TECHNIQUES FOR MANAGING SCALE FORMATION IN WATER FILTRATION SYSTEMS AND A REVERSE OSMOSIS (RO) AND NANOFILTRATION (NF) SYSTEM IMPLEMENTING SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application Serial No. 62/991,393, filed on March 18, 2020 which is fully incorporated herein by reference.

TECHNICAL FIELD

[0002] This specification relates to filtration systems and managing scale formation within the same.

BACKGROUND INFORMATION

[0003] Water filtration systems often include at least one filter membrane for producing permeate from a feed stream. One approach to water filtration utilizes a steady-state continuous reverse osmosis (RO) operation/cycle and a pump that displaces feed through one or more filter membranes at a substantially constant pressure. The proportion of feed exiting as permeate relative to the portion of the feed exiting as retentate/reject establishes the recovery rate for the system. Such continuous flow systems typically operate at a recovery rate that is at or below a rate at which scaling conditions are induced. Consequently, continuous flow systems have a relatively low maximum recovery rate, e.g., 50-75%, to avoid formation of scale and fouling.

[0004] Another approach to water filtration utilizes a batch RO operation/cycle. In batch RO a pump varies pressure over time to overcome the osmotic pressure of one or more filter membrane(s). While batch RO systems enable a relatively higher rate of recovery relative to continuous flow systems, such systems must be periodically flushed to maintain permeate flux.

SUMMARY

[0004a] In one aspect, the present disclosure relates to a filter system comprising: at least one inlet fluidly coupled to at least one feed stream; at least one filter membrane fluidly coupled to the at least one inlet to receive feed water from the at least one feed stream; at least one pump to generate a pressure to displace the feed water from the at least one feed stream into the at least one filter membrane and produce an output permeate stream; and a controller configured to cause

a first driving signal to be provided to the at least one pump to cause the generated pressure to produce the output permeate stream at a recovery rate that is substantially equal to a first target recovery rate during a first period of time, the first target recovery rate being greater than a maximum non-scaling recovery rate for the at least one filter membrane and less than 100%.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] Various aspects and features of the present disclosure will be better understood by reading the following detailed description, taken together with the drawings wherein:

What is claimed is:

~~1. A method of operating a filtration system, the filtration system having at least one inlet fluidly coupled to at least one feed stream, at least one filter membrane fluidly coupled to the at least one inlet to receive feed water from the at least one feed stream, and at least one pump to generate a pressure to displace the feed water from the at least one feed stream into the at least one filter membrane and produce an output permeate stream, the method comprising:~~

~~causing a first driving signal to be provided to the at least one pump to cause the generated pressure to produce the output permeate stream at a recovery rate that is substantially equal to a first target recovery rate during a first period of time, the first target recovery rate being greater than a maximum non-scaling recovery rate for the at least one filter membrane and less than 100%.~~

~~2. The method of claim 1, further comprising:~~

~~causing a second driving signal to be provided to the at least one pump to cause the generated pressure to produce the output permeate stream at a recovery rate substantially equal to a second target recovery rate during a second period of time.~~

~~3. The method of claim 2, wherein the second target recovery rate is equal to or less than a maximum non-scaling recovery rate for the at least one filter membrane.~~

~~4. The method of claim 2, wherein the second target recovery rate is greater than the maximum non-scaling recovery rate for the at least one filter membrane.~~

~~5. The method of claim 2, wherein the second target recovery rate is greater than the maximum non-scaling recovery rate for the at least one filter membrane and the first target recovery rate.~~

~~6. The method of claim 2, wherein the second driving signal is configured to cause at least a partial flush of the at least one filter membrane such that the second target recovery rate is less than the maximum non-scaling recovery rate for the at least one filter membrane.~~

~~7. The method of claim 6, wherein the second target recovery rate is equal to zero such that all of the received feed water of the at least one feed stream is output as reject.~~

~~8. The method of claim 2, wherein the second target recovery rate is less than or equal to the maximum non-scaling recovery rate for the at least one filter membrane during a portion of the second period of time, and above the maximum non-scaling recovery rate during a portion of the second period of time.~~

