

APPARATUS WITH MULTI-STAGE CROSS FLOW MEMBRANE FILTRATION

The present invention relates to an apparatus and a method for cross-flow membrane filtration which may be used for filtration processes requiring a controllable low Transmembrane Pressure (TMP) and at the same time a controllable high cross-flow. This may be the case both for microfiltration and for
5 ultrafiltration processes. Particularly, the apparatus is directed to use in preparation of food ingredients where fractionating is required.

Background Art:

A membrane is a thin layer of semi-permeable material that separates substances when TMP is applied to the membrane. Membrane processes are increasingly used for removal of bacteria, microorganisms,
10 particulates, and natural organic material, which can impart color, tastes, and odors to water and react with disinfectants to form disinfection byproducts. As advancements are made in membrane production and module design, capital and operating costs continue to decline. Often used membrane processes are microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO).

Microfiltration (MF) is loosely defined as a membrane separation process using membranes with a pore
15 size of approximately 0.03 to 10 microns (1 micron = 0.0001 millimeter), and a relatively low feed operating pressure of approximately 50 to 400 kPa (7 to 60 psi). Materials commonly removed by MF include sand, silt, clays, Giardia lamblia and Cryptosporidium cysts, algae, and some bacterial species. MF is also used as a pretreatment to RO or NF to reduce fouling potential.

Ultrafiltration (UF) is loosely defined as a membrane separation process using membranes with a pore
20 size of approximately 0.002 to 0.1 microns, a MWCO of approximately 1,000 to 100,000 daltons, and an operating pressure of approximately 120 to 700 kPa (17 to 100 psi). UF will remove all microbiological species removed by MF (partial removal of bacteria), as well as some viruses (but not an absolute barrier to viruses) and humic materials.

The document **WO 2015/135545** discloses an apparatus and a method for membrane filtration. The
25 apparatus has a membrane housing (2) comprising a feed inlet (3) and a feed outlet (4), further, the membrane housing (2) comprises at least two membrane elements (10, 20) each element having an associated permeate tube and outlet (11, 21). WO 2015/135545 teaches how to increase flux of material by placing more than one membrane element in serial position relative to fluid feed flow, but as the permeate flows countercurrent compared to the fluid feed flow, the permeate will face an increasing pressure and
30 increasing incoming flux when flowing towards the feed inlet (3). This feature causes a risk of a dead pocket appearing in the permeate tube closest to the central ATD (15), either during production or during cleaning, which is highly undesirable if the apparatus is used for separating food components such as whey or the like. Also, it is necessary to use a non-standard component in form of the ATD (15) blocking transport of permeate between the membrane elements, contrary to standard operation where the ATD allows
35 transport of permeate through a central opening of the ATD.

The document **WO 2003/055580** discloses a process for ultrafiltration using a spiral wound membrane filter. The document points to that the membrane elements of the apparatus disclosed in WO 2003/055580 may be operated at pressures significantly higher than the pressures known before publication of this document, the membrane elements may be operated at a pressure difference of 2 bar or more between

the entrance and the outlet of a membrane element having a length of approximately 1 meter (see page 6, lines 3-7). The high pressure is established by designing the filter in a way so that the passage between the spiral wound element and the housing is open for incoming fluid at the entrance of the membrane element and blocked or restricted at the outlet of the membrane element. Fig. 11 discloses an embodiment where 4 membrane elements are serially positioned inside a membrane housing, in this embodiment, the flow is also directed toward the inlet of the fluid feed thereby providing the risk of a dead pocket. The prior art documents do not teach how to overcome use of non-standard components and prevent possible dead-pockets in the permeate flow.

Also, the present invention secures concurrent flow directions for both retentate and permeate in all membrane elements using only standard equipment in the modules.

Also, the prior art documents do not teach how to build membrane systems where membrane housing in the same fluid feed loop can be placed on top of each other e.g. in layers e.g. in a square or rectangular matrix while problems relating to increased static pressure are overcome.

Definitions of words:

ATD – Anti Telescoping Device, prevents spiral wound membranes from extending in a longitudinal direction due to liquid flow through the membrane element.

TMP – Trans Membrane Pressure, pressure difference between feed and permeate. The TMP is calculated according to the formula: $TMP = \frac{p_{in} + p_{out}}{2} - p_{perm}$, where p_{in} is the fluid feed/retentate pressure before or at the inlet of a membrane module and p_{out} is the fluid feed/retentate pressure after or at the outlet of a membrane module. p_{perm} is the permeate pressure at the permeate outlet of the module.

Dead leg – or dead pocket is used to describe a piping or the like where flow has ceased creating pockets of stagnant fluid which pockets support microbial amplification in the fluid. This is highly undesirable in systems used to prepare foodstuff or food components or drinking water.

Cross flow – Linear flow along the membrane surface. Purpose is to minimize or control the dynamic layer on the membrane surface.

Pressure loss per membrane element or dP per membrane element or dP/element - is the driving force for the above described cross flow. $dP/element$ is the difference in pressure between p_{in} , pressure of the fluid feed/retentate pressure before or at the inlet of a membrane module, and p_{out} , pressure of the fluid feed/retentate pressure after or at the outlet of a membrane module. $dP/element = p_{in} - p_{out}$.

Membrane element or element - a membrane element is an element comprising or constituted of a membrane which membrane provides a barrier allowing permeate to pass through the membrane and preventing retentate from passing through. In the context of the present application a membrane element may be a spiral wound membrane, where permeate flows from a peripheral position to a central opening of the membrane element.

Membrane module or module – assembly of one membrane housing including or comprising one or more membrane elements and ATDs and similar membrane housing interior, an inlet for fluid feed/retentate, an outlet for retentate and an outlet for permeate through which permeate separated from the one or more membrane elements of the one membrane housing is removed. The outlet for retentate and the outlet for

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

5 *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 of invention:

10 The present invention 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 invention offers a high controllability for TMP of each membrane module, independence of static lift height and allows independently adjustable cross flow.

15 According to one aspect of the invention, the invention 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),

20 - 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
25 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).

30 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 embodiment of the invention, each membrane module (1) may comprise a maximum of four membrane elements, normally each membrane module comprises only one or two membrane elements (4).

