

DETECTION APPARATUS AND METHOD USING MEMBRANES

5 FIELD OF THE INVENTION

The present invention relates generally to a detection apparatus and method using membranes for monitoring the integrity of a filtration membrane or the presence of a foulant in a fluid, and more particularly but not exclusively to such a detection apparatus and method having an integrated cleaning function.

BACKGROUND TO THE INVENTION

The use of a detection apparatus or a detection method in a filtration membrane system, where one or more membranes are used to filter a fluid, is generally known. One such detection apparatus and method was proposed by the present applicant in PCT Publication No. WO 2007/129994, the contents of which are incorporated herein by reference. In that apparatus and method, effluent from a filtration membrane is directed through a first permeable membrane and then through a second permeable membrane. The term 'filtration membrane' as used herein denotes one or more membrane filters of a filtration membrane system upstream of the detection apparatus, while the term 'permeable membrane' denotes one or more membranes of the detection apparatus. As effluent passes through the permeable membranes, measurements are made of a first pressure P_1 at a feed side of the first permeable membrane, a second pressure P_2 between the first and second permeable membranes, and a third pressure P_3 at a permeate side of the second permeable membrane. A ratio Π called the relative trans-membrane pressures (TMP) is then determined using the equation $\Pi = (P_1 - P_2)/(P_2 - P_3)$, and is used to determine the integrity of the filtration membrane or the presence of a foulant in the fluid. In the embodiments described, this is done by determining if the ratio Π or a time-derivative of the ratio $d\Pi/dt$ is higher than a respective threshold.

While the above detection apparatus and method provide a relatively simple and inexpensive way in which to monitor the integrity of a filtration membrane or the presence of a foulant in a fluid, drawbacks have been observed in terms of a reduced life of the permeable membranes.

SUMMARY OF THE INVENTION

The present invention is defined in the appended independent claims. Some optional
5 features of the present invention are defined in the appended dependent claims.

In one specific expression, the present invention relates to a detection apparatus comprising a first permeable membrane and a second permeable membrane, a middle section between the first permeable membrane and the second permeable membrane,
10 and at least two pressure sensors configured to produce signals for a determination of a ratio between $(P_1 - P_2)$ and $(P_2 - P_3)$, P_1 being a pressure adjacent an outer surface of the first permeable membrane, P_2 being a pressure between the first and second permeable membranes, and P_3 being a pressure adjacent an outer surface of the second permeable membrane, the apparatus being configured: in a first mode of
15 operation, to allow fluid to permeate from the outer surface of the first permeable membrane to the middle section and out of the second permeable membrane, and in a second mode of operation, to allow fluid to permeate from the middle section to the outer surface of the first permeable membrane.

20 Preferably the apparatus is further configured to allow at least some of the fluid received on the outer surface of the second permeable membrane to permeate through and to flow between the permeable membranes and out of the first permeable membrane.

25 Preferably apparatus further comprises at least one inlet and one outlet configured to reverse the flow between the permeable membranes to switch between the first mode of operation and the second mode of operation. Preferably the at least one inlet comprises a first inlet and a second inlet, and wherein the at least one outlet comprises a first outlet and a second outlet.

30

Preferably the first permeable membrane is configured to allow fluid received at the first inlet to flow over the first permeable membrane to the first outlet, and to allow some of the fluid to permeate through the first and second permeable membranes to flow out of the second outlet, and wherein the second permeable membrane is configured to allow
35 fluid received at the second inlet to flow over the second permeable membrane to the

second outlet, and to allow some of the fluid to permeate through the second and first permeable membranes to flow out of the first outlet.

5 Preferably the first permeable membrane is arranged on a plane that is substantially parallel to a path between the first inlet and the first outlet, and the second permeable membrane is arranged on a plane that is substantially parallel to a path between the second inlet and the second outlet.

10 Preferably the apparatus further comprises a pressure controller arranged upstream of the first and second permeable membranes, the pressure controller being configured to perform one or more selected from the group consisting of: a reduction of the pressure of the fluid to be delivered to the first and second permeable membranes, and a smoothening of the pressure of the fluid to be delivered to the first and second permeable membranes.

15 Preferably the apparatus further comprises a control valve arranged upstream of the first and second permeable membranes and downstream of the pressure controller, the control valve being controllable to direct fluid to one of the first and second permeable membranes. Preferably the control valve is a three-way control valve having a first
20 open position configured to direct fluid to the first inlet, a second open position configured to direct fluid to the second inlet and a closed position configured to prevent fluid from reaching the first and second inlets.

25 Preferably the apparatus further comprises a regulating valve arranged downstream of each of the first and second permeable membranes, each regulating valve being configured to regulate fluid pressure out of the respective permeable membrane.

30 Preferably the middle section includes an inlet configured to receive a fluid directly from a source. Preferably the apparatus in this form further comprises an outlet valve arranged downstream of the second permeable membrane, the outlet valve being configured, when closed, to force fluid from the inlet of the middle section to flow out of the first permeable membrane. Preferably the apparatus also further comprises a pump configured to pump fluid from the source to the inlet of the middle section.

Preferably the first permeable membrane and the second permeable membrane are each supported by a porous plate. Preferably the porous plate has an average pore size of at least 45 μ m, and more preferable of about 100 μ m.

- 5 Preferably the apparatus further comprises an air bleeder configured to vent air trapped between the first and second permeable membranes.

Preferably the apparatus further comprises a plurality of parallel vanes arranged on or adjacent the outer surface of the first and second permeable membranes.

10

Preferably the at least two pressure sensors comprise a first pressure sensor, a second pressure sensor and a third pressure sensor, wherein the first and third pressure sensors are respectively configured to produce signals indicative of the pressure between the first inlet and the first outlet, and the pressure between the second inlet and the second outlet.

15

Preferably the at least two pressure sensors comprise a first differential pressure meter and a second differential pressure meter, wherein the first differential pressure meter is configured to measure the pressure difference of ($P_1 - P_2$) and wherein the second differential pressure meter is configured to measure the pressure difference of ($P_2 - P_3$).