~~9. The method of claim 2, wherein the second target recovery rate is greater than 0% and less than or equal to the maximum non-scaling recovery rate to cause a partial flush of the at least one filter membrane.~~

~~10. The method of claim 2, wherein the second target recovery rate is between 96-100% such that a ratio of the received feed water to output permeate stream by volume is between 0.96 and 1.0 during the second period of time.~~

~~11. The method of claim 2, further comprising causing at least one bleed valve fluidly coupled to the at least one filter membrane to output a first predetermined portion of the feed water of the at least one feed stream as reject water during the second period of time.~~

~~12. The method of claim 11, wherein the second target recovery rate is equal to 100%, and wherein causing the at least one bleed valve to output the first predetermined portion of the at least one feed stream as reject water during the second period of time further comprises closing the at least one bleed valve such that substantially 0% of the at least one feed stream is output as reject water.~~

~~13. The method of claim 11, wherein the second target recovery rate is less than 100%, and wherein causing the at least one bleed valve to output the first predetermined portion of the at least one feed stream as reject water during the second period of time further comprises opening the at least one bleed valve to output the first predetermined portion of the feed water as reject water.~~

~~14. The method of claim 2, wherein the second target recovery rate is 100% such that 0% of the at least one feed stream is output as reject water during at least a portion of the second period of time.~~

~~15. The method of claim 2, wherein the second period of time occurs prior to or after the first period of time based on a predetermined sequence of filter operations.~~

~~16. The method of claim 2, wherein the second target recovery rate is 100%, and causing the second driving signal to be provided to the at least one pump further comprises causing one or a plurality of antiscalant doses to be introduced into the at least one filter membrane at a predetermined moment during the second period of time, and wherein the predetermined moment delineates the second period of time into a first induction period occurring prior to the predetermined moment and a second induction period occurring after the predetermined moment at which antiscalant is introduced, the first induction period being a period of time operating before scaling and/or fouling of the at least one filter membrane occurs, the second induction period being a period of time measured from when the antiscalant is introduced to when scaling and/or fouling of the at least one filter membrane occurs.~~

~~17. The method of claim 2, further comprising causing a third driving signal to be provided to the at least one pump to at least partially flush the at least one filter membrane, wherein causing third driving signal to be provided to the at least one pump to at least partially flush the at least one filter membrane further comprises causing the third driving signal to be provided to the at least one pump during a third period of time, the third period of time subsequent to the second period of time.~~

~~18. The method of claim 17, wherein the third driving signal is configured to cause the at least one pump to generate a pressure to produce the output permeate stream at a recovery rate that is substantially equal to a third target recovery rate during the third period of time.~~

~~19. The method of claim 18, wherein the third target recovery rate is between 0% and 80% during the third period of time to cause at least a partial flush of the at least one filter membrane.~~

~~20. The method of claim 18, wherein the third target recovery rate is substantially 0% to cause a full flush of the at least one filter membrane, the third target recovery rate being different than the first target recovery rate and the second target recovery rate.~~

~~21. The method of claim 2, wherein the second period of time is subsequent to the first period of time, and wherein causing the second driving signal to be provided during the second~~

~~period of time occurs without causing an intervening full flush of the at least one filter membrane between the first and second periods of time.~~

~~22. The method of claim 2, wherein the second driving signal is configured to cause pressure generated by the at least one pump to increase to an amount exceeding osmotic pressure of the at least one filter membrane such that over the second period of time pressure increases by at least 10 psi per minute, the second period of time being at least two (2) minutes.~~

~~23. The method of claim 2, wherein the second driving signal is configured to cause the at least one pump to generate a substantially constant pressure such that over the second period of time the substantially constant pressure increases by a maximum of 10 pounds per square inch (psi) per hour, the second period of time being at least 6 hours.~~

~~24. The method of claim 1, wherein the first driving signal is configured to cause pressure generated by the at least one pump to increase to an amount exceeding osmotic pressure of the at least one filter membrane such that over the first period of time pressure increases by at least 10 psi per minute, the first period of time being at least two (2) minutes.~~