35 According to any embodiment of the invention, 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 embodiment of the invention, 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 embodiments of the invention, 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 embodiment of the invention, 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 embodiment of the invention, 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 embodiment of the invention, 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 embodiment of the invention, 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.

According to a second aspect of the invention, the invention 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,
- 5 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
- 10 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
- 15 fluid feed is connected to the fluid inlet for fluid feed of the first membrane module.
- According to an embodiment of the second aspect of the invention, 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 embodiment of the second aspect of the invention, a secondary fluid such as a
- 20 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 embodiment of the second aspect of the invention, the pressure p_1 at the outlet of a first
- 25 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. $p_1 > p_2 > p_3 > \dots > p_n$.
- According to any embodiment of the second aspect of the invention, 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.
- 30 According to any embodiment of the second aspect of the invention, 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 embodiment of the second aspect of the invention, 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
- 35 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 embodiment of the second aspect of the invention, 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. $P_{\text{perm}} \leq P_{\text{OUT}}$, or e.g. $P_{\text{perm}} \leq P_{\text{OUT}} + 0,5 \text{ bar}$.

5 According to any embodiment of the second aspect of the invention, 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
- 10 • 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
- 15 • 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.

20

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;

25 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;

30 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.

Figure 8 illustrates a process carried out in an apparatus according to prior art comprising 10 membrane modules. The apparatus comprises one loop with 10 modules each comprising 1 element, the 10 modules being in hydraulic parallel connection on fluid feed/retentate side.

5 Figure 9 illustrates a process carried out in an apparatus according to prior art comprising 1 membrane module. The apparatus comprises one loop with 1 module comprising 10 elements.

Figure 10 illustrates a process carried out in an apparatus according to the invention comprising 10 membrane modules. The apparatus comprises one loop with 1 segment/section with 10 modules each comprising 1 element, the 10 modules being in hydraulic serial connection on fluid feed/retentate side.

10 Throughout the application identical or similar elements of different embodiments are given the same reference numbers.

Detailed description of invention:

Figure 1 shows an embodiment of a prior art membrane module which is used in the industry today.

The prior art membrane module 1 shown in fig. 1 comprises a housing in which two membrane elements, a first membrane element 4a and second membrane element 4b, are positioned. The membrane elements
15 4a and 4b are spiral wound membranes which may be used for microfiltration or ultrafiltration. Feed or retentate flows through the membrane elements 4a and 4b in a direction from left to right, i.e. from a feed inlet 2 to a feed outlet 3, the permeate passes through the membrane elements 4a and 4b and ends up in a central tube 5a or 5b, either the permeate enters into the first central tube 5a having a permeate outlet 6a or into the second central tube 5b having a permeate outlet 6b. If the permeate ends up in the first central tube 5a the permeate flows in a direction from right to left i.e. counter current to the flow of feed or retentate in the first membrane element 4a, and if the permeate ends up in the second central tube 5b, the permeate flows in a direction from the left to the right, i.e. it flows concurrent to the flow of feed or retentate in the second membrane element 4b. Each central tube 5a and 5b for permeate is provided with a back-pressure valve 9a and 9b and possibly a pressure transmitter 10a and 10b which may be used to
25 control the pressure in the permeate tube and therefore control the TMP in each membrane element. An ATD, respectively 8 and 7b, is positioned at least at the feed outlet end of each membrane element 4a and 4b, an ATD 7a may also be positioned at the permeate outlet end of the first membrane element 4a. The ATD 8 positioned at the feed outlet end of the first membrane element 4a is not a standard ATD as the ATD does not have a central opening, the central opening is closed to prevent the permeate obtained from the first membrane element 4a to flow into the central tube 5b of the second membrane element 4b.
30

According to the prior art membrane module, each membrane element is provided with pressure regulating means contrary to the present invention where each membrane module – no matter the number of membrane elements inside each housing - comprises a single permeate tube or central opening and a single outlet for permeate and therefore also a single means for regulating the pressure at the outlet
35 of the permeate tube or central opening.

A complete facility or apparatus comprising prior art membrane module(s) will normally comprise a circulation pump forcing feed liquid through a plurality of parallelly positioned prior art membrane modules, i.e. each membrane module is fed directly from the pump and the permeate flowing from each

membrane of each membrane module is collected into a common flow as illustrated in fig. 5 in WO 2015/135545 for two membrane modules.

Also, as the first membrane element 4a is constructed having a permeate flow running countercurrent compared to the fluid feed flow, the permeate will face an increasing pressure and an increasing incoming flux as the permeate flow approaches the feed inlet 2 and the permeate outlet 6a. This feature causes a risk of an undefined flow behavior (possible dead leg 11) appearing in the central tube 5a closest to the central ATD 8, either during production or during cleaning. This is highly undesirable if the apparatus is used for separating food ingredients.

Also, it is necessary to use a non-standard component in form of the ATD 8 blocking transport of permeate between the membrane elements 4a and 4b, contrary to a standard operation where the ATD allows transport of permeate through a central opening of the ATD.

The present invention relates to an apparatus for cross-flow membrane filtration working at a low TMP and the apparatus comprises one or more segment(s) where each segment is constituted of a plurality of n membrane modules: 2, 3, 4, ..., n. The membrane modules in one segment are serially connected on the fluid feed or retentate side, i.e. one segment has one inlet for fluid feed which fluid feed is forced through all membrane modules of the segment, whereas a plurality of segments may be either parallelly connected, i.e. each segment may have a separate inlet for fluid feed, or serially connected. The apparatus comprises a loop circulation pump forcing feed or retentate through one or more segment(s) of n membrane modules. A single circulation pump may force the feed or retentate through a segment comprising a plurality of membrane modules, such as two membrane modules or a larger group of membrane modules e.g. 4 or 8 or 16 or 32 membrane modules, or all membrane modules of the apparatus. The maximum number $n_{\max}$ of membrane modules in a loop is determined by the ability of the circulation pump to maintain an adequate pressure in all membrane modules and the ability to maintain a desired TMP. To increase capacity, a single circulation pump may be replaced by a plurality of circulation pumps.

A membrane module positioned immediately downstream of a loop circulation pump is named the first membrane module 1a.