20

In another specific expression, the present invention relates to a detection method using a first permeable membrane, a second permeable membrane and a middle section between the first permeable membrane and the second permeable membrane, each permeable membrane having an outer surface, the method comprising: flowing a fluid from the outer surface of the first permeable membrane to the middle section and out of the second permeable membrane, determining a ratio between ($P_1 - P_2$) and ($P_2 - P_3$), P_1 being a pressure adjacent the outer surface of the first permeable membrane, P_2 being a pressure between the first and second permeable membranes, and P_3 being a pressure adjacent the outer surface of the second permeable membrane, and flowing a fluid from the middle section to the outer surface of the first permeable membrane.

25

30

Preferably the method further comprises flowing a fluid over the outer surface of the second permeable membrane and allowing at least some of the fluid to permeate

through the second permeable membrane and to flow between the permeable membranes and out of the first permeable membrane.

5 Preferably the method further comprises reversing the flow of the fluid between the permeable membranes.

10 Preferably the method further comprises: receiving the fluid at a first inlet and flowing the fluid over the first permeable membrane to a first outlet, with at least some of the fluid permeating through the first and second permeable membranes and flowing out of a second outlet, and receiving the fluid at a second inlet and flowing the fluid over the second permeable membrane to the second outlet, with at least some of the fluid permeating through the second and first permeable membranes and flowing out of the first outlet.

15 Preferably reversing the flow comprises controllably directing fluid to the first permeable membrane or the second permeable membrane.

20 Preferably the method further comprises reducing or smoothening the pressure of the fluid being directed to the first permeable membrane or the second permeable membrane.

Preferably the method further comprises regulating fluid pressure out of the first permeable membrane or the second permeable membrane.

25 Preferably the method further comprises venting air trapped between the first and second permeable membranes.

30 Preferably flowing a fluid from the middle section to the outer surface of the first permeable membrane comprises pumping the fluid from a source to an inlet in the middle section. Preferably the method in this form further comprises restricting the fluid flow out of the second permeable membrane so as to force most of the fluid flowing into the middle section via the inlet to flow out of the first permeable membrane.

35 In a further specific expression, the present invention relates to a treatment system comprising the above described apparatus in fluid communication with an upstream

filtration membrane system, wherein the fluid received on the first or second permeable membrane of the apparatus is an effluent of the upstream filtration membrane system.

Preferably the system further comprises a control unit configured to:

- 5 receive the signals from the pressure sensors of the apparatus,
 determine the ratio between $(P_1 - P_2)$ and $(P_2 - P_3)$, and
 correlate the ratio with one selected from the group consisting of: a failure of the
upstream filtration membrane system and a presence of a foulant in the effluent.

- 10 Preferably the control unit is further configured to direct fluid alternately to the first and
second permeable membranes based on a pre-set interval or a pre-set value of the
ratio between $(P_1 - P_2)$ and $(P_2 - P_3)$.

- 15 Preferably the control unit is further configured to control a collection of the fluid from
outlets of the apparatus, and to control a pump to pump the collected fluid into the
middle section via an inlet in the middle section. Of course, the fluid need not be the
collected fluid but can be any cleaning fluid.

- 20 By using an apparatus, method or system incorporating the features of the independent
claims or of the above specific expressions, a flow reversal at the first permeable
membrane or between the first and second permeable membranes is made possible,
which effectively allows the permeable membranes to be backwashed and cleaned
while the detection apparatus or method is in use. Specifically, by reversing the fluid
flow through the permeable membranes, foulants that have been deposited on or within
25 pores of the permeable membranes can be dislodged. This prevents the permeable
membranes from fouling prematurely and accordingly extends the useful life of the
permeable membranes without requiring downtime to clean the permeable membranes.
Similar advantages apply for embodiments of the invention that provide central
backwashing by introducing or pumping fluid directly into the chamber between the two
30 permeable membranes as opposed to providing flow reversal between the permeable
membranes. This and other advantages arising from the invention will be apparent
from the following description.

BRIEF DESCRIPTION OF THE FIGURES

Preferred embodiments of the apparatus, method and system will now be described with reference to the accompanying figures in which:

5

Figure 1 is a block diagram of the apparatus,

Figures 2A and 2B are block diagrams of the apparatus in a first mode of operation and a second mode of operation respectively,

10

Figure 3 is a flow diagram of the method,

Figure 4 is a block diagram of the system including the apparatus,

15

Figures 5A and 5B are graphs of the test results of the apparatus,

Figures 6A and 6B are block diagrams of alternative embodiments of the apparatus,

20

Figure 7 is a flow diagram of an alternative embodiment of the method, and

Figure 8 is a graph of the test results of the apparatus of Figure 6A.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

25

Referring to Figure 1, the apparatus 100 according to one preferred embodiment includes first and second permeable membranes in the form of a first membrane coupon 102 and a second membrane coupon 104. Each membrane coupon 102, 104 selectively allows certain substances to permeate therethrough but do not allow others to pass through. That is to say, each membrane coupon 102, 104 is porous and allows a permeate to pass through.

30

Membrane coupons 102, 104 are selected so that a given foulant when fed to the membrane coupons will cause fouling of the membrane coupons. Fouling is a process that results in a decrease in performance of a membrane coupon, caused by the

35

deposition of suspended solids on the external or outer surface, on the membrane pores, or within the membrane pores of the membrane coupon. Typical foulants are particles that have sizes larger than the pore sizes of the membrane coupons. Other types of potential foulants will be known to those skilled in the art, and may include
5 other materials that are adsorptive on the membrane surface due to their chemical or physical properties, including but not limited to biofoulants.

Each of the first and second membrane coupons 102, 104 has an outer surface 102a, 104a and an inner surface 102b, 104b, and is configured to allow at least some of the
10 fluid received on the outer surface of one of the membrane coupons to permeate through said one of the membrane coupons, to flow between the membrane coupons and to permeate out of the other of the membrane coupons. Details of one preferred form configuration will be described later with reference to Figures 2A and 2B.

