing the flux over the membrane to thereby remove as much solute from the feed side as possible, and therefore pressure conditions for forward osmosis with $\Delta P=0$ are typically preferred. However, to exploit potential energy released by the mixing, i.e. a resulting pressure, pressure conditions may be adjusted to give PRO, possibly not optimized for power yield, but rather being a compromise between power yield and flux.

Another application could be within food processing, e.g. juice concentration. In food processing, FO has advantages over PRO in terms of the temperature of operation and the retention of sensory qualities of the products (e.g. taste, aroma etc). Therefore FO operation may be preferred in food processing.

If, in the above FO examples the feed solution is pressurized, pressure conditions for obtaining FO can in this embodiment be established by allowing the draw side pressure to build up by osmosis until $\Delta P \sim 0$ is obtained. If none of the compartments are pressurized, FO pressure conditions are established as soon as the compartments are filled. As soon as forward osmosis sets in, the volume in the draw side solution increases, leading to an increased pressure in the draw side compartment. This increased pressure can be regulated according to the invention to maintain zero or near zero pressure difference and thereby maintain FO pressure conditions.

It is to be understood that in all embodiments described in the above, feed solution and draw solution could be others than fresh water and salt water. Other examples may be solutions containing ammonium which can be artificially added to water to form a draw solution, and later removed from the mixed solution using precipitation reactions. Other examples may be wastewater from industrial processes containing high solute concentrations, e.g. from washing of various materials and liquids. Especially interesting are solutions in industrial processes that nevertheless need to be diluted before being suitable for further use or discharge.

Although the present invention has been described in connection with the specified embodiments, it should not be construed as being in any way limited to the presented examples. The scope of the present invention is set out by the accompanying claim set. In the context of the claims, the terms "comprising" or "comprises" do not exclude other possible elements or steps. Also, the mentioning of references such as "a" or "an" etc. should not be construed as excluding a plurality. The use of reference signs in the claims with respect to elements indicated in the figures shall also not be construed as limiting the scope of the invention. Furthermore, individual features mentioned in different claims, may possibly be advantageously combined, and the mentioning of these features in different claims does not exclude that a combination of features is not possible and advantageous.

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CLAIMS

1. An osmotic system (19) comprising:
- a feed side compartment (41) for receiving a feed solution(4);
- a draw side compartment (31) for receiving a draw solution (3);
- a semi-permeable membrane (2) separating said feed and draw side compartments and allowing feed solution from the feed side compartment to enter the draw side compartment by osmosis to form a mixed solution (32);
- pressure conversion means (7) in fluid communication with a first outlet (22) of the draw side compartment for conversion of pressure into another form of energy;
- a pressure exchanger (5) for transferring pressure in the draw side compartment from a second outlet (22) to an inlet (23) of the draw side compartment, the pressure exchanger ensuring mass balance between draw solution received by the inlet and mixed solution leaving the draw side compartment through the second outlet;
- a first pressure sensor (9a, 9b, 9c) for sensing a pressure in the draw side compartment;
- adjustable flow control means (20) for regulating a volume of mixed solution entering the pressure conversion means from the first outlet of the draw side compartment; and
- a pressure regulation unit (26) for regulating pressure in the draw side compartment to maintain pressure conditions for PRO by regulation the volume of mixed solution entering the pressure conversion means from the first outlet through adjustment of an opening degree of the adjustable flow control means in response to a signal from the first pressure sensor .

2. The osmotic system according to claim 1, wherein the first pressure sensor is placed in the draw side compartment between the semi-permeable membrane and the flow control means.

3. The osmotic system according to any of the preceding claims, wherein the pressure regulation unit, after start-up and establishment of stable pressure conditions for PRO of the osmotic system, is configured to operate the flow control

means to regulate pressure in the draw side compartment to maintain pressure conditions for PRO by:

- when the input from the first pressure sensor indicate a decrease in pressure, operate the flow control means to reduce the volume of solution entering the pressure conversion means; and
- when the input from the first pressure sensor indicate an increase in pressure, operate the flow control means to increase the volume of solution entering the pressure conversion means.