Embodiments of a single membrane module 1 of the present invention are shown in fig. 2A and 2B. The embodiment of a membrane module shown in fig. 2A is without a second inlet for liquid whereas the embodiment of a membrane module shown in fig. 2B has a second inlet for liquid.

Each membrane module 1 will normally only comprise one or two membrane elements 4, possibly up to 4 or up to 6 membrane elements during a microfiltration operation or an ultrafiltration operation.

Each membrane module 1 has one inlet 2 for fluid feed leading fluid feed to an inlet distribution chamber 2a and an outlet distribution chamber 3a wherefrom fluid feed is lead through one outlet 3 for fluid feed, one outlet for permeate 6 and a back-pressure control means 9 configured to control the pressure at the outlet for permeate 6. Each membrane module 1 may also comprise a pressure transmitter 10 which may be used to control the pressure at the permeate outlet 6, e.g. providing an automatic control procedure maintaining a constant pressure at the outlet or maintaining a constant TMP in the membrane module. Also, the feed-side of the membrane module 1 may optionally be provided with a pressure transmitter 12 either at the inlet distribution chamber 2a or at the outlet distribution chamber 3a for more precise control

of the TMP, the presence of a pressure transmitter 12 will increase the likeliness of being able to maintain a constant TMP in a membrane module.

- Each membrane element 4 may have a central tube or opening 5 configured to collect permeate and direct the permeate to the outlet for permeate 6, permeate may flow into the central opening 5 over the full length of the opening 5, and the opening 5 will be closed at the end facing the inlet distribution chamber 2a to prevent unfiltered retentate to enter the opening 5. A central opening 5 is e.g. provided when using a spiral wound membrane as membrane element 4. The outlet for permeate 6 is positioned at the same end of the membrane module 1 as the outlet 3 for fluid feed providing concurrent flow of fluid feed and permeate in the complete length of the membrane element 4 and the membrane module.
- Optionally, a single membrane module 1 according to the present invention may comprise a second inlet 24 as illustrated in fig. 2B, the second inlet 24 may be used to add washing liquid e.g. water or diafiltration buffer to the membrane module 1. The second inlet 24 may lead liquid into the inlet distribution chamber 2a or into the conduit ending at the fluid inlet 2. A membrane module 1 comprising a second inlet 24 may optionally comprise flow control means 25 e.g. in form of a valve controlling the flow through the second inlet 24. Also, a membrane module 1 comprising a second inlet 24 may optionally comprise a flow transmitter 26 which may allow for automatic control of the flow to the membrane module 1.

Although a membrane module 1 comprises a second inlet 24, liquid may not enter into the membrane module 1 through this second inlet 24. The flow of liquid through the second inlet 24 may be continuous or temporary or not take place at all during some operations.

- Fig. 3 disclose part of an apparatus comprising a segment with four membrane modules 1a, 1b, 1c, 1d. 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 1c, 1d, the outlet 3 for fluid feed of the previous membrane module (n-1) is connected to the fluid inlet 2 of the 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 normally via a circulation pump 13.

- The apparatus comprises a storage unit 19 for fluid feed or retentate, the storage unit 19 may be constituted of one or more tanks or containers which may provide a continuous flow of feed or retentate or a mixture between feed and retentate into the membrane modules. A pump 20 e.g. together with a not shown control device such as a frequency converter or valve may control the inlet of retentate or fluid feed to fluid flow recirculating through the membrane modules 1a-1d.