15 At least one inlet and one outlet are provided to allow the flow between the membrane coupons 102, 104 to be reversible. In the embodiment shown, the first membrane coupon 102 is configured to allow fluid received at a first inlet 106 to flow over the outer surface 102a of the first membrane coupon 102 to a first outlet 108, and to allow some of the fluid to permeate through the first membrane coupon 102 and the second
20 membrane coupon 104 to flow out of a second outlet 110. Similarly, the second membrane coupon 104 is configured to allow fluid received at a second inlet 112 to flow over the outer surface 104a of the second membrane coupon 104 to the second outlet 110, and to allow some of the fluid to permeate through the second membrane coupon 104 and the first membrane coupon 102 to flow out of the first outlet 108.

25 The apparatus 100 in this embodiment also includes first, second and third pressure sensors A, B, and C, which are configured to produce pressure signals for a determination of a ratio between $(P_1 - P_2)$ and $(P_2 - P_3)$, P_1 being a pressure adjacent the outer surface 102a of the first membrane coupon 102 (i.e. the pressure between
30 the first inlet 106 and the first outlet 108), P_2 being a pressure between the first membrane coupon 102 and the second membrane coupon 104, and P_3 being a pressure adjacent the outer surface 104a of the second membrane coupon 104 (i.e. the pressure between the second inlet 112 and the second outlet 110). The operation of the sensors A, B and C will be described later in this specification.

35

The apparatus 100 in this embodiment also includes a pressure controller 114 in the form of a pressure reducing valve upstream of the membrane coupons 102, 104 and is connected to the first inlet 106 and the second inlet 112 by pipes or like tubing. As will be described below, the pressure controller 114 is configured to reduce and/or smoothen the pressure of the fluid to be delivered to the membrane coupons 102, 104.

The apparatus 100 also includes a control valve in the form of a three-way valve 116 arranged upstream of the first and second membrane coupons 102, 104 and downstream of the pressure controller 114. In the preferred form, the three-way valve 116 is located between the pressure controller 114 and the first and second inlets 106, 112. The three-way valve 116 has two open positions and a closed position. In the first open position, fluid is directed to the first inlet 106 (i.e. to the first membrane coupon 102) and no fluid is directed to the second inlet 112, while in the second open position, fluid is directed to the second inlet 112 (i.e. to the second membrane coupon 104) and no fluid is directed to the first inlet 106. In the closed position, the three-way valve 116 is configured to prevent fluid from flowing to the first and second membrane coupons 102, 104.

Further valves in the form of regulating valves 118 and 120 are arranged on pipes or like tubing downstream of each of the first and second membrane coupons 102, 104 or downstream of the first outlet 108 and second outlet 110 to regulate the fluid pressure and/or the fluid flow out of the respective membrane coupon or outlet.

Porous plates 122 and 124 are provided to support the first and second membrane coupons 102, 104 while allowing fluid to permeate throughout the surface of the membrane coupons 102, 104. The porous plates 122, 124 each have an average pore size larger than the pores of its membrane coupon so as not to restrict flow through the membrane coupon. In the preferred form, the porous plates 122, 124 are porous steel plates with an average pore size of at least 45 μ m, and more preferably of about 100 μ m.

The apparatus 100 also includes a plurality of parallel vanes 126, 128 arranged on or adjacent the outer surface 102a, 104a of the first and second membrane coupons 102, 104. In the preferred form, the plurality of parallel vanes 126, 128 are arranged between the first inlet 106 and the first outlet 108, and between the second inlet 112 and the second outlet 110. The vanes 126, 128 are configured to guide or direct fluid

received on the outer surface of a membrane coupon to its outlet, or more generally to direct fluid from an inlet to its corresponding outlet. The vanes 126, 128 also act to provide support to the respective membrane coupon 102, 104 during a reverse flow cycle. An air bleeder 130 having two vent channels 130a and 130b is also provided to vent air trapped between the first and second membrane coupons 102, 104 which may otherwise hinder fluid flow between or through the first and second membrane coupons 102, 104.

The operation of above preferred form apparatus will now be described with reference to Figures 2A and 2B. In Figure 2A, fluid (generally indicated with arrow F) is shown entering the apparatus. Specifically, feed from an upstream source is channeled through the pressure controller 114 to smoothen the pressure of the incoming fluid (or pressure P_1 as will be later described) and/or to eliminate excessive upstream pressure.

Once past the pressure controller 114, the fluid is directed to the first inlet 106 by the three-way control valve 116, which is set at the first open position. This provides the following first mode of operation: Fluid at the first inlet 106 skims over the first membrane coupon 102 and is directed to the first outlet 108 by the plurality of parallel vanes 126. Some of the fluid (indicated with broken arrows) permeates through the first membrane coupon 102 and the porous steel plate 122 into a middle section 200. The middle section 200 in the preferred embodiment is substantially in the middle of the distance between the membrane coupons 102, 104, but this is not essential as an asymmetrical arrangement of the middle section 200 between the membrane coupons 102, 104 can be implemented instead. The paths from the porous plates 122, 124 taper towards the middle section 200 to support and secure the porous plates 122, 124 in place while allowing effective capturing of pressure P_2 and, at the same time, providing a maximum permeation surface area at the membrane coupons 102, 104. Air trapped in the middle section 200, which may hinder fluid permeation, is vented through the air-bleeder 130. All of the fluid in the middle section 200 then permeates through the porous steel plate 124 and the second membrane coupon 104 to flow out of the second outlet 110. It will be appreciated that the broken arrows have been illustrated as permeating through the middle of the membrane coupons 102, 104 for clarity only and is therefore not limiting. The actual fluid permeation takes place throughout the surface of the respective membrane coupon.

During the above operation, pressure readings are taken by the first, second and third pressure sensors A, B and C in the locations shown in Figure 1. Sensor A takes readings of P_1 , sensor B takes readings of P_2 , and sensor C takes readings of P_3 . The readings of the pressure sensors are then processed to determine the ratio of trans-membrane pressures Π . As will be appreciated from the applicant's PCT Publication WO 2007/129994, the ratio Π is determined by calculating $(P_1 - P_2)/(P_2 - P_3)$. The calculation may be carried out by a data processing unit or like control unit, which may determine the ratio Π in response to receiving the pressure readings or at any given time. The ratio Π at time t is:

$$\Pi(t) = [(P_1(t) - P_2(t)) / (P_2(t) - P_3(t))]$$

It will be appreciated by skilled persons that $[(P_1(t) - P_2(t))]$ is the trans-membrane pressure for the first membrane coupon 102, while $[P_2(t) - P_3(t)]$ is the trans-membrane pressure for the second membrane coupon 104, making Π the ratio of the two trans-membrane pressures. As disclosed in the applicant's earlier PCT publication, the ratio Π may vary over time and may be correlated with the presence of foulant in the fluid being received in the apparatus and, consequently, a failure of an upstream filtration membrane.