~~25. The method of claim 1, wherein the first driving signal is configured to cause the at least one pump to generate a substantially constant pressure such that over the first period of time the substantially constant pressure increases by a maximum of 10 pounds per square inch (psi) per hour, the first period of time being at least 6 hours.~~

~~26. The method of claim 1, further comprising causing at least one bleed valve fluidly coupled to the at least one filter membrane to output a second predetermined portion of feed water of the at least one feed stream as reject water during the first period of time.~~

~~27. The method of claim 26, wherein the first target recovery rate is less than or equal to 98%, and wherein causing the at least one bleed valve to output the second predetermined portion of feed water of the at least one feed stream as reject water during the first period of time further comprises opening the at least one bleed valve to cause at least 2% of the feed water of the at least one feed stream to be output as reject water during the first period of time.~~

~~28. The method of claim 1, wherein causing the first driving signal to be provided to the at least one pump further comprises causing one or a plurality of antiscalant doses to be~~

~~introduced into the at least one filter membrane at a predetermined moment during the first period of time, the predetermined moment at an initial start of the first period of time or at a moment following the initial start of the first period of time and prior to scaling and/or fouling of the least one filter membrane.~~

~~29. The method of claim 28, wherein the predetermined moment delineates the first period of time into a first induction period occurring prior to the predetermined moment and a second induction period occurring after the predetermined moment at which antiscalant is introduced, the first induction period being a period of time operating before scaling and/or fouling of the at least one filter membrane occurs, the second induction period being a period of time measured from when the antiscalant is introduced to when scaling and/or fouling of the at least one filter membrane occurs.~~

~~30. The method of claim 29, wherein causing the first driving signal to be provided to the at least one pump further comprises causing the at least one pump to monotonically increase pressure beyond osmotic pressure of the at least one filter membrane from the predetermined moment the antiscalant is introduced to maintain the first target recovery rate during at least a portion of the second induction period.~~

~~31~~1. A filter system comprising:

at least one inlet fluidly coupled to at least one feed stream;

at least one filter membrane fluidly coupled to the at least one inlet to receive feed water from the at least one feed stream;

at least one pump to generate a pressure to displace the feed water from the at least one feed stream into the at least one filter membrane and produce an output permeate stream; and

a controller configured to cause a first driving signal to be provided to the at least one pump to cause the generated pressure to produce the output permeate stream at a recovery rate that is substantially equal to a first target recovery rate during a first period of time, the first target recovery rate being greater than a maximum non-scaling recovery rate for the at least one filter membrane and less than 100%.

~~32~~2. The filter system of claim ~~31~~1, wherein the controller is further configured to cause a second driving signal to be provided to the at least one pump to cause the generated pressure to produce the output permeate stream at a recovery rate substantially equal to a second target recovery rate during a second period of time.

~~33~~3. The filter system of claim ~~32~~2, wherein the second target recovery rate is equal to or less than a maximum non-scaling recovery rate for the at least one filter.

~~34~~4. The filter system of claim ~~32~~2, wherein the second target recovery rate is greater than the maximum non-scaling recovery rate for the at least one filter membrane.

~~35~~5. The filter system of claim ~~32~~2, wherein the second target recovery rate is greater than the maximum non-scaling recovery rate for the at least one filter membrane and the first target recovery rate.

~~36~~6. The filter system of claim ~~32~~2, wherein the second driving signal is configured to cause at least a partial flush of the at least one filter membrane.

~~37~~7. The filter system of claim ~~36~~6, wherein the second target recovery rate is equal to zero such that all of the feed water of the at least one feed stream is output as reject.

~~38~~8. The filter system of claim ~~36~~6, wherein the second target recovery rate is less than or equal to a maximum non-scaling recovery rate for the at least one filter membrane during a portion of the second period of time and greater than the maximum non-scaling recovery rate for a portion of the second period of time.