- A loop of recirculating retentate may be provided with an outlet 21 for retentate, the outlet for retentate may be controlled by a valve 22. The outlet for retentate may be positioned upstream of the inlet for new retentate from the storage unit 19. However, if the loop shown in fig. 3 is the first loop in a series of filtration loops providing a further reduction in material content of the circulating fluid, then the loop may be provided with an outlet 23 directing a fraction of the circulating fluid to a second loop, following there might be up to 16 or 20 loops. If a portion of the circulating fluid is directed to a second loop, then the loop shown in fig. 3 will normally not be provided with an outlet 21 for retentate. The loop shown in fig. 3 may be the first loop in a series of loop each comprising an outlet 23 directing circulating fluid to the next loop, in this case normally only the last loop in the series will be provided with an outlet 21 for retentate.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715
716
717
718
719
720
721
722
723
724
725
726
727
728
729
730
731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
774
775
776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796
797
798
799
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
816
817
818
819
820
821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846
847
848
849
850
851
852
853
854
855
856
857
858
859
860
861
862
863
864
865
866
867
868
869
870
871
872
873
874
875
876
877
878
879
880
881
882
883
884
885
886
887
888
889
890
891
892
893
894
895
896
897
898
899
900
901
902
903
904
905
906
907
908
909
910
911
912
913
914
915
916
917
918
919
920
921
922
923
924
925
926
927
928
929
930
931
932
933
934
935
936
937
938
939
940
941
942
943
944
945
946
947
948
949
950
951
952
953
954
955
956
957
958
959
960
961
962
963
964
965
966
967
968
969
970
971
972
973
974
975
976
977
978
979
980
981
982
983
984
985
986
987
988
989
990
991
992
993
994
995
996
997
998
999
1000
1001
1002
1003
1004
1005
1006
1007
1008
1009
1010
1011
1012
1013
1014
1015
1016
1017
1018
1019
1020
1021
1022
1023
1024
1025
1026
1027
1028
1029
1030
1031
1032
1033
1034
1035
1036
1037
1038
1039
1040
1041
1042
1043
1044
1045
1046
1047
1048
1049
1050
1051
1052
1053
1054
1055
1056
1057
1058
1059
1060
1061
1062
1063
1064
1065
1066
1067
1068
1069
1070
1071
1072
1073
1074
1075
1076
1077
1078
1079
1080
1081
1082
1083
1084
1085
1086
1087
1088
1089
1090
1091
1092
1093
1094
1095
1096
1097
1098
1099
1100
1101
1102
1103
1104
1105
1106
1107
1108
1109
1110
1111
1112
1113
1114
1115
1116
1117
1118
1119
1120
1121
1122
1123
1124
1125
1126
1127
1128
1129
1130
1131
1132
1133
1134
1135
1136
1137
1138
1139
1140
1141
1142
1143
1144
1145
1146
1147
1148
1149
1150
1151
1152
1153
1154
1155
1156
1157
1158
1159
1160
1161
1162
1163
1164
1165
1166
1167
1168
1169
1170
1171
1172
1173
1174
1175
1176
1177
1178
1179
1180
1181
1182
1183
1184
1185
1186
1187
1188
1189
1190
1191
1192
1193
1194
1195
1196
1197
1198
1199
1200
1201
1202
1203
1204
1205
1206
1207
1208
1209
1210
1211
1212
1213
1214
1215
1216
1217
1218
1219
1220
1221
1222
1223
1224
1225
1226
1227
1228
1229
1230
1231
1232
1233
1234
1235
1236
1237
1238
1239
1240
1241
1242
1243
1244
1245
1246
1247
1248
1249
1250
1251
1252
1253
1254
1255
1256
1257
1258
1259
1260
1261
1262
1263
1264
1265
1266
1267
1268
1269
1270
1271
1272
1273
1274
1275
1276
1277
1278
1279
1280
1281
1282
1283
1284
1285
1286
1287
1288
1289
1290
1291
1292
1293
1294
1295
1296
1297
1298
1299
1300
1301
1302
1303
1304
1305
1306
1307
1308
1309
1310
1311
1312
1313
1314
1315
1316
1317
1318
1319
1320
1321
1322
1323
1324
1325
1326
1327
1328
1329
1330
1331
1332
1333
1334
1335
1336
1337
1338
1339
1340
1341
1342
1343
1344
1345
1346
1347
1348
1349
1350
1351
1352
1353
1354
1355
1356
1357
1358
1359
1360
1361
1362
1363
1364
1365
1366
1367
1368
1369
1370
1371
1372
1373
1374
1375
1376
1377
1378
1379
1380
1381
1382
1383
1384
1385
1386
1387
1388
1389
1390
1391
1392
1393
1394
1395
1396
1397
1398
1399
1400
1401
1402
1403
1404
1405
1406
1407
1408
1409
1410
1411
1412
1413
1414
1415
1416
1417
1418
1419
1420
1421
1422
1423
1424
1425
1426
1427
1428
1429
1430
1431
1432
1433
1434
1435
1436
1437
1438
1439
1440
1441
1442
1443
1444
1445
1446
1447
1448
1449
1450
1451
1452
1453
1454
1455
1456
1457
1458
1459
1460
1461
1462
1463
1464
1465
1466
1467
1468
1469
1470
1471
1472
1473
1474
1475
1476
1477
1478
1479
1480
1481
1482
1483
1484
1485
1486
1487
1488
1489
1490
1491
1492
1493
1494
1495
1496
1497
1498
1499
1500
1501
1502
1503
1504
1505
1506
1507
1508
1509
1510
1511
1512
1513
1514
1515
1516
1517
1518
1519
1520
1521
1522
1523
1524
1525
1526
1527
1528
1529
1530
1531
1532
1533
1534
1535
1536
1537
1538
1539
1540
1541
1542
1543
1544
1545
1546
1547
1548
1549
1550
1551
1552
1553
1554
1555
1556
1557
1558
1559
1560
1561
1562
1563
1564
1565
1566
1567
1568
1569
1570
1571
1572
1573
1574
1575
1576
1577
1578
1579
1580
1581
1582
1583
1584
1585
1586
1587
1588
1589
1590
1591
1592
1593
1594
1595
1596
1597
1598
1599
1600
1601
1602
1603
1604
1605
1606
1607
1608
1609
1610
1611
1612
1613
1614
1615
1616
1617
1618
1619
1620
1621
1622
1623
1624
1625
1626
1627
1628
1629
1630
1631
1632
1633
1634
1635
1636
1637
1638
1639
1640
1641
1642
1643
1644
1645
1646
1647
1648
1649
1650
1651
1652
1653
1654
1655
1656
1657
1658
1659
1660
1661
1662
1663
1664
1665
1666
1667
1668
1669
1670
1671
1672
1673
1674
1675
1676
1677
1678
1679
1680
1681
1682
1683
1684
1685
1686
1687
1688
1689
1690
1691
1692
1693
1694
1695
1696
1697
1698
1699
1700
1701
1702
1703
1704
1705
1706
1707
1708
1709
1710
1711
1712
1713
1714
1715
1716
1717
1718
1719
1720
1721
1722
1723
1724
1725
1726
1727
1728
1729
1730
1731
1732
1733
1734
1735
1736
1737
1738
1739
1740
1741
1742
1743
1744
1745
1746
1747
1748
1749
1750
1751
1752
1753
1754
1755
1756
1757
1758
1759
1760
1761
1762
1763
1764
1765
1766
1767
1768
1769
1770
1771
1772
1773
1774
1775
1776
1777
1778
1779
1780
1781
1782
1783
1784
1785
1786
1787
1788
1789
1790
1791
1792
1793
1794
1795
1796
1797
1798
1799
1800
1801
1802
1803
1804
1805
1806
1807
1808
1809
1810
1811
1812
1813
1814
1815
1816
1817
1818
1819
1820
1821
1822
1823
1824
1825
1826
1827
1828
1829
1830
1831
1832
1833
1834
1835
1836
1837
1838
1839
1840
1841
1842
1843
1844
1845
1846
1847
1848
1849
1850
1851
1852
1853
1854
1855
1856
1857
1858
1859
1860
1861
1862
1863
1864
1865
1866
1867
1868
1869
1870
1871
1872
1873
1874
1875
1876
1877
1878
1879
1880
1881
1882
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901
1902
1903
1904
1905
1906
1907
1908
1909
1910
1911
1912
1913
1914
1915
1916
1917
1918
1919
1920
1921
1922
1923
1924
1925
1926
1927
1928
1929
1930
1931
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2036
2037
2038
2039
2040
2041
2042
2043
2044
2045
2046
2047
2048
2049
2050
2051
2052
2053
2054
2055
2056
2057
2058
2059
2060
2061
2062
2063
2064
2065
2066
2067
2068
2069
2070
2071
2072
2073
2074
2075
2076
2077
2078
2079
2080
2081
2082
2083
2084
2085
2086
2087
2088
2089
2090
2091
2092
2093
2094
2095
2096
2097
2098
2099
2100
2101
2102
2103
2104
2105
2106
2107
2108
2109
2110
2111
2112
2113
2114
2115
2116
2117
2118
2119
2120
2121
2122
2123
2124
2125
2126
2127
2128
2129
2130
2131
2132
2133
2134
2135
2136
2137
2138
2139
2140
2141
2142
2143
2144
2145
2146
2147
2148
2149
2150
2151
2152
2153
2154
2155
2156
2157
2158
2159
2160
2161
2162
2163
2164
2165
2166
2167
2168
2169
2170
2171
2172
2173
2174
2175
2176
2177
2178
2179
2180
2181
2182
2183
2184
2185
2186
2187
2188
2189
2190
2191
2192
2193
2194
2195
2196
2197
2198
2199
2200
2201
2202
2203
2204
2205
2206
2207
2208
2209
2210
2211
2212
2213
2214
2215
2216
2217
2218
2219
2220
2221
2222
2223
2224