At some point, whether based on a pre-set interval, on a pre-set Π value or on the command of a user, the three-way control valve 116 is moved to the second open position to effect a second mode of operation illustrated in Figure 2B. Here, fluid from the upstream source is directed to the second inlet 112 by the three-way control valve 116 such that it skims over the second membrane coupon 104 and is directed to the second outlet 110 by the plurality of parallel vanes 128. Some of the fluid (indicated with broken arrows) permeates through the second membrane coupon 104 and the porous steel plate 124 into the middle section 200. Air trapped in the middle section 200 is vented through the air-bleeder 130 as in the first mode of operation. All of the permeated fluid in the middle section 200 then permeates through the porous steel plate 122 and the first membrane coupon 102 to flow out of the first outlet 108. At the same time, the role of pressure sensors A and C are reversed – sensor A is used to determine the value of P_3 and sensor C is used to determine the value of P_1 . Pressure readings are continuously taken and processed to determine Π .

One difference between the first mode of operation and the second mode of operation is that the flow between the membrane coupons 102, 104 (i.e. the flow in the middle section) in the first mode is substantially the reverse of (i.e. flows in substantially an opposite direction to) the flow in the second mode. This allows backwashing or cleaning of the membrane coupon out of which the fluid permeates. That is to say, in the second mode of operation of Figure 2B, the first membrane coupon 102 is cleaned by virtue of the flow out of the first membrane coupon 102 dislodging any foulants trapped on or in the pores of the first membrane coupon 102 after the operation of Figure 2A. Similarly, if the first mode of operation, as shown in Figure 2A, is repeated after the second mode of operation, the second membrane coupon 104 would be cleaned by virtue of the flow out of the second membrane coupon 104 dislodging any foulants trapped on or in the pores of the second membrane coupon 104 after the operation of Figure 2B. In the preferred form, only one of the above modes of operation is implemented at any one time, and the membrane coupons are cleaned by alternating between the first and second modes of operation.

As can be seen from Figures 2A and 2B, the first membrane coupon 102 is arranged on a plane that is substantially parallel to the path between the first inlet 106 and the first outlet 108, while the second membrane coupon 104 is arranged on a plane that is substantially parallel to the path between the second inlet 112 and the second outlet 110. This allows incoming fluid to skim over (i.e. flow horizontally as opposed to vertically or being forced through) the membrane coupons 102, 104, thus providing an improved cross-flow over the membrane coupons 102, 104 and prolonging the life of the membrane coupons 102, 104. In the preferred form, the planes of the membrane coupons 102, 104 are substantially parallel to each other.

Although the detection apparatus 100 (and thus the membrane coupons 102, 104) in Figures 1 and 2A and 2B are shown in operation in a horizontal position, it may be preferable to position the apparatus 100 vertically such that the membrane coupons 102, 104 are in a vertical position (or position the membrane coupons 102, 104 vertically themselves). This is advantageous as it eliminates the effect of gravity such that both membrane coupons 102, 104 may foul evenly. In a horizontal position, it has been found that the first membrane coupon 102 fouls more quickly than the second membrane coupon 104. This was attributed to the gravitational effect of the horizontal positioning of the apparatus 100.

Referring now to Figure 3, the method in one preferred embodiment of the invention begins at 300 with the flowing of a fluid over the outer surface of one of the permeable membranes and allowing some of the fluid to permeate through said one of the permeable membranes and to flow between the permeable membranes and out of the other of the permeable membranes. For clarity, the description below assumes that step 300 covers the previously described first mode of operation, where fluid is flowed over the first membrane coupon. This would take place when the three-way control valve is at the first open position illustrated in Figure 2A.

At step 302, the ratio of trans-membrane pressures is determined (i.e. a ratio between $(P_1 - P_2)$ and $(P_2 - P_3)$, P_1 being a pressure between the first inlet and the first outlet, P_2 being a pressure between the first and second permeable membranes, and P_3 being a pressure between the second inlet and the second outlet). Skilled persons will appreciate that the value of the ratio may be determined on a continuous basis (provided pressure measurements are taken continuously) or may be determined at intervals. The value or values of the ratio so determined may be used in the correlation described in the applicant's earlier PCT publication or may alternatively be saved for later processing. Skilled persons will also appreciate that it is possible to use a differential pressure transducer to measure the pressure across each of permeable membranes 102 and 104.

At some point, either based on a pre-set interval, a pre-set Π value or on the command of a user, the method proceeds to step 304 where the flow of the fluid between the permeable membranes is reversed. In the preferred form as described earlier, this occurs in the second mode of operation, which takes place when the three-way control valve is moved to the second open position. This effects a flow between the permeable membranes as illustrated in Figure 2B, which is in substantially the opposite direction to the flow between the permeable membranes as illustrated in Figure 2A. As described earlier, as fluid is flowed from the second inlet over the second permeable membrane to the second outlet, at least some of the fluid permeates through the second permeable membrane and the first permeable membrane to flow out of the first outlet. The effect of the flow at this step is that the fluid that permeates the second membrane coupon and the first membrane coupon is able to dislodge any foulant from, and effectively clean, the first membrane coupon in a backwashing action.

Once the flow is reversed, the method reverts back to step 302 to determine the trans-membrane pressures ratio, this time based on a reversal of roles of sensors A and C as described earlier. The monitoring of the integrity of an upstream filtration membrane
5 therefore continues while the first permeable membrane is in the process of backwashing.

At some later point, either based on a pre-set interval, a pre-set Π value or on the command of a user, the flow of the fluid between the permeable membranes is
10 reversed once again in step 304. This time, the second permeable membrane undergoes backwashing while the apparatus monitors the integrity of the upstream filtration membrane. It will be appreciated that the above operation allows the apparatus to monitor the integrity of the upstream filtration membrane while one permeable membrane is being backwashed.