4. The osmotic system according to claim 1 or 2, wherein the pressure regulation unit is configured to operate the flow control means in response to a differential pressure, $\Delta P = P_1 - P_2$, between the feed and draw side compartments using signals P_1 and P_2 from the first pressure sensor and a second pressure sensor (15) placed in the feed side compartment, respectively.

5. The osmotic system according to claim 4, wherein the pressure regulation unit, after start-up and establishment of stable pressure conditions for PRO of the osmotic system, is configured to operate the flow control means in the draw side compartment to maintain differential pressure conditions for PRO by:

- when the input from the first and second pressure sensors indicate a decrease in differential pressure, operate the flow control means to reduce the volume of solution entering the pressure conversion means; and
- when the input from the first and second pressure sensors indicate an increase in differential pressure, operate the flow control means to increase the volume of solution entering the pressure conversion means.

6. The osmotic system according to any of the preceding claims, wherein the pressure regulation unit, during start-up of the osmotic system, is configured to operate the flow control means to regulate pressure in the draw side compartment to establish pressure conditions for PRO by:

- when the input from the first pressure sensor indicate a pressure outside a predefined pressure range, set the flow control means to allow little or no solution to enter the pressure conversion means; and

- when the input from the first pressure sensor indicate a pressure within the predefined pressure range, operate the flow control means to regulate pressure in the draw side compartment.

7. The osmotic system according to any of the preceding claims, further comprising a draw solution supply pump (8) in connection with an inlet of the draw side compartment for providing draw solution to the draw side compartment in a continuous manner, the semi-permeable membrane being arranged so that solution in front of the semi-permeable membrane in the draw side compartment is continuously replaced by the flow generated by the draw solution supply pump.

8. The osmotic system according to any of the preceding claims, wherein only the flow control means are operated to regulate the pressure in the draw side compartment after start-up of, and establishment of stable pressure conditions for PRO in, the osmotic system.

9. The osmotic system according to any of the preceding claims, wherein the pressure regulation unit holds pressure control software configured to carry out the following when executed by an electronic processor (27): receiving the sensed pressure from the first pressure sensor and, using a pressure regulation algorithm and a preset desired pressure, generating an operation signal to the flow control means.

10. The osmotic system according to claim 9, wherein the pressure control software is further configured to set an adjusted desired pressure from received input related to feed solution availability.

11. The osmotic system according to any of the preceding claims, wherein the osmotic system is an osmotic power plant operating by PRO, and wherein the flow control means is operated to regulate pressure in the draw side compartment to establish or maintain pressure conditions $\Delta P \in [\frac{1}{8}P_{osmotic}; \frac{7}{8}P_{osmotic}]$, such as preferably $\Delta P \in [\frac{3}{8}P_{osmotic}; \frac{5}{8}P_{osmotic}]$.

12. A method for regulating pressure conditions in an osmotic system (19) comprising a semi-permeable membrane (2) separating a feed side compartment

(41) holding a feed solution (4) and a draw side compartment (31) holding a draw solution (3), pressure conversion means (7) in fluid communication with a first outlet (21) of the draw side compartment for converting pressure generated in the draw side compartment by pressure retarded osmosis (PRO) into energy, and a pressure exchanger (5) for transferring pressure in the draw side compartment from a second outlet (22) to an inlet (23) of the draw side compartment, the method comprising regulating pressure in the draw side compartment to maintain pressure conditions for PRO by adjusting an opening degree of flow control means (20) controlling a volume of mixed solution entering the pressure conversion means from the draw side compartment in response to input relating to a pressure in the draw side compartment from a first pressure sensor placed therein.

13. The method for regulating pressure conditions in an osmotic system according to claim 12, further comprising adjusting, using the flow control means, the flow of mixed solution entering the pressure conversion means to at least substantially correspond to the flow, $F_{osmosis}$, of solvent over the semi-permeable membrane; and wherein the flow control means is operated in response to a pressure in the draw compartment, and not in reponse to a determination or estimation of a flow.