From the feeding pipe 14a, the fluid feed flows into each of first membrane modules 1a in each of the segments A, B, C and D, the fluid feed is then forced through the following membrane modules 1b, 1c, and 1d. In each segment the fluid feed or retentate is collected in the feed outlet pipe 16 wherefrom fluid feed or retentate normally is recirculated to the feeding pipe 14a of the filtration apparatus by a not shown circulation pump. To maintain a continuous process, a flow of new fluid feed is normally added to the fluid feed circulation loop between the outlet pipe 16 and the feeding pipe 14a. Also, a flow of fluid feed or retentate may be removed from the recirculating flow, either as a product or to a second filtration loop, to maintain a desired yield of product.

The permeate flowing from the permeate outlets of each membrane module level are collected in outlet permeate pipes 15a, 15b, 15c and 15d, i.e. the first membrane module 1a of each segment A, B, C and D, has a common outlet permeate pipe 15a, the second membrane module 1b of each segment A, B, C and D, has a common outlet permeate pipe 15b, the third membrane module 1c of each segment A, B, C and D, has a common outlet permeate pipe 15c and the fourth membrane module 1d of each segment A, B, C and D, has a common outlet permeate pipe 15d. A pressure transmitter 10 is positioned in each permeate outlet pipe 15a, 15b, 15c and 15d downstream of the last permeate outlet, as the membrane modules 1 of each level a, b, c or d, are positioned at the same height and as the outlet permeate pipes 15 are horizontal, the pressure is assumed constant in the full length of each outlet permeate pipe and therefore a single common pressure transmitter 10 and a single common back pressure valve for each outlet permeate pipe may provide for proper control of the pressure in each membrane module.

In general, the number of membrane modules 1 being vertically aligned in a segment may be from 2-16, normally between 2-12, e.g. between 2-8, and the number of segments of vertically aligned membrane modules may be from 1-32, e.g. between 2-32 or between 4-16. The optimum number of membrane modules in the vertical dimension as well as the optimum number of sets of vertically aligned membrane modules will depend on the pump capacity and area available for the filtration facility.

Fig. 5 discloses an embodiment of an apparatus according to the invention comprising a double matrix of 16 + 12 membrane modules. The embodiment may comprise the same elements as the embodiments shown in fig. 2 and 3.

This embodiment comprises a first section of 4 segments A, B, C, D of four membrane modules 1 positioned beside each other, each segment comprises four membrane modules 1a, 1b, 1c, 1d as the embodiment of fig.4. To increase the capacity of the apparatus compared to the apparatus of fig. 4, a second section comprising 3 vertically extending segments E, F, G of each four membrane modules 1a, 1b, 1c, 1d has been placed on top of the first section.

The first or lower section of the embodiment comprises the same elements as the embodiment of fig. 4, however the feed outlet of the embodiment of fig. 4 is replaced with a manifold 14b having four inlets receiving fluid feed from each of the lower section segments A, B, C and D, and three outlets distributing fluid feed to the three upper section segments E, F and G.

Fig. 6 discloses an embodiment of an apparatus according to the invention comprising one matrix of respectively 32 membrane modules.

This embodiment comprises one section of 4 segments A, B, C, D of eight membrane modules 1 positioned beside each other, each segment comprises eight membrane modules 1a, 1b, 1c, 1d, 1e, 1f, 1g, 1h. The embodiment may comprise the same elements as the embodiments shown in fig. 2 and 3.

- 5 To provide an optimized flow of fluid feed into the membrane modules positioned at the top or upper half of the segments, a supply of feed fluid may be distributed directly to membrane modules at the top or upper half of the segments, e.g. via a supply pipe 14c. The flow to the supply pipe 14c may be controlled by a flow transmitter 17 and a valve 18. The fluid feed to the supply pipe 14c may be distributed by the same pump or pumping system supplying the fluid feed to the first membrane module 1a of each segment A, B, C and D.

- 10 Fig. 7 discloses an embodiment of an apparatus according to the invention comprising a matrix of 16 membrane modules ($n=16$).

This embodiment – like the embodiment of fig. 4 - comprises four segments A, B, C, D and each segment A, B, C and D comprises four membrane modules 1a, 1b, 1c, 1d. The connections between the membrane modules of one segment may be as shown in fig. 3.

- 15 In the embodiment shown in fig.7, the four segments are identical, permeate is drained from the fluid feed or retentate from a permeate outlet 6 of each membrane module and collected into a single flow at each membrane module level a, b, c and d, also, each membrane module comprises a second inlet 24 at the feed-inlet end of the membrane module.

- 20 In the shown embodiment, the membrane modules 1a, 1b, 1c, 1d of each segment are placed on top of each other, where the membrane modules 1a are lowest and the membrane modules 1d are at the top. The membrane modules within a segment A, B, C and D are serially connected at the feed side of the membrane modules, i.e. the fluid feed or retentate exiting the last membrane module 1d may be pumped to the first membrane module 1a of either the same segment or to a common feed container receiving circulating feed or retentate from all four segments.

- 25 The four segments A, B, C, D each comprise vertically aligned membrane modules which may be fed with fluid feed or retentate from a common feeding pipe 14a, the feeding pipe 14a may be fed by a single pump or by a pumping system.