15 A treatment system embodying the above apparatus and method is shown in Figure 4. The apparatus 100 is shown in fluid communication with a conduit 500 having therein a filtration membrane 502 (or more generally a filtration membrane system) upstream of the apparatus 100. It is clear from the illustration that fluid that is received at the first
20 inlet or second inlet (or on the outer surface of the first and second membrane coupons) of the apparatus 100 is an effluent of the filtration membrane 502. The system also includes a control unit 504 configured to receive the pressure signals from the first, second and third pressure sensors (indicated with solid circles), to determine the ratio Π , and to correlate the ratio with one selected from the group consisting of: a failure of
25 the filtration membrane 502 and the presence of a foulant in the effluent. The control unit 504 is also shown in communication with the pressure controller 114, the three-way control valve 116 and the regulating valves 118 and 120 to control the respective components. This allows the control unit 504 to, amongst others, direct fluid alternately to the first permeable membrane and the second permeable membrane of the
30 apparatus 100 based on a pre-set interval (e.g. every 2 hours), based on a pre-set value of the ratio between $(P_1 - P_2)$ and $(P_2 - P_3)$ (i.e. the control unit 504 causes a flow reversal between the permeable membranes when the measured value of Π is higher than a threshold), or based on a user command. The control unit 504 is also configured to maintain a consistent P_1 value at a pre-set value, to vent air at a pre-set interval/time
35 or user command, and to set the operational pressure of the pressure controller 114.

As will be appreciated from the applicant's earlier PCT publication, when effluent from the upstream filtration membrane 502 is substantially free of foulant, fluid flowing into the apparatus 100 will also be substantially free of foulant. In such a state, the value of the ratio Π will remain relatively constant, and its time derivative will be zero or close to zero. However, when the effluent (and consequently the flow into the apparatus 100), contains a significant amount of foulant, one of the first and second membrane coupons (depending on the position of the three-way control valve 116) will start to foul. Specifically, when the upstream filtration membrane 502 fails, foulant in an influent can pass through the filtration membrane 502 and be subsequently fed to the respective membrane coupon. A substantial amount of foulant being fed to the respective membrane coupon will result in fouling of the membrane coupon, which consequently causes an increase in Π . The rate of change in Π may also increase because slow fouling may exist when the upstream filtration membrane 502 has not failed but after failure, the fouling rate may become significantly faster thus giving rise to a higher rate of change of Π . Thus, the ratio Π or its time derivative $d\Pi/dt$ can be correlated to the presence of foulants and/or a failure of the upstream filtration membrane 502. The operation of the preferred embodiment of the invention in this system is the reversal of the flow between the membrane coupons of the apparatus 100 so as to allow cleaning of the membrane coupons while the apparatus continues to operate as described above. This avoids the need to disconnect or remove the apparatus from the system for cleaning of the membrane coupons or changing the membrane coupons.

Example results obtainable using the apparatus of the invention will now be described with reference to Figures 5A and 5B, which show graphs of test results of the sensitivity of the apparatus. The graphs specifically show the ability of the apparatus to restore the value of the ratio Π after fouling by reversing the flow direction between the membrane coupons.

At point A of Figure 5A, the apparatus was in a first mode of operation under normal operating conditions and the value of Π was set at about 1. The normal value of Π was set by controlling one or both of: (i) the value of P_1 using the pressure controller and/or the regulating valve downstream of the first outlet, or (ii) the value of P_3 using the regulating valve downstream of the second outlet such that the value of $(P_1 - P_2)/(P_2 - P_3)$ is substantially 1.

A simulation was then run at point B1 by dosing Bentonite solution into the fluid being delivered to the apparatus. This simulated the presence of a foulant in the effluent of a filtration membrane.

5

As can be seen from the graph at point B2, the value of Π increased from 1 to 3 in about 29 minutes. In a practical application, such an increase in the value of Π or the rate of change of its value would be sensed by a control unit and compared with a threshold. Assuming the threshold for the value of Π is 1.8, an increase in value to 3 would clearly signify fouling of the first membrane coupon and thus the failure of an upstream filtration membrane.

10

Between points C1 and C2, Bentonite dosing was stopped and the fouled membrane coupons were replaced for a repeat dosing in the reverse cycle/direction.

15

Between C2 and D1, the apparatus was under normal operating conditions in the second mode and the value of Π was adjusted to about 1.

At point D1, a dosing with Bentonite solution was repeated with the apparatus operating in the second mode. As is apparent from point D2 of the graph, this repeated dosing in the reverse cycle resulted in an increase in the Π value from 1 to 3 in about 28 minutes, similar to the dosing result in the normal cycle between points B1 and B2.

20

At point E1, the dosing was continued while the flow between the membrane coupons was reversed (i.e. back to the first mode of operation). Bentonite that had previously fouled the second membrane coupon was washed away and cleaned by a process akin to backwash. The effect of this backwashing is clearly represented by the dropping of the Π value from over 3 back to 1 at about point E2 (representing a restoration of normal operating conditions) in a relatively short frame of time. The advantageous effect of the backwashing can also be seen from Figure 5B, which shows the Π value measured as Bentonite dosing began at point F1, followed by a flow reversal at point F2 20 minutes later. The figure shows the value of Π increasing from 1 to 2 and dropping back to around 1 after the flow reversal at point F2. It then took another 27 minutes before the value of Π increased to 3 at point F3. This shows that fouling was

25

30

detected within an hour (47 minutes in this case) when flow reversal occurred in the midst of fouling.

Figures 6A and 6B show two alternative embodiments of the apparatus of the invention.

