Poor brine removal in the flush step of batch and semi-batch reverse osmosis systems can result in higher salt concentrations in the system, however, and can thus cause a higher mineral scaling potential at the end of the filtration period. See, e.g., M. Li, *Desalination*, 496 (2020), 114646. Higher salt concentrations within the system after a flush step can also cause higher operating pressures and elevated concentrations of undesired solutes in the permeate. Improved flushing of brine from the system also provides an incremental improvement in achievable volume recovery and a reduction in energy consumption.

Clearly, there remains a need for batch and semi-batch reverse osmosis systems with more efficient hydraulics during the flushing cycles.

SUMMARY

Accordingly, provided herein is a filtration system for batch or semi-batch hyperfiltration comprising:

(a) a recirculation loop,

(b) a pump providing pressurized feed solution to the recirculation loop,

(c) a waste outlet conduit,

(d) a valve separating the recirculation loop from a waste outlet conduit suitable to provide a discontinuous flow of a concentrated fluid from the recirculation loop,

(d) a control device suitable to actuate said valve,

(e) a membrane pressure vessel within said recirculation loop comprising a feed port, a concentrate port and a permeate port, and containing one or more, preferably two or more hyperfiltration elements aligned in an axial direction, including an end hyperfiltration element located nearest a fluid port, wherein the fluid port is selected from one of said inlet port and said outlet port, and said end hyperfiltration element has a length in the axial direction, and a first distance between said fluid port and said end hyperfiltration element which is at least one third of said length,

(f) a flow distributor located between said end hyperfiltration element and said fluid port; preferably wherein said flow distributor is suitable to provide: (i) a

velocity profile across a cross section of said pressure vessel, wherein said velocity profile has a coefficient of variation of less than 0.1, or (ii) a flow resistance of between 10 and 200 kPa·sec·m^{-1} wherein flow resistance (R) is defined as:

$$R = \frac{\Delta P}{v}$$

wherein ΔP is pressure drop across the flow distributor, *v* is the average velocity and R is measured using pure water at 25°C and an average velocity of 5 cm/sec,

(g) wherein the flow distributor is comprised of a proximal surface nearest the end hyperfiltration element and a distal surface nearest said fluid port, and

(h) an axial positioner within said vessel that locates said distal surface of said flow distributor a second distance from said end hyperfiltration element, wherein said second distance is at least 50% of said first distance.

In one aspect, there is provided a filtration system for batch or semi-batch hyperfiltration comprising:

(a) a recirculation loop,

(b) a pump providing pressurized feed solution to the recirculation loop,

(c) a waste outlet conduit,

(d) a valve separating the recirculation loop from a waste outlet conduit suitable to provide a discontinuous flow of a concentrated fluid from the recirculation loop,

(d) a control device suitable to actuate said valve,

(e) a membrane pressure vessel within said recirculation loop comprising a feed port, concentrate port and a permeate port, and containing two or more hyperfiltration elements aligned in an axial direction, including an end hyperfiltration element located nearest a fluid port, wherein the fluid port is selected from one of said inlet port and said outlet port, and said end hyperfiltration element has a length in the axial direction, and a first distance between said fluid port and said end hyperfiltration element which is at least one third of said length,

(f) a flow distributor located between said end hyperfiltration element and said fluid port;

(g) wherein the flow distributor is comprised of a proximal surface nearest the end hyperfiltration element and a distal surface nearest said fluid port, and

(h) an axial positioner within said vessel that locates said distal surface of said flow distributor a second distance from said end hyperfiltration element, wherein said second distance is at least 50% of said first distance.

The advantages and features of novelty that characterize the invention are pointed out with particularity in the claims annexed hereto and forming a part hereof. For a better understanding of the invention, its advantages, and the objects obtained by its use, however, reference should be made to the drawings which form a further part hereof, and to the accompanying descriptive matter, in which there is illustrated and described one or more preferred embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagram of an embodiment of the CCRO filtration system described herein.

Figure 2 is an isometric view of a flow distributor assembly.

Figure 3 is a side view of a flow distributor assembly.

Figure 4 is a side cross-sectional view of a membrane pressure vessel.

Figure 5 is a cut-away view of a portion of a membrane pressure vessel.

Figure 6 is an exploded cutaway view of a portion of a membrane pressure vessel.

Figure 7 is a plan view of a flow distributor surface using slots.

CLAIMS

1. A filtration system for batch or semi-batch hyperfiltration comprising:

(a) a recirculation loop,

(b) a pump providing pressurized feed solution to the recirculation loop,

(c) a waste outlet conduit,

(d) a valve separating the recirculation loop from a waste outlet conduit suitable to provide a discontinuous flow of a concentrated fluid from the recirculation loop,

(d) a control device suitable to actuate said valve,

(e) a membrane pressure vessel within said recirculation loop comprising a feed port, concentrate port and a permeate port, and containing two or more hyperfiltration elements aligned in an axial direction, including an end hyperfiltration element located nearest a fluid port, wherein the fluid port is selected from one of said inlet port and said outlet port, and said end hyperfiltration element has a length in the axial direction, and a first distance between said fluid port and said end hyperfiltration element which is at least one third of said length,

(f) a flow distributor located between said end hyperfiltration element and said fluid port;

(g) wherein the flow distributor is comprised of a proximal surface nearest the end hyperfiltration element and a distal surface nearest said fluid port, and

(h) an axial positioner within said vessel that locates said distal surface of said flow distributor a second distance from said end hyperfiltration element, wherein said second distance is at least 50% of said first distance.

2. The filtration system of claim 1, wherein said flow distributor is suitable to provide: (i) a velocity profile across a cross section of said pressure vessel, wherein said velocity profile has a coefficient of variation of less than 0.1, or (ii) a flow resistance of between 10 and 200 kPa·sec·m^{-1} wherein flow resistance (R) is defined as:

$$R = \frac{\Delta P}{v}$$

wherein ΔP is pressure drop across the flow distributor, *v* is the average velocity and R is measured using pure water at 25°C and an average velocity of 5 cm/sec.

3. The filtration system of claim 1 or claim 2, in which said end hyperfiltration element has a length in the axial direction and said second distance is greater than one third of said length.

4. The filtration system of any of claims 1, 2, or 3 in which said flow distributor comprises: (i) a flow plate having at least one opening, wherein total area of said at least one opening is from 1 to 50% of total area of the flow plate; (ii) sintered porous media; (iii) a mesh, a screen or a fabric; or (iv) a set of parallel or concentric tubes.

5. The filtration system of any preceding claim in which the flow plate has a central opening to accommodate a permeate tube and remaining area of the flow plate has at least one additional opening, wherein total area of said at least one additional opening is from 2 to 10% of said remaining area of the flow plate.