- 30 Also, each membrane module at each level 1a, 1b, 1c or 1d may be fed with secondary liquid through a common feeding pipe for each level 27a, 27b, 27c or 27d. Each of the common feeding pipes for secondary liquid 27a, 27b, 27c or 27d may comprise inlet control means e.g. comprising an inlet valve 25a, 25b, 25c and 25d for each level (25b and 25d are not shown on fig. 7 as they are hidden behind the apparatus), e.g. in combination with a flow transmitter 26a, 26b, 26c, 26d (26b and 26d are not shown on fig. 7 as they are hidden behind the apparatus). In the shown embodiment all levels comprise a common inlet for secondary fluid, it is however optional to feed all levels with secondary liquid, i.e. some levels may not be supplied with secondary liquid. E.g. the first and the last level of membrane modules may not be fed with secondary fluid, in the embodiment of fig. 7 this would be the first level (1a) and the fourth level (1d).

When using a constant pressure pump system, the static pressure p_{s1} in the feeding pipe 14a may be kept constant.

From the feeding pipe 14a, the fluid feed flows into each of first membrane modules 1a, i.e. the first level a, in each of the segments A, B, C and D, the fluid feed is then forced through the following membrane modules 1b, 1c, and 1d. From the last membrane module 1d of each segment the fluid feed or retentate is collected in the feed outlet pipe 16 wherefrom fluid feed or retentate normally is recirculated to the feeding pipe 14a of the filtration apparatus by a not shown circulation pump. To maintain a continuous process, a flow of new fluid feed may be added to the fluid feed circulation loop between the outlet pipe 16 and the feeding pipe 14a. Also, a flow of fluid feed or retentate may be removed from the recirculating flow, either as a product or to a second filtration loop, to maintain a desired yield of product.

The permeate flowing from the permeate outlets of each membrane module level are collected in outlet permeate pipes 15a, 15b, 15c and 15d, i.e. the first membrane module 1a of each segment A, B, C and D, has a common outlet permeate pipe 15a, the second membrane module 1b of each segment A, B, C and D, has a common outlet permeate pipe 15b, the third membrane module 1c of each segment A, B, C and D, has a common outlet permeate pipe 15c and the fourth membrane module 1d of each segment A, B, C and D, has a common outlet permeate pipe 15d. Compared to the embodiment of fig. 4 where no secondary fluid is added, the amount of permeate will have increased as the majority of secondary fluid normally passes through the filter and ends up in the permeate fraction.

A pressure transmitter 10 is positioned in each permeate outlet pipe 15a, 15b, 15c and 15d downstream of the last permeate outlet, as the membrane modules 1 of each level a, b, c or d, are positioned at the same height and as the outlet permeate pipes 15 are horizontal, the pressure is assumed constant in the full length of each outlet permeate pipe and therefore a single common pressure transmitter 10 and a single common back pressure valve for each outlet permeate pipe may provide for proper control of the pressure in each membrane module.

A pressure transmitter 12 is positioned at the outlet distribution chamber 3a at each membrane module or at each level i.e. a, b, c, d, ... in a section, to improve the possibility for controlling the TMP at each level and thereby control the separation process.

In general, the number of membrane modules 1 being vertically aligned in a segment may be from 2-16, normally between 2-12, e.g. between 2-8, and the number of segments of vertically aligned membrane modules may be from 1-32, e.g. between 2-32 or between 4-16. The optimum number of membrane modules in the vertical dimension as well as the optimum number of sets of vertically aligned membrane modules will depend on the pump capacity and area available for the filtration facility.

In general, an apparatus according to the present invention may comprise one or more matrices of membrane modules. Each matrix comprises one or more segments of vertically displaced and/or aligned membrane modules which are serially connected in respect of fluid feed, i.e. the fluid feed which enters the first membrane module flows through all membrane modules of the segment and will either be removed as fluid feed from an outlet of the last membrane module of the segment or be removed as permeate from permeate outlets of one of the membrane modules comprised in the segment. If a matrix comprises more than one segment, the fluid feed may be distributed in parallel to the segments through a common feeding pipe which feeding pipe is connected to a source of feeding fluid and a constant pressure pump forcing the feeding fluid into the feeding pipe and through the segments of membrane modules. If the apparatus comprises more than one matrix of membrane modules, each matrix may be referred to as a

section, and a second or following sections may be positioned on top of a first or lower section, the fluid feed flow from a first or lower section may be connected to a second or upper section through a manifold having a number of inlets corresponding to the number of segments in the lower section and a number of outlets corresponding to the number of segments in the upper section. If a segment comprises more than 2 or 3 or 4 membrane modules displaced and/or aligned in a vertical direction, where the lowest membrane module is considered the first membrane module, then a supply of fluid feed may be added to the third or fourth or fifth membrane module, respectively, e.g. through a supply pipe which may distribute fluid feed to more than one segment of membrane modules. Also, a series of membrane modules at a same vertical level and fed by the same pump or pumping system, may have an permeate outlet feeding permeate into a common outlet permeate pipe which is provided with a common pressure transmitter and back pressure valve.

Description of method for filtration of a liquid

The apparatus of the present invention is primarily directed to use within food production as the apparatus provides a high sanitary level by avoiding dead legs in the apparatus structure.

Also, as the apparatus only use standard components it is less expensive and less complex than apparatus using non-standard components.

The apparatus and the method according to the invention are particularly suitable for microfiltration, or processes of ultrafiltration facing the same problems as microfiltration. Microfiltration, and some ultrafiltration processes, works at a very low TMP, and it is difficult to optimize the cross flow while maintaining a constant low TMP through a series of inter-connected membrane elements whether these membrane elements are positioned in a single membrane module or a series of membrane modules. The pressure at the inlet of the fluid feed is determined by the settings of the pump, and it is possible to control the pressure on the permeate side of the membrane module by positioning a back-pressure valve at the permeate outlet. According to the present invention the pressure in a series of membrane modules through which membrane modules fluid feed is pumped in a loop is adapted to the decrease in pressure occurring in the fluid feed as the distance between a membrane module and the pump is increased in the flow direction of the fluid feed.