5 The pressure sensors have been omitted for clarity. Referring to Figure 6A first, the layout of the detection apparatus is similar to that described earlier with the addition of a pump 600 and a fluid source 602 in fluid communication with an inlet 604 in the middle section 200. In the preferred form, the fluid source 602 is configured to store fluid that flows out of one or more of the outlets described earlier. This is, however, not
10 necessarily so but preferred – it will be appreciated that the fluid can also be cleaning fluid from any external source. Regulating valves 118, 120 downstream of the outlets may be left open to allow fluid from the middle section to exit both membrane coupons 102, 104 or may alternatively be configured to restrict flow out of one of the outlets to optimize backwashing of one of the membrane coupons 102, 104. That is to say, if the
15 first membrane coupon 102 should be backwashed, the regulating valve 120 is closed. In this way, fluid being pumped into the middle section 200 via inlet 604 would be forced to flow out of the first membrane coupon 102 (i.e. from the middle section 200 to the outer surface of the first membrane coupon 102), and is thus able to remove any foulants trapped on or in the pores of the first membrane coupon 102. Conversely, if
20 the second membrane coupon 104 should be backwashed, the regulating valve 118 is closed. Fluid being pumped into the middle section 200 via inlet 604 is therefore forced to flow out of the second membrane coupon 104 (i.e. from the middle section 200 to the outer surface of the second membrane coupon 104), and is thus able to remove any foulants trapped on or in the pores of the second membrane coupon 104. As
25 before, in a first mode of operation, fluid is received on the outer surface of one of the membrane coupons 102, 104 and is directed to the respective outlets with at least some of the fluid being flowed to the middle section 200. In a second mode of operation, the pump 600 is turned on to pump fluid directly into the middle section 200 to flow out of one or both of the membrane coupons 102, 104 in a backwashing action.
30 It will be appreciated that where both membrane coupons 102, 104 are backwashed simultaneously (i.e. where both regulating valves 118, 120 are open), fluid from the middle section 200 will select the lesser-fouled membrane (due to lower resistance) from which to exit. This would result in one membrane being better cleaned than the other.

The above alternative embodiment allows backwashing centrally from the middle section 200 rather than having to rely on a flow reversal between the membrane coupons 102 and 104. A bi-directional detection apparatus, as described earlier in this specification, is therefore not essential to implement the central backwashing process.

5 That is to say, central backwashing can also be applied to the uni-directional detection apparatus disclosed in the applicant's earlier PCT publication. A schematic of this is provided in Figure 6B. The arrow F shows the uni-directional flow of fluid through the apparatus in a first mode of operation. As before, the detection apparatus includes at least two sensors (not shown) for a determination of Π , first and second membrane coupons 102, 104, a middle section 200 in between the membrane coupons 102, 104, and an inlet 604 in the middle section 200 to receive fluid pumped by a pump 600 from a source 602. An outlet valve (not shown) downstream of the second membrane coupon 104 is also provided. This arrangement provides the apparatus with a second mode of operation whereby the outlet valve is closed and the pump is operated to
10 pumped fluid from the source 602 into the middle section 200 via the inlet 604. Given the closure of the outlet valve, the fluid is unable to flow in the usual direction F as before and is therefore forced to go through the first permeable membrane 102 in a backwashing action.

20 Given the above alternative backwashing embodiments, a central cleaning system could be implemented whereby backwash cleaning can be effected for multiple detection apparatus at a time or for a single apparatus at a time.

The method of the above embodiments is shown in the flow diagram of Figure 7. In the first mode of operation, fluid is flowed from the outer surface of the first membrane coupon to the middle section and out of the second permeable membrane, shown as step 700. Step 702 represents the determination of the value of Π as before. When central backwashing should be performed, a second mode of operation is implemented at step 704 whereby fluid is flowed from the middle section to the outer surface of the first permeable membrane (i.e. the reverse of the first mode of operation). As described
30 above, this is done by pumping fluid directly (i.e. not via the membrane coupons) into the middle section via an inlet in the middle section. The fluid being pumped into the middle section preferably, but not necessarily, comes from fluid exiting the second membrane coupon.

35

Example results of the central backwashing embodiment are shown in the graph of Figure 8. Line 1 of the graph represents the Π value, while lines 2, 3 and 4 respectively represent pressures P_1 , P_2 and P_3 . During the time period G1, the detection apparatus was operated in the first and second modes of operation of the earlier embodiment, where fluid was directed from the outer surface of the first membrane coupon to the middle section and out of the second membrane coupon, followed by a reversal of the flow between the membrane coupons by directing fluid from the second membrane coupon to the middle section and out of the first membrane coupon (i.e. a forward/reverse/forward/reverse flow between the membrane coupons). This can be observed from the wavelike shape of the graph during the time period G1. At period G2, central backwashing was carried out at 0.65 bar. The backwashing was carried out on both first and second membrane coupons simultaneously. A visible drop in the value of Π can be seen for a time period G3 after the central backwashing process. Also after the backwash, during the time period G3, the apparatus was again operated in a forward/reverse/forward/reverse manner like in G1. It is notable that the baseline during G3 shifted to a lower level averaging from ~ 1.8 to ~ 0.5 . The upper point of the wave is for one membrane coupon, the lower point of the wave is for the second membrane coupon.

The advantages of the present invention will be apparent to skilled persons from the foregoing description. For instance, by virtue of arranging the apparatus and system of the invention as above, or by carrying out the method of the invention, an efficient cleaning of the membrane coupons is possible without having to cease operation of the invention. Specifically, by providing inlets and outlets such that the flow of fluid between the first and second membrane coupons is reversible or by providing a central backwashing inlet in the middle section, the invention allows each membrane coupon to be backwashed and thus cleaned. The ratio Π or its time derivative $d\Pi/dt$ can therefore be monitored for longer periods at a time without interruption. In the case of backwashing by flow reversal, there is also the related benefit of extending the useful life of the membrane coupons by having a cleaning function that is integral with the operation of the invention. Moreover, where the membrane coupons are each provided on a plane that is parallel to the path between the respective inlet and outlet, most of the fluid into the apparatus skims the membrane coupons rather than being forced through. This has been found to reduce the fouling rate of the membrane coupons. Where a pressure controller is used upstream of the membrane coupons, feed

pressure to the membranes is able to be reduced/smoothened, thus eliminating any fluctuation of P_1 based on erratic feed pressure, which in turn allows a more consistent determination of the ratio Π or its time derivative $d\Pi/dt$ regardless of feed pressure. Similar control is also provided for P_1 and P_3 where regulating valves are implemented downstream of the outlets of the apparatus. Such control allows a calibration of the apparatus to provide the theoretical value 1 for the ratio Π under normal operations. Where parallel vanes are employed on or adjacent the outer surface of the membrane coupons, flushing or removal of fouling/suspended solids in a cross-flow over the membrane coupons is facilitated. The flow of fluid through and between the membrane coupons is also improved by providing porous plates as supports (which allows a full and effective use of the entire surface area of the membrane coupons) and by removing trapped air or air bubbles from the middle section using an air bleeder. This can be contrasted with the invention of the applicant's earlier PCT publication, where membrane coupons were supported by plates with 1mm holes (which would allow permeation only through those holes) and where no dedicate provision was made for the removal of trapped air bubbles.