14. The method for regulating pressure conditions in an osmotic system according to claim 12, further comprising:

- receiving information relating to internal or external factors affecting the pressure conditions for PRO;
- setting a new predefined pressure for the draw side compartment;
- using input from the first pressure sensor, regulating the pressure in the draw side compartment towards the new predefined pressure.

15. The method for regulating pressure conditions in an osmotic system according to any of claims 12-14, wherein the regulation is in an osmotic power plant operating by PRO, and wherein the pressure conditions for PRO corresponds to an optimized power yield in the pressure converting means.

1/5

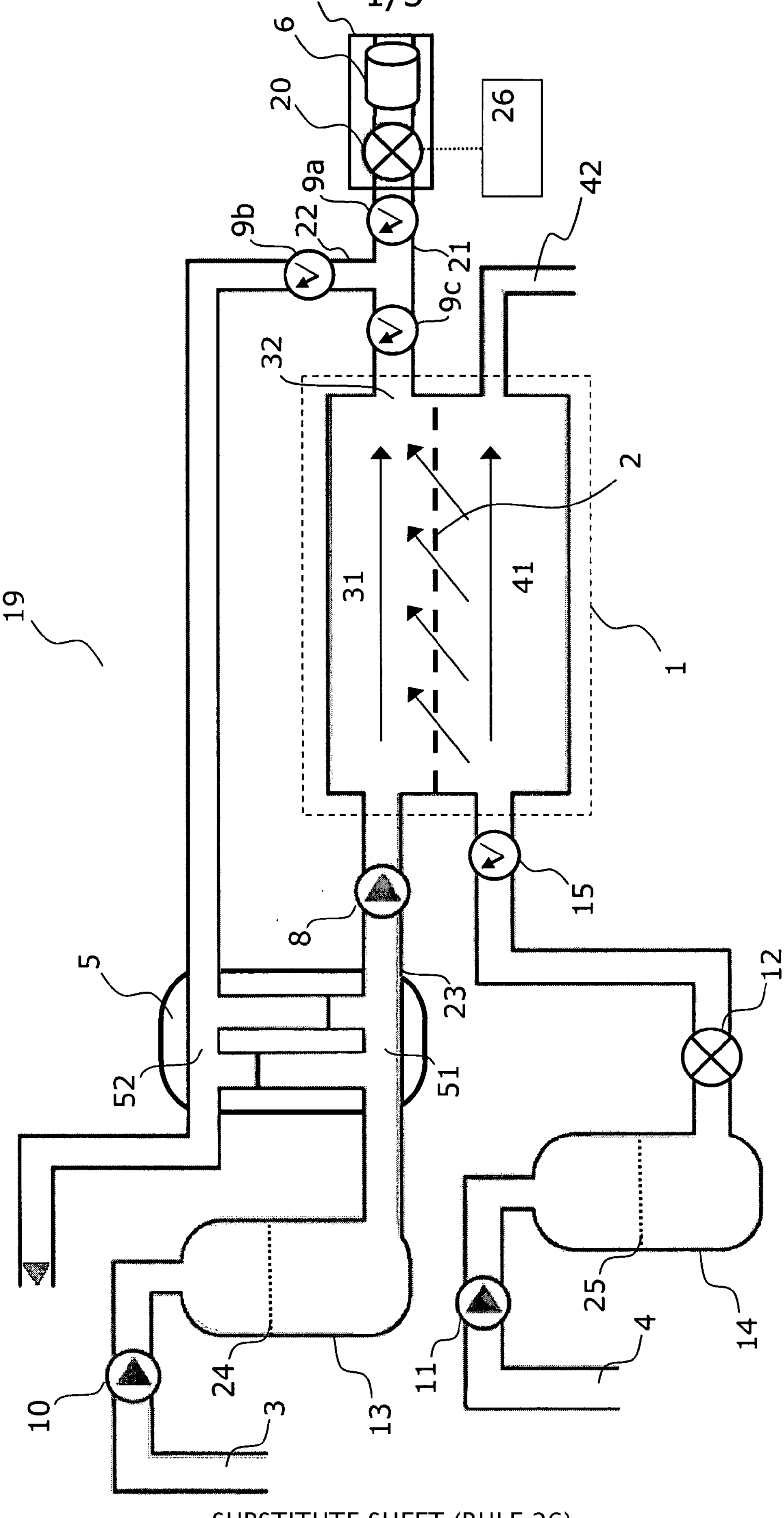
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Fig. 1