In general, the present invention relates to a method for filtrating a liquid in an apparatus for membrane filtration comprising the following step,

a) An amount of fluid feed wherefrom a permeate is separated is continuously pumped through a loop comprising a multiplicity of membrane modules, each membrane module being provided with one inlet and one outlet for fluid feed/retentate and permeate respectively, the inlet for the fluid feed/retentate is positioned at the opposite end of the membrane module as the outlets for respectively the fluid feed/retentate and the permeate, ensuring that the flows of fluid feed/retentate and the permeate are concurrent in the full lengths of the membrane(s) in each membrane module. This causes a well-defined flow behavior inside the membrane module without appearance of a dead leg in the central tube of the membrane.

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

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

- 5 d) optionally, to obtain an optimized separation the number of membrane modules which the fluid feed flows through is varied either when designing the separation process or during the separation process.

During microfiltration or ultrafiltration, the TMP may be in the area of 0.02-12 bar, e.g. 0.07-10 bar, or 0.2-8 bar, or 0.3-2 bar.

10 The method of the present invention can be used in connection with membrane filtration operations within the dairy industry. E.g. the feed fluid can be a fluid in the dairy industry and dairy ingredients industry requiring accurate and same-time control of TMP and cross flow to obtain the result in particular protein separation, fat separation, micro-organism separation and protein fractionation on

- cheese whey
- cheese whey WPC
- skim milk
- 15 • skim milk MPC
- raw whole milk
- whole milk
- microfiltration permeates

20 Also, method of the present invention can be used in connection with membrane filtration operations within a fluid in the

- liquid food industry or
- liquid beverage industry or
- liquid life Science industry

25 requiring accurate and same-time control of TMP and cross flow to obtain the result in

- protein separation or
- fat separation or
- micro-organism separation or
- protein fractionation or
- alcohol separation

30 on

- vegetable (green) solutions or
- meat solutions or
- fish solutions or
- beverage solutions or
- 35 • microfiltration permeates.

Figure 8 illustrates a process carried out in an apparatus according to prior art comprising 10 membrane modules 1a, 1b, ... , 1j. The apparatus comprises one loop comprising 10 modules and each module comprises 1 membrane element, the 10 modules are parallelly connected on the fluid feed/retentate side. Fluid feed/retentate are circulated in the loop by recirculation pump 13, the circulation pump provides a
40 booster pressure P_B .

This build is according to prior art the prevalent method for achieving the lowest possible TMP per membrane element same time with the highest possible cross flow.

In this process example the dP/element is set to 0.5 bar and at traditionally 0 bar in p_{perm} .

$Q_{CROSSFLOW}$ is the volumetric flow (m^3/h) in the loop after the circulation pump 13, the volumetric flow downstream of the modules are lower as permeate is removed in the modules, additional feed is added to the loop by the feed pump 20.

The membrane modules are positioned in a parallel structure receiving fluid feed/retentate at the same pressure P_{IN} . The base line pressure P_{BL} provided by the feed pump 20 of this system is set to 0.3 bar in order to minimize TMP. The pressure at the inlet of each membrane module is the same for all 10 membrane modules i.e. the inlet pressure P_{IN} is the sum of the base line pressure P_{BL} and the booster pressure P_B , which in the example is $0.3 + 0.5 = 0.8$ bar.

The system is difficult to control because it may be under influence from differences in static head i.e. differences in geographic height may influence on the desired low and uniform TMP per membrane element. Also, the system is influenced by the base line pressure, P_{BL} , which has to be sufficiently high to avoid damaging cavitation in the circulation pump(s) which in some cases can have a negative effect on TMP, but also sufficiently low in order to obtain a desired low TMP.

The flow $Q_{CROSSFLOW}$ through the booster pump or recirculation pump 13 is high as the recirculation pump 13 delivers equal amounts of fluid to all 10 membrane modules 1a-1j. A high flow through the recirculation pump, means that the installation has a relatively high consumption of energy and therefore this apparatus is relatively expensive to operate.

Table 1

$Q_{CROSSFLOW} = \text{Index } 1000$					Figure 8
Module	P_{in}	P_{out}	P_{perm}	TMP	
1a	0.8	0.3	0	0.55	$= (0.8+0.3)/2 - 0$
1b	0.8	0.3	0	0.55	$= (0.8+0.3)/2 - 0$
1c	0.8	0.3	0	0.55	$= (0.8+0.3)/2 - 0$
1d	0.8	0.3	0	0.55	$= (0.8+0.3)/2 - 0$
1e	0.8	0.3	0	0.55	$= (0.8+0.3)/2 - 0$
1f	0.8	0.3	0	0.55	$= (0.8+0.3)/2 - 0$
1g	0.8	0.3	0	0.55	$= (0.8+0.3)/2 - 0$
1h	0.8	0.3	0	0.55	$= (0.8+0.3)/2 - 0$
1i	0.8	0.3	0	0.55	$= (0.8+0.3)/2 - 0$
1j	0.8	0.3	0	0.55	$= (0.8+0.3)/2 - 0$

Figure 9 illustrates a process carried out in an apparatus according to prior art comprising 1 membrane module. The apparatus comprises one loop with 1 module and the 1 module comprises 10 membrane elements. The module has a single outlet for permeate where permeate separated from all 10 membrane elements of the one membrane housing is removed.

Inside the 1 module, the membrane elements are positioned in an end-to-end structure receiving fluid feed/retentate feed at different pressures corresponding to dP/element. The numbering 1a, 1b, ... , 1j is

applied, although this embodiment only comprises a single module according to the definition of a module of this specification, to illustrate that the number of membrane elements are the same as in the embodiments of fig. 8 and fig. 10.

- 5 In the process example the $dP/\text{element}$ is set to 0.5 bar and at traditionally 0 bar in p_{perm} . The base line pressure P_{BL} provided by the feed pump 20 of this system is set to 0.3 bar in order to minimize TMP. The pressure into the membrane module is the sum of the base line pressure P_{BL} and the booster pressure P_{B} , which in the example is $0.3 + 5 = 5.3$ bar.

- 10 As the below Table 2 clearly indicates it is for an apparatus of this configuration or a similar configuration with fewer membrane elements, not possible to maintain the same and low TMP per membrane element, however, the index figure $Q_{\text{CROSSFLOW}}$ is 100, a factor 10 lower than for the embodiment of Fig. 8. As below table 2 illustrates, it is according to this embodiment impossible to obtain a constant low TMP if the number of membrane elements in a module is two or higher, if an embodiment instead of 10 membrane elements comprised 2 membrane elements the TMP would be as for 1i and 1j.

