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 described herein 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 on the fluid feed or retentate side, 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. $p_1 > p_2 > p_3 > \ldots > p_n$.

CLAIMS

1. Apparatus for cross-flow membrane filtration comprising a plurality of n membrane modules (2, ..., n) and a pump, 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),

characterized in that 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 fluid inlet (2) for fluid feed of the first membrane module (1a).

2. Apparatus according to claim 1, wherein each membrane module (1) comprises a maximum of four or e.g. of six membrane elements, normally each membrane module comprises one or e.g. two or three membrane elements (4).

3. Apparatus according to any previous claims, wherein $n \geq 2$, or $n \geq 4$, or $n \geq 8$, or $2 \leq n \leq 40$, or $2 \leq n \leq 36$, or $4 \leq n \leq 32$.

4. Apparatus according to any previous claims, wherein an Anti Telescoping Device (ATD) allowing flow of permeate through a central opening of the ATD is positioned between the membrane elements, if more than one membrane element is applied in one membrane module, wherein the membrane element is spiral wound membranes.

5. Apparatus according to any previous claims, wherein 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 the following membrane module.

6. Apparatus according to any previous claims, wherein the plurality of membrane modules is 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.

7. Apparatus according to any previous claims, wherein at least one membrane module(s), optionally 2, 3, 4 or more or all membrane modules, comprises a second inlet (24) for a secondary fluid such as washing fluid or diafiltration buffer which secondary fluid is added to the feed or retentate flow.

8. Apparatus according to any previous claims, wherein a plurality of membrane modules is positioned in segments 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, and at least one layer of membrane modules, optionally 2, 3, 4 or more or all layers, each comprises a second inlet (24) for a secondary fluid such as washing fluid or diafiltration buffer which secondary fluid is added to the feed or retentate flow, and optionally comprises a common feeding pipe (27a, 27b, 27c, 27d) for all membrane modules at one level.

9. Method for filtrating a liquid in an apparatus for cross-flow membrane filtration according to any of the claims 1-8 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 on the fluid feed or retentate side, 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.

10. Method according to claim 9, wherein a secondary fluid such as a diafiltration buffer is added to at least one of the n membrane modules, optionally a secondary fluid such as a diafiltration buffer is added to a plurality of membrane modules, optionally a secondary fluid such as a diafiltration buffer is added to a plurality of segments of membrane modules at one or 2 or 3 or 4 or more levels or at all levels.

11. Method according to claim 9 or 10, wherein the pressure p_1 at the outlet of a first membrane module (1a) is higher than the pressure p_2 at the outlet of a second membrane module (1b), and similar for the following membrane modules, i.e. $p_1 > p_2 > p_3 > \ldots > p_n$.

12. Method according to claim 9 or 10 or 11, wherein the pressure at the inlet of the first membrane module is 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 for

each membrane module is in the area of 0.02-12 bar, e.g. 0.07-10 bar, or at 0.2-8 bar, or at 0.2-2 bar, or at 0.2-1.0 bar.

13. Method according to any of the claims 9-12, wherein the base line pressure P_{BL} i.e. the pressure with which fluid feed is pumped into the loop, is above 0.2 bar, or above 0.3 bar, or above 0.5 bar, or above 0,9 bar, or above 1,0 bar.

14. Method according to any of the claims 9-13, wherein the booster pressure P_B is above 0.1 bar per module in the loop or segment, i.e. $P_B > n \cdot 0.1$ bar, or P_B is 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.

15. Method according to any of the claims 9-14, wherein the fluid feed is 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, alcohol separation or micro-organism separation in dairy industry or dairy ingredients industry, liquid food industry, liquid beverage industry or liquid life science industry, typically the fluid feed is

- 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 or
- beverage solutions.