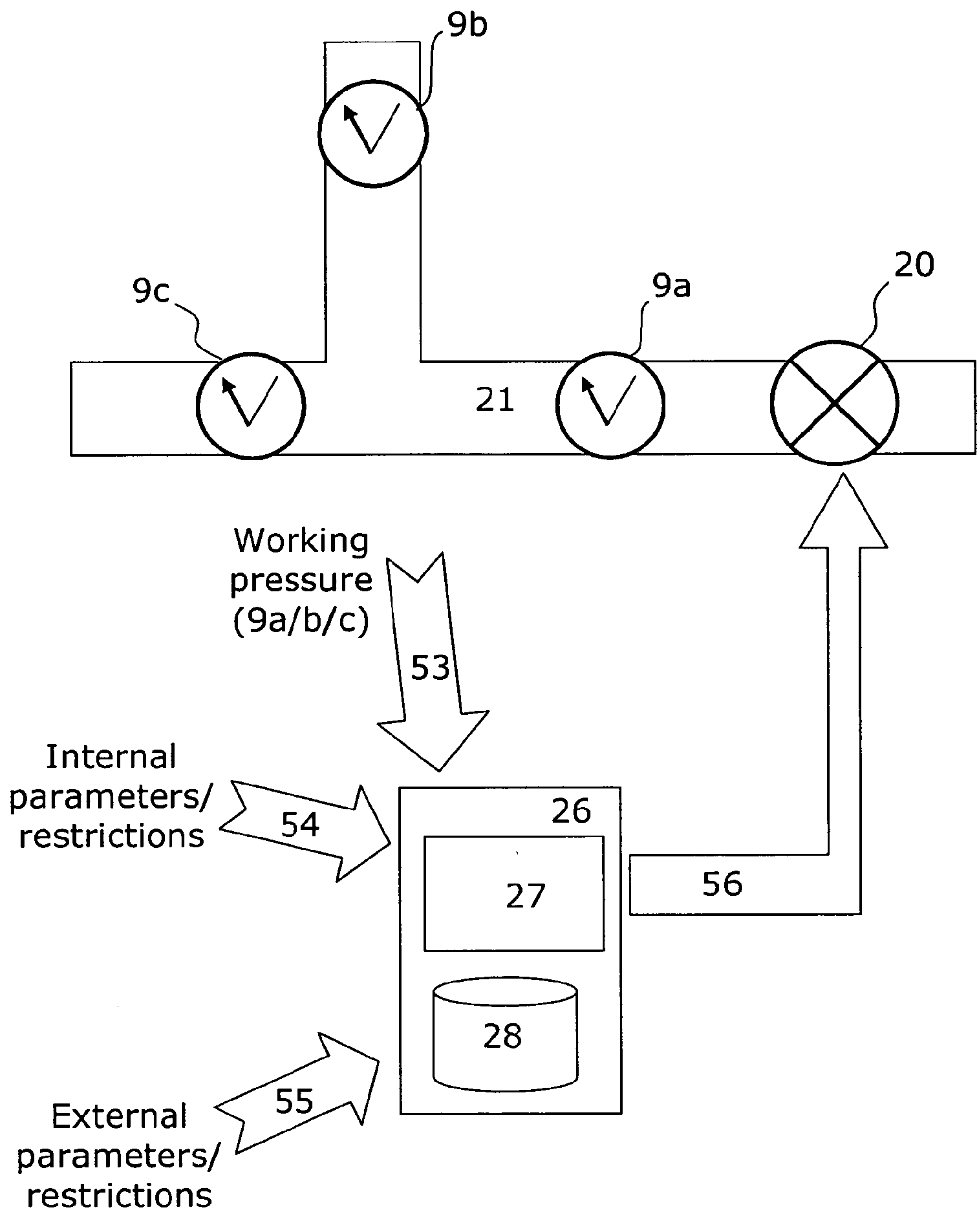
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Fig. 2