15 Table 2

$Q_{\text{CROSSFLOW}} = \text{Index } 100$					Figure 9
Module	P_{in}	P_{out}	P_{perm}	TMP	
1a	5.3	4.8	0	5.05	$= (5.3+4.8)/2 - 0$
1b	4.8	4.3	0	4.55	$= (4.8+4.3)/2 - 0$
1c	4.3	3.8	0	4.05	$= (4.3+3.8)/2 - 0$
1d	3.8	3.3	0	3.55	$= (3.8+3.3)/2 - 0$
1e	3.3	2.8	0	3.05	$= (3.3+2.8)/2 - 0$
1f	2.8	2.3	0	2.55	$= (2.8+2.3)/2 - 0$
1g	2.3	1.8	0	2.05	$= (2.8+1.8)/2 - 0$
1h	1.8	1.3	0	1.55	$= (1.8+1.3)/2 - 0$
1i	1.3	0.8	0	1.05	$= (1.3+0.8)/2 - 0$
1j	0.8	0.3	0	0.55	$= (0.8+0.3)/2 - 0$

In the great majority of filtration processes requiring a low TMP, a system according to fig. 9 will not separate as desired due to fast fouling of the membrane surfaces and same time altering membrane characteristics to a tighter membrane retaining substances which during a filtration operation were intended to pass through the membrane into the permeate.

- 20 Figure 10 illustrates a process carried out in an apparatus according to the invention comprising 10 membrane modules. The apparatus comprises one loop comprising 1 segment or section with 10 modules each module comprising 1 membrane element, the 10 modules are in hydraulic serial connection on fluid feed/retentate side. The modules of the apparatus of fig. 10 corresponds to a segmentation of the single module of fig. 9, the segmentation or splitting up of the single module to a series of modules each
- 25 comprising one membrane element, makes it possible to perform an individual control of each membrane element, and the apparatus as shown in fig. 10 may overcome the problems experienced with the apparatuses shown in figs. 8 and 9.

In the process example of fig. 10, the pressure loss dP per membrane modules is set to 0.5 bar.

The pressure difference between fluid feed/retentate and permeate at the outlet end of a membrane

module is set to 0.1 bar.

The base line pressure P_{BL} provided by the feed pump 20 is set to 1 bar. The base line pressure P_{BL} is the pressure at which the fluid feed is directed to the circulating fluid feed or retentate, and there is a limit to how low this pressure may be due to risk of cavitation in the circulation pump(s) and it suits commercially available pumps better than a very low pressure at needed volumetric capacities.

The circulation pump 13 is set to increase or boost the pressure P_B by 5 bar. In general, the pressure to be provided by the circulation pump is determined by the need for dP /element and by the number of serially and parallel connected membrane modules/elements, the used membranes etc. ($p_{out,1j} = P_{BL}$)

The permeate pressure P_{perm} is controlled for each module thereby establishing a desired TMP for each membrane element in each module. By this method it is possible to maintain a low and constant TMP at each membrane modules at a reasonable cost.

In order to obtain a desired flux and permeation through membrane elements over long time, it is necessary to maintain a for the application suitable cross flow – high or low -, the cross flow being the flow along the surface of the membrane on the retentate side. The cross flow minimizes accumulation of material on the surface of the membrane. The cross flow through each membrane module 1a, 1b, ... , 1j corresponds to the recirculated fluid minus the permeate being drained from upstream membrane modules plus possible added diafiltration water.

Table 3

Q _{CROSSFLOW} = Index 100					Figure 10
Module	P_{in}	P_{out}	P_{perm}	TMP	
1a	6.0	5.5	5.4	0.35	$= (6.0+5.5)/2 - 5.4$
1b	5.5	5.0	4.9	0.35	$= (5.5+5.0)/2 - 4.9$
1c	5.0	4.5	4.4	0.35	$= (5.0+4.5)/2 - 4.4$
1d	4.5	4.0	3.9	0.35	$= (4.5+4.0)/2 - 3.9$
1e	4.0	3.5	3.4	0.35	$= (4.0+3.5)/2 - 3.4$
1f	3.5	3.0	2.9	0.35	$= (3.5+3.0)/2 - 2.9$
1g	3.0	2.5	2.4	0.35	$= (3.0+2.5)/2 - 2.4$
1h	2.5	2.0	1.9	0.35	$= (2.5+2.0)/2 - 1.9$
1i	2.0	1.5	1.4	0.35	$= (2.0+1.5)/2 - 1.4$
1j	1.5	1.0	0.9	0.35	$= (1.5+1.0)/2 - 0.9$

Table 3 shows the effect of the present invention in terms of being able to provide

- Very low and equal TMP in each membrane element
- Energy savings; Q_{CROSSFLOW} index 100 versus 1000 in Fig. 8, prior art method, Table 1.

Ref. no.	Ref. name
1, 1a, 1b, 1c, 1d, ..., 1n	Membrane module
2, 2a	Inlet for feed/retentate, inlet distribution chamber
3, 3a	Outlet for feed/retentate, outlet distribution chamber
4, 4a, 4b	Membrane element
5	Central tube or opening of membrane element
6	Outlet for permeate
7, 7a, 7b	Standard ATD
8	Non-standard ATD of prior art
9, 9a, 9b	Back pressure valve at permeate outlet
10	Pressure transmitter at permeate outlet of membrane
11	Dead pocket of prior art
12	Pressure transmitter at fluid feed inlet of membrane
13	Fluid feed/retentate recirculation pump
14a, 14b, 14c	Feeding pipe for segment comprising a plurality of membrane modules
15a, 15b, 15c, ..., 15h	Outlet permeate pipes
16	Feed outlet pipe
17	Flow transmitter
18	Feed flow control valve
19	Storage unit
20	Feed pump
21	Retentate outlet
22	Retentate outlet valve
23	Fluid feed/retentate outlet to a downstream or secondary loop
24	Second inlet
25, 25a, 25b, 26c, 26d	Flow control means
26, 26a, 26b, 26c, 26d	Flow transmitter
27, 27a, 27b, 27c, 27d	Common feeding pipe for secondary fluid for two or more segments