~~39~~9. The filter system of claim ~~36~~6, wherein the second target recovery rate is greater than 0% and less than the maximum non-scaling recovery rate to cause a partial flush of the at least one filter membrane.

~~40~~10. The filter system of claim ~~32~~2, wherein the second target recovery rate is between 96-100% such that a ratio of the received feed water to output permeate stream by volume is between 0.96 and 1.0 during the second period of time.

~~41~~11. The filter system of claim ~~32~~2, further comprising at least one bleed valve fluidly coupled to the at least one filter membrane to output a first predetermined portion of the feed water of the at least one feed stream as reject water during the second period of time.

~~42~~12. The filter system of claim ~~41~~11, wherein the second target recovery rate is equal to 100%, and wherein the controller is configured to cause the at least one bleed valve to close such that the first predetermined portion of feed water output as reject water is zero percent during the second period of time.

~~43~~13. The filter system of claim ~~41~~11, wherein the second target recovery rate is 100% such that 0% of the at least one feed stream is output as reject water during the second period of time.

~~44~~14. The filter system of claim ~~41~~11, wherein the second period of time occurs prior to or after the first period of time based on a predetermined sequence of filter operations stored in a memory.

~~45~~15. The filter system of claim ~~32~~2, wherein the second driving signal is further configured to cause one or a plurality of antiscalant doses to be introduced into the at least one filter membrane at a predetermined moment during the second period of time.

~~46~~16. The filter system of claim ~~45~~15, wherein the predetermined moment delineates the second period of time into a first induction period occurring prior to the predetermined moment and a second induction period occurring after the predetermined moment at which antiscalant is introduced, the first induction period being a period of time operating before scaling and/or fouling of the at least one filter membrane occurs, the second induction period being a period of time measured from when the antiscalant is introduced to when scaling and/or fouling of the at least one filter membrane occurs.

~~47~~17. The filter system of claim ~~32~~2, wherein the controller is further configured to cause a third driving signal to be provided to the at least one pump to cause at least a partial flush during a third period of time, the third period of time subsequent to the second period of time.

~~48~~18. The filter system of claim ~~47~~17, wherein the third driving signal is configured to cause the at least one pump to generate a pressure to produce the output permeate stream at a

recovery rate that is substantially equal to a third target recovery rate during the third period of time, the third target recovery rate being different than the first and second target recovery rates.

~~49~~19. The filter system of claim ~~47~~17, wherein the third target recovery rate is between 0% and 80% during the third period of time to cause at least a partial flush of the at least one filter membrane.

~~50~~20. The filter system of claim ~~48~~18, wherein the third recovery rate is substantially 0% to cause a full flush of the at least one filter membrane.

~~51~~21. The filter system of claim ~~32~~2, wherein the second period of time is subsequent to the first period of time, and wherein causing the second driving signal to be provided during the second period of time occurs without causing an intervening full flush of the at least one filter membrane between the first and second periods of time.

~~52~~22. The filter system of claim ~~32~~2, wherein the second driving signal is configured to cause pressure generated by the at least one pump to increase to an amount exceeding osmotic pressure of the at least one filter membrane such that over the second period of time pressure increases by at least 10 psi per minute, the second period of time being at least two (2) minutes.

~~53~~23. The filter system of claim ~~32~~2, wherein the second driving signal is configured to cause the at least one pump to generate a substantially constant pressure such that over the second period of time the substantially constant pressure increases by a maximum of 10 pounds per square inch (psi) per hour, the second period of time being at least 6 hours.

~~54~~24. The filter system of claim ~~31~~1, wherein the first driving signal is configured to cause pressure generated by the at least one pump to increase to an amount exceeding osmotic pressure of the at least one filter membrane such that over the first period of time pressure increases by at least 10 psi per minute, the first period of time being at least two (2) minutes.

~~55~~25. The filter system of claim ~~31~~1, wherein the first driving signal is configured to cause the at least one pump to generate a substantially constant pressure such that over the first period of time the substantially constant pressure increases by a maximum of 10 pounds per square inch (psi) per hour, the first period of time being at least 6 hours.