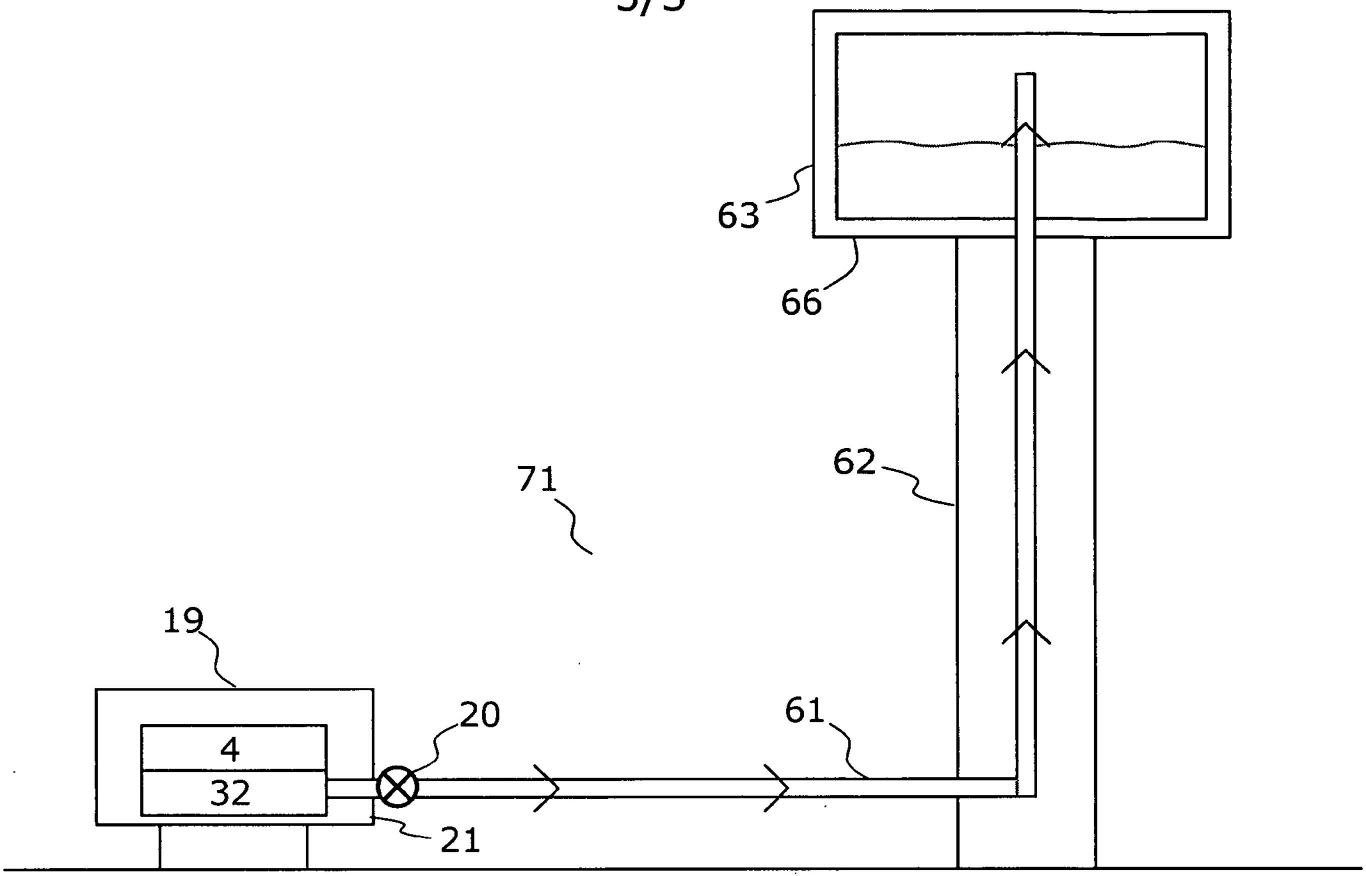

Fig. 3

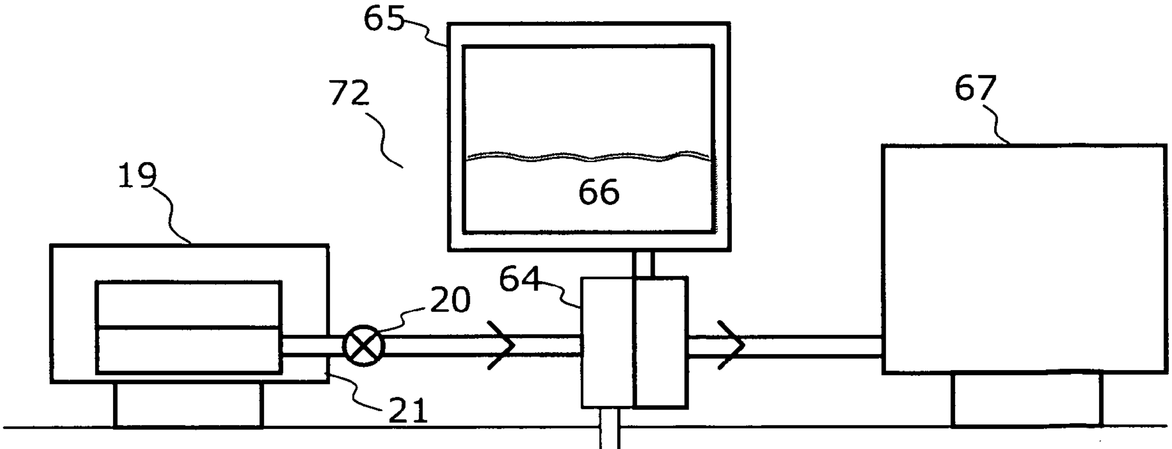

Fig. 4

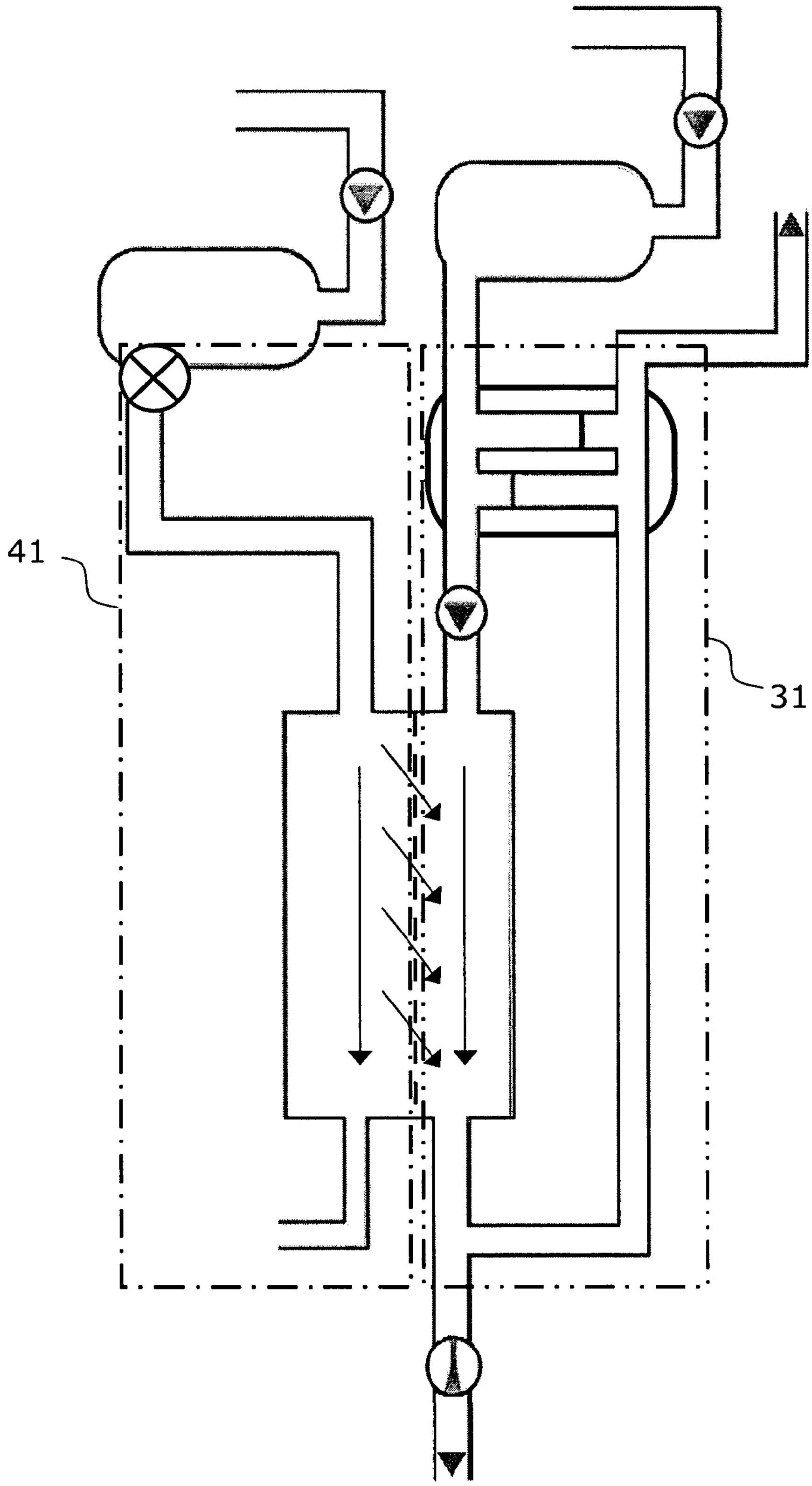

Fig. 5

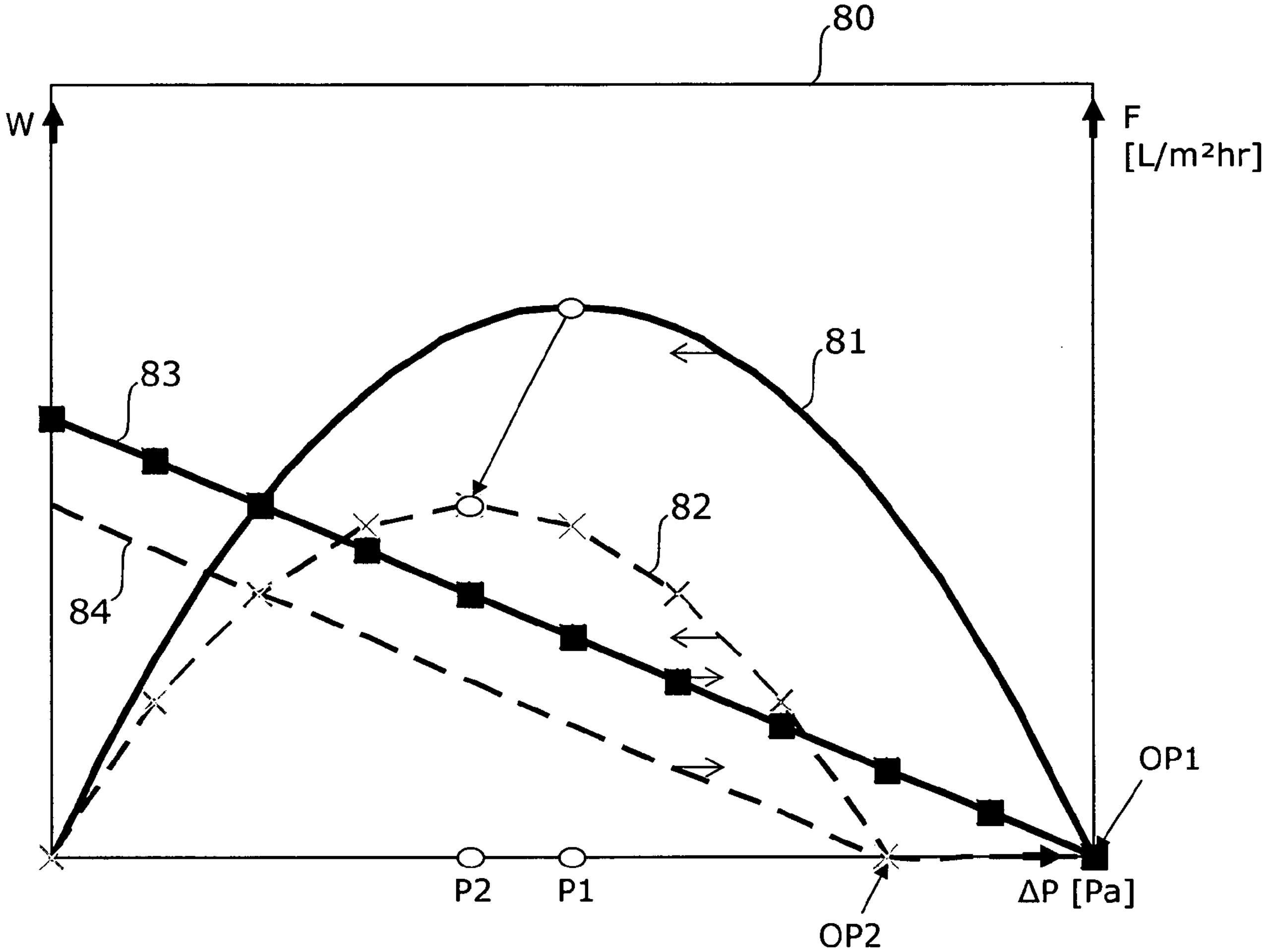

Fig. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2010/068121

A. CLASSIFICATION OF SUBJECT MATTER
INV. B01D61/00 F03G7/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B01D F03G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2007/134226 A1 (ENERGY RECOVERY INC [US]; STOVER RICHARD L [US]; PIQUE GONZALO G [US]) 22 November 2007 (2007-11-22) page 2, line 25 - page 3, line 8 page 3, lines 13-22 page 4, lines 7-21 figures 1,2 page 7, line 9 - page 10, line 21 -----	1-15
A	GB 1 343 891 A (WEINGARTEN M.H., WEINGARTEN J.W.) 16 January 1974 (1974-01-16) page 1, column 1, lines 11-15 page 1, column 2, lines 57-77 page 3, column 2, lines 80-100 page 4, column 2, lines 118-127 page 2, lines 88-97 ----- -/--	1-15

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
7 March 2011	17/03/2011

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Lançon, Eveline

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International application No
PCT/EP2010/068121

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2005/012185 A1 (UNIV SURREY [GB]; SHARIF ADEL [GB]; AL-MAYAHI ABDULSALAM [GB]) 10 February 2005 (2005-02-10) page 2, line 20 - page 3, line 3 page 6, lines 22-32 page 7, lines 2-4 page 28, line 20 - page 29, line 10 -----	1-15
A	US 3 906 250 A (LOEB SIDNEY) 16 September 1975 (1975-09-16) column 1, line 58 - column 2, line 11 -----	1-15
A	US 2006/144789 A1 (CATH TZAHI Y [US] ET AL) 6 July 2006 (2006-07-06) paragraphs [0007], [0013], [0087], [0100] -----	1-15

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2010/068121

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			EP 2021586	A1	11-02-2009
			JP 2009536878	T	22-10-2009
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US 2006144789	A1	06-07-2006	US 2011017666	A1	27-01-2011