The foregoing describes a preferred embodiment, which, as will be understood by those skilled in the art, may be subject to variations or modifications in design, construction or operation without departing from the scope of the claims. For instance, it will be appreciated from the above description that it is not essential to provide the two inlets and two outlets as illustrated in the figures. All that is required is an arrangement that permits the flow through at least the first membrane coupon to be reversible to allow backwashing of at least the first membrane coupon. This can be achieved by providing the middle section of the applicant's earlier uni-directional detection apparatus with an inlet (as shown in Figure 6B). For a bi-directional detection apparatus, the backwashing of the first membrane coupon can be achieved, for example, by providing one inlet and one outlet each with one or more internal controllable channels, bifurcations, valves or the like to direct fluid accordingly. Similarly, it is not essential that fluid for flowing between the membrane coupons be obtained directly from the inlets adjacent the membrane coupons. It is conceivable, as outlined with reference to Figures 6A and 6B, that the flow from the first outlet and the second outlet can be collected and, at pre-set time intervals via a pump, the collected solution can be pumped into the chamber between the two membrane coupons (i.e. middle section 200) to effect a central backwashing process. In this instance, the

control valve 116 will be shut and regulating valves 118 and 120 will be open. The solution pumped into the chamber between the first and second membrane coupons will flow across the first and second membrane coupons effectively backwashing the two membrane coupons. The control unit described earlier may be configured to carry out the necessary fluid collection, pumping and valve control to put this into effect. As noted earlier, this central backwashing process may also be applied to the uni-directional apparatus of the applicant's earlier PCT publication.

It is also not essential for a steel porous plate to be provided to support the membrane coupons. Where necessary or desired, other hard materials inert to water (e.g. PVC) may be used instead. Alternatively, the membrane coupons can be supported at its periphery or by a non-porous plate that is provided with sufficient holes to allow the flow of fluid between the membrane coupons. Where a porous plate is provided, the pores need not be limited to the average size of 100µm but may instead be as large as 1mm provided the pores are arranged such that sufficient support is still provided by the plate for its membrane coupon.

It will also be appreciated that the provision of an air bleeder is not essential since, in certain embodiments, air bubbles may be allowed to permeate out of the membrane coupons instead.

In terms of the pressure sensors, it is not essential that three pressure sensors or transducers be provided. It is conceivable that two differential pressure meters may be used that will measure the pressure difference across the first membrane coupon and the second membrane coupon. Where differential pressure meters are used, only two transducers are necessary rather than three since each differential pressure meter has a first tube for placement on one side of a permeable membrane and a second tube for placement on the other side of the permeable membrane. Each differential meter senses the difference across the respective membrane and produces a signal representative of that difference. For the apparatus of the invention, one differential pressure meter may be implemented across the first permeable membrane, and a second implemented across the second permeable membrane. That is to say, one differential pressure meter will measure the pressure across the first membrane coupon, which will give the value for $(P_1 - P_2)$, and a second differential pressure meter will measure the pressure difference across the second membrane coupon, which will

give the value for $(P_2 - P_3)$. The value of Π can be calculated as before using the ratio of the two pressure meter readings.

5 In terms of the regulating valves, calibrated orifices may be used instead where necessary or desired.

10 In terms of the control unit of the system, a computer apparatus may be used to implement the described determinations and controls in hardware, for instance using individual or separate processors programmed to carry out the determination and controls. The control unit may alternatively be implemented in software, as a series of instructions which, when executed by a processor or other computing device, perform the same function as the embodiment described above. A combination of hardware and software implementations may also be used. Also, although the control unit as described and illustrated controls only one detection apparatus of the invention, the control unit may be configured to control a plurality of the detection apparatus (e.g. a network of detection apparatus) instead. Such variations, for instance, are intended to be covered by the scope of the present invention as claimed.

15

CLAIMS

1. A detection apparatus comprising:

a first permeable membrane and a second permeable membrane,

5 a middle section between the first permeable membrane and the second permeable membrane, and

at least two pressure sensors configured to produce signals for a determination of a ratio between $(P_1 - P_2)$ and $(P_2 - P_3)$, P_1 being a pressure adjacent an outer surface of the first permeable membrane, P_2 being a pressure between the first and second permeable membranes, and P_3 being a pressure adjacent an outer surface of the second permeable membrane,

10

the apparatus being configured:

in a first mode of operation, to allow fluid to permeate from the outer surface of the first permeable membrane to the middle section and out of the second permeable membrane, and

15

in a second mode of operation, to allow fluid to permeate from the middle section to the outer surface of the first permeable membrane.

2. The detection apparatus of claim 1, wherein the apparatus is further configured to allow at least some of the fluid received on the outer surface of the second permeable membrane to permeate through and to flow between the permeable membranes and out of the first permeable membrane.

20

3. The detection apparatus of claim 2, wherein the apparatus further comprises at least one inlet and one outlet configured to reverse the flow between the permeable membranes to switch between the first mode of operation and the second mode of operation.

25

4. The detection apparatus of claim 3, wherein the at least one inlet comprises a first inlet and a second inlet, and wherein the at least one outlet comprises a first outlet and a second outlet.

30

5. The detection apparatus of claim 4, wherein the first permeable membrane is configured to allow fluid received at the first inlet to flow over the first permeable membrane to the first outlet, and to allow some of the fluid to

35

permeate through the first and second permeable membranes to flow out of the second outlet, and wherein the second permeable membrane is configured to allow fluid received at the second inlet to flow over the second permeable membrane to the second outlet, and to allow some of the fluid to permeate through the second and first permeable membranes to flow out of the first outlet.

5

6. The detection apparatus of claim 4 or 5, wherein the first permeable membrane is arranged on a plane that is substantially parallel to a path between the first inlet and the first outlet, and the second permeable membrane is arranged on a plane that is substantially parallel to a path between the second inlet and the second outlet.

