permeate is positioned at the same end of the housing, i.e. opposite the inlet for feed/retentate providing concurrent flow of retentate and permeate.

Membrane module segment or segment – assembly of two or more membrane modules in serial connection

Section – parallel assembly of one or more segments

Loop – assembly of one or more modules or modules which may constitute one or more sections through which fluid feed is forced by a circulation pump.

Summary:

The present disclosure provides a possibility for building both small and large compact apparatus for cross flow membrane filtration comprising membrane modules for filtration processes requiring even very low TMP. The apparatus according to the present disclosure offers a high controllability for TMP of each membrane module, independence of static lift height and allows independently adjustable cross flow.

According to one aspect of the disclosure, the disclosure relates to an apparatus for cross-flow membrane filtration comprising a plurality of n membrane housings (2, ..., n) and a pump (13), where the membrane module (1) positioned immediately downstream of the pump is named the first membrane module (1a),

- each membrane module (1) comprises at least one membrane element (4), one inlet (2) for fluid feed and one outlet (3) for fluid feed, one outlet for permeate (6), and a back-pressure control means (9) such as a valve configured to control the pressure and/or the flow at the outlet for permeate (6),

- each membrane element (4) has a central opening (5) configured to collect permeate and direct the permeate to the outlet for permeate (6), which outlet for permeate (6) is positioned at the same end of the membrane module (1) as the outlet (3) for fluid feed providing concurrent flows in fluid feed and permeate in full length of each membrane module (1), wherein the outlet (3) for fluid feed of the first membrane module (1a) is connected to the fluid inlet (2) of the second membrane module (1b), and if further membrane module(s) is/are present, the outlet (3) for fluid feed of a previous membrane module (n-1) is connected to the fluid inlet (2) of a following membrane module (n), and for the last membrane module (n), the outlet (3) for fluid feed is connected to the inlet (2) for fluid feed of the first membrane module (1a).

The apparatus is directed to working at a low TMP, which is normally the case for microfiltration. That an outlet is connected to an inlet means that at least part of the fluid leaving through the outlet, normally all of the fluid, will enter the inlet.

According to any example of the disclosure, each membrane module (1) may comprise a maximum of four membrane elements, normally each membrane module comprises only one or two membrane elements (4).

According to any example of the disclosure, the number of membrane modules n is: $n \geq 2$, or $n \geq 4$, or $2 \leq n \leq 40$, or $2 \leq n \leq 36$, or $4 \leq n \leq 32$.

The number n of membrane modules refers to membrane modules belonging to one segment, a segment is a group of membrane modules being serially connected on the fluid feed side of the membrane module, i.e. a part of the fluid feed entering the first membrane module of the segment through an inlet for fluid feed exits the first membrane module through an outlet for fluid feed, and the complete amount of fluid feed exiting the first membrane module enters the inlet for fluid feed of the second membrane module, then a part of the fluid feed entering the second membrane module of the segment through the inlet for fluid feed exits the second membrane module through the outlet for fluid feed, and the complete amount of fluid feed exiting the second membrane module enters the inlet for fluid feed of the following membrane module, if such a membrane module exists, etc., and this procedure is repeated for all membrane modules being part of the segment. A part of the fluid feed entering a membrane module will in each membrane module enter into the permeate. The number of membrane modules in a segment and the number of segments in an apparatus will be determined by the desired capacity of the apparatus.

According to any example of the disclosure, the membrane element may be a spiral wound membrane and may e.g. be made of polymer such as cellulose acetate, polyvinylidene fluoride, polyacrylonitrile, polypropylene, polysulfone, polyethersulfone.

According to any examples of the disclosure, an ATD allowing flow of permeate through a central opening of the ATD may be positioned between the membrane elements, if more than one membrane element is applied in one membrane module.

In the context of the present application an ATD allowing flow of permeate through a central opening of the ATD is referred to as a standard ATD.

According to any example of the disclosure, at least one of the membrane modules is positioned above at least one of the other membrane modules, i.e. the fluid feed is pumped upwards when passing from one membrane module to a following membrane module.

According to any example of the disclosure, the plurality of membrane modules may be positioned in layers of 2 or 3 or 4 or more on top of each other, i.e. the fluid feed is pumped upwards when passing through the plurality of membrane modules being part of same segment or same section.

According to any example of the disclosure, at least one membrane module(s), optionally 2, 3, 4 or more or all membrane modules, may comprise a second inlet for a secondary fluid such as washing fluid e.g. water or diafiltration buffer which secondary fluid is added to the feed or retentate flow.

According to any example of the disclosure, where a plurality of membrane modules is positioned in segments of 2 or 3 or 4 or more on top of each other, and the fluid feed is pumped upwards when passing through the plurality of membrane modules, and at least one layer of membrane modules, optionally 2, 3, 4 or more or all layers, each may comprise a second inlet for a secondary fluid such as washing fluid e.g. water or diafiltration buffer, the secondary fluid being added to the feed or retentate flow, and may optionally comprise a common feeding pipe for all membrane modules at one level.

The disclosure also relates to a method for filtrating a liquid comprising the following step,

a) An amount of fluid feed is continuously pumped with pressure P_B through a loop comprising a multiplicity of n membrane modules which modules are serially connected, the fluid feed and permeate flow concurrently through each of the n membrane module(s),

b) generated permeate is continuously drained from each membrane module through a permeate outlet,

c) the permeate pressure or flow at the permeate outlet of each membrane module is controlled keeping TMP within a desired range, optionally the pressure is measured at the feed inlet end and/or at the outlet end of the membrane module,

d) optionally, to obtain a desired separation the number n of membrane modules which the fluid feed flows through may be varied either when designing the separation process or during the separation process i.e. the number of active membrane modules may be varied before or during operation.

According to a second aspect of the disclosure, the disclosure relates to a method for filtrating a liquid in an apparatus for cross-flow membrane filtration comprising the following step,
a) An amount of fluid feed is continuously pumped with pressure P_B through a loop comprising a multiplicity of n membrane modules which modules are serially connected, the fluid feed and permeate flow concurrently through each of the n membrane module(s),

b) generated permeate is continuously drained from each membrane module through a permeate outlet,

c) the permeate pressure at the permeate outlet of each membrane module is controlled keeping TMP within a desired range, optionally the pressure is also measured at the feed inlet end and/or at the outlet end of the membrane module,

d) Optionally, to obtain a desired separation the number n of membrane modules which the fluid feed flows through may be varied either when designing the separation process or during the separation process i.e. the number of active membrane modules may be varied before or during operation.

That membrane modules are serially connected means that the outlet for fluid feed of the first membrane module is connected to the fluid inlet of the second membrane module, and if further membrane module(s) is/are present, the outlet for fluid feed of a previous membrane module (n-1) is connected to the fluid inlet of a following membrane module (n), and for the last membrane module (n), the outlet (3) for fluid feed is connected to the fluid inlet for fluid feed of the first membrane module.

According to an example of the second aspect of the disclosure, a loop may comprise one or two or more Membrane module segment or a loop may comprise one or two or more Sections where a section is a parallel assembly of one or more membrane module segments.

According to any example of the second aspect of the disclosure, a secondary fluid such as a diafiltration buffer may be added to at least one of the n membrane modules, optionally a secondary fluid such as a diafiltration buffer may be added to a plurality of membrane modules, optionally a secondary fluid such as a diafiltration buffer may be added to a plurality of segments of membrane modules at one or 2 or 3 or 4 or more levels or at all levels.

According to any example of the second aspect of the disclosure, the pressure p_1 at the outlet of a first membrane module (1a) may be higher than the pressure p_2 at the outlet of a second membrane module (1b), and similar for the following membrane modules, i.e. $p_1 > p_2 > p_3 > \ldots > p_n$.

According to any example of the second aspect of the disclosure, the pressure at the inlet of the first membrane module may be in the area of 0.05-35 bar, e.g. at 0.1-25 bar or at 0.5-10 bar or at 2-4 bar, and/or the TMP may be in the area of 0.02-12 bar, e.g. 0.07-10 bar, or at 0.2-8 bar, or at 0.3-2 bar.

According to any example of the second aspect of the disclosure, the base line pressure P_{BL} i.e. the pressure with which fluid feed is pumped into the loop, may be above 0.2 bar, or above 0.3 bar, or above 0.5 bar, or above 0,9 bar, or above 1,0 bar.

According to any example of the second aspect of the disclosure, the booster pressure P_B may be above 0.1 bar per module in the loop or segment, i.e. P_B > n times 0.1 bar, or P_B may be above 0.2 bar, or above 0.3 bar, or above 0.4 bar, or above 0.5 bar, or above 0.6 bar, or above 0,9 bar, or above 1, 0 bar per module in the loop or segment. The preferred booster pressure will depend on the application i.e. for which separation process the method is used.

According to any example of the second aspect of the disclosure, the permeate pressure of each module P_{perm} is smaller than or equal to the pressure at the outlet of the module P_{OUT}, i.e. $P_{perm} \leq P_{OUT}$, or e.g. $P_{perm} \leq P_{OUT} + 0,5$ bar.

According to any example of the second aspect of the disclosure, the feed fluid may be a fluid in dairy industry or in dairy ingredients industry or in liquid food industry requiring accurate and same time control of TMP and cross flow, in particular the feed fluid can be feed for protein separation, fat separation, protein fractionation in dairy industry or dairy ingredients industry or liquid food industry, typically the fluid feed may be

- dairy industry and dairy ingredients industry cheese whey or
- dairy industry and dairy ingredients industry cheese whey WPC or
- dairy industry and dairy ingredients industry skim milk or
- dairy industry and dairy ingredients industry skim milk MPC or
- dairy industry and dairy ingredients industry raw whole milk or
- dairy industry and dairy ingredients industry whole milk or
- dairy industry and dairy ingredients industry microfiltration permeates or
- liquid food industry vegetable (green) protein solutions or
- liquid food industry fish protein solutions or
- liquid food industry meat protein solutions or
- liquid food industry microfiltration permeates.

List of figures:

Figure 1 illustrates a single prior art membrane module having counter-current flow in one membrane element;

Figure 2 shows an embodiment of a membrane module of an apparatus according to the invention;

Figure 3 shows an embodiment of an apparatus according to the invention comprising a segment having four membrane modules in series and a circulation loop for retentate;

Figure 4 shows an embodiment of a filtration unit of an apparatus according to the invention comprising a section having four segments and having a matrix of 16 membrane modules;

Figure 5 shows an embodiment of a filtration unit of an apparatus according to the invention comprising 2 sections having a matrix of 28 membrane modules;

Figure 6 shows an embodiment of a filtration unit of an apparatus according to the invention comprising 1 section having a matrix of 32 membrane modules.

Figure 7 shows an embodiment of a filtration unit of an apparatus according to the invention comprising 1 section having 16 membrane modules.