10

7. The detection apparatus of any one of claims 4 to 6, further comprising a pressure controller arranged upstream of the first and second permeable membranes, the pressure controller being configured to perform one or more selected from the group consisting of: a reduction of the pressure of the fluid to be delivered to the first and second permeable membranes, and a smoothing of the pressure of the fluid to be delivered to the first and second permeable membranes.

15

20

8. The detection apparatus of claim 7, further comprising a control valve arranged upstream of the first and second permeable membranes and downstream of the pressure controller, the control valve being controllable to direct fluid to one of the first and second permeable membranes.

25

9. The detection apparatus of claim 8, wherein the control valve is a three-way control valve having a first open position configured to direct fluid to the first inlet, a second open position configured to direct fluid to the second inlet and a closed position configured to prevent fluid from reaching the first and second inlets.

30

10. The detection apparatus of any one of the preceding claims, further comprising a regulating valve arranged downstream of each of the first and second permeable membranes, each regulating valve being configured to regulate fluid pressure out of the respective permeable membrane.

35

11. The detection apparatus of claim 1, wherein the middle section includes an inlet configured to receive a fluid from a source.

5 12. The detection apparatus of claim 11, further comprising an outlet valve arranged downstream of the second permeable membrane, the outlet valve being configured, when closed, to force fluid from the inlet of the middle section to flow out of the first permeable membrane.

10 13. The detection apparatus of claim 12, further comprising a pump configured to pump fluid from the source to the inlet of the middle section.

14. The detection apparatus of any one of the preceding claims, wherein the first permeable membrane and the second permeable membrane are each
15 supported by a porous plate.

15. The detection apparatus of claim 14, wherein the porous plate has an average pore size of at least 45 μ m.

20 16. The detection apparatus of claim 15, wherein the porous plate has an average pore size of about 100 μ m.

17. The detection apparatus of any one of the preceding claims, further comprising an air bleeder configured to vent air trapped between the first and
25 second permeable membranes.

18. The detection apparatus of any one of the preceding claims, further comprising a plurality of parallel vanes arranged on or adjacent the outer surface of the first and second permeable membranes.

30 19. The detection apparatus of any one of the preceding claims, wherein the at least two pressure sensors comprise a first pressure sensor, a second pressure sensor and a third pressure sensor, wherein the first and third pressure sensors are respectively configured to produce signals indicative of the pressure

between the first inlet and the first outlet, and the pressure between the second inlet and the second outlet.

20. The detection apparatus of any one of claims 1 to 18, wherein the at least
5 two pressure sensors comprise a first differential pressure meter and a second
differential pressure meter, wherein the first differential pressure meter is
configured to measure the pressure difference of $(P_1 - P_2)$ and wherein the
second differential pressure meter is configured to measure the pressure
difference of $(P_2 - P_3)$.

10

21. A detection method using a first permeable membrane, a second permeable
membrane and a middle section between the first permeable membrane and
the second permeable membrane, each permeable membrane having an outer
surface, the method comprising:

15

flowing a fluid from the outer surface of the first permeable membrane to
the middle section and out of the second permeable membrane,

20

determining a ratio between $(P_1 - P_2)$ and $(P_2 - P_3)$, P_1 being a pressure
adjacent the outer surface of the first permeable membrane, P_2 being a
pressure between the first and second permeable membranes, and P_3 being a
pressure adjacent the outer surface of the second permeable membrane, and

flowing a fluid from the middle section to the outer surface of the first
permeable membrane.

25

22. The detection method of claim 21, further comprising flowing a fluid over the
outer surface of the second permeable membrane and allowing at least some of
the fluid to permeate through the second permeable membrane and to flow
between the permeable membranes and out of the first permeable membrane.

30

23. The detection method of claim 22, further comprising reversing the flow of
the fluid between the permeable membranes.

24. The detection method of claim 23, further comprising:

receiving the fluid at a first inlet and flowing the fluid over the first
permeable membrane to a first outlet, with at least some of the fluid permeating

through the first and second permeable membranes and flowing out of a second outlet, and

receiving the fluid at a second inlet and flowing the fluid over the second permeable membrane to the second outlet, with at least some of the fluid permeating through the second and first permeable membranes and flowing out of the first outlet.

25. The detection method of claim 24, wherein reversing the flow comprises controllably directing fluid to the first permeable membrane or the second permeable membrane.

26. The detection method of any one of claims 21 to 25, further comprising reducing or smoothening the pressure of the fluid being directed to the first permeable membrane or the second permeable membrane.

27. The detection method of any one of claims 21 to 26, further comprising regulating fluid pressure out of the first permeable membrane or the second permeable membrane.

28. The detection method of any one of claims 21 to 27, further comprising venting air trapped between the first and second permeable membranes.

29. The detection method of claim 21, wherein flowing a fluid from the middle section to the outer surface of the first permeable membrane comprises pumping the fluid from a source to an inlet in the middle section.

30. The detection method of claim 29, further comprising restricting the fluid flow out of the second permeable membrane so as to force most of the fluid flowing into the middle section via the inlet to flow out of the first permeable membrane.

31. A treatment system comprising the apparatus of any one of claims 1 to 20 in fluid communication with an upstream filtration membrane system, wherein the fluid received on the first or second permeable membrane of the apparatus is an effluent of the upstream filtration membrane system.

32. The treatment system of claim 31, further comprising a control unit configured to:

5 receive the signals from the pressure sensors of the apparatus,
 determine the ratio between $(P_1 - P_2)$ and $(P_2 - P_3)$, and
 correlate the ratio with one selected from the group consisting of: a
failure of the upstream filtration membrane system and a presence of a foulant
in the effluent.

10 33. The treatment system of claim 32, wherein the control unit is further
configured to direct fluid alternately to the first and second permeable
membranes based on a pre-set interval or a pre-set value of the ratio between
 $(P_1 - P_2)$ and $(P_2 - P_3)$.

15 34. The treatment system of any one of claims 31 to 33, wherein the control unit
is further configured to control a collection of the fluid from outlets of the
apparatus, and to control a pump to pump the collected fluid into the middle
section via an inlet in the middle section.