~~56~~26. The filter system of claim ~~3~~1, further comprising at least one bleed valve fluidly coupled to the at least one filter membrane to output a second predetermined portion of feed water of the at least one feed stream as reject water during the first period of time.

~~57~~27. The filter system of claim ~~56~~26, wherein the first target recovery rate is less than or equal to 98%, the first predetermined portion of feed water being at least 2%, and wherein the controller is configured to cause the at least one bleed valve to output the first predetermined portion of feed water of the at least one feed stream to be output as reject water during the first period of time.

~~58~~28. The filter system of claim ~~3~~1, wherein the controller is further configured to cause one or a plurality of antiscalant doses to be introduced into the at least one filter membrane at a predetermined moment during the first period of time.

~~59~~29. The filter system of claim ~~58~~28, wherein the predetermined moment delineates the first period of time into a first induction period occurring prior to the predetermined moment and a second induction period occurring after the predetermined moment at which antiscalant is introduced, the first induction period being a period of time operating before scaling and/or fouling of the at least one filter membrane occurs, the second induction period being a period of time measured from when the antiscalant is introduced to when scaling and/or fouling of the at least one filter membrane occurs.

~~60~~30. The filter system of claim ~~59~~29, wherein causing the first driving signal to be provided to the at least one pump further comprises causing the at least one pump to monotonically increase pressure beyond osmotic pressure of the at least one filter membrane from the predetermined moment the antiscalant is introduced to maintain the first target recovery rate during at least a portion of the second induction period.

~~61~~31. The filter system of claim ~~3~~1, wherein the at least one filter membrane comprises at least one high-pressure filter membrane with a pressure casing capable of withstanding at least 90 bar of pressure.

~~62~~32. The filter system of claim ~~31~~1, wherein the at least one filter membrane comprises at least first and second filter membranes, each of the first and second filter membranes providing at least a portion of first and second filter stages, respectively.

~~63~~33. The filter system of claim ~~62~~32, further comprising a filter valve arrangement to switchably fluidly couple the first and/or second filter membranes to the at least one feed stream.

~~64~~34. The filter system of claim ~~63~~33, wherein the controller is further configured to cause the filter valve arrangement to switchably fluidly couple the first and/or second filter membranes to the at least one feed stream during the first and/or second periods of time.

~~65~~35. The filter system of claim ~~31~~1, wherein the at least one inlet fluidly couples to a bleed of a filter system such that the at least one feed stream comprises concentrate from the filter system.

~~66~~36. The filter system of claim ~~31~~1, wherein the wherein the at least one inlet fluidly couples to an outlet of a filter system such that the at least one feed stream comprises permeate output by the filter system.

~~67. A method for operating a filtration system, the filtration system having an inlet fluidly coupled to at least one feed stream, at least one filter membrane fluidly coupled to the inlet to receive feed water of the at least one feed stream, and at least one pump to generate a pressure to displace the feed water of the at least one feed stream into the at least one filter membrane and produce an output permeate stream, the method comprising:~~

~~causing a first driving signal to be provided to the at least one pump, the first driving signal to increase the generated pressure of the at least one pump to an amount exceeding osmotic pressure of the at least one filter membrane and maintain a target recovery during a first period of time, the target recovery exceeding a maximum non-scaling recovery rate and having an associated duration of time prior to when a maximum non-scaling recovery state is reached for the at least one filter membrane;~~

~~detecting when the maximum non-scaling recovery state is reached for the at least one filter membrane during the first period of time; and~~

~~in response to detecting the maximum non-scaling recovery state is reached, causing one or a plurality of antiscalant doses to be introduced into the at least one filter membrane to increase an amount of time between when the maximum non-scaling recovery state is reached and when scaling and/or fouling of the at least one filter membrane occurs.~~

~~68. A method for operating a batch reverse osmosis (RO) filtration system, the batch RO filtration system having an inlet fluidly coupled to at least one feed stream, at least one filter membrane fluidly coupled to the inlet to receive feed water of the at least one feed stream, and at least one pump to generate a pressure to displace the feed water of the at least one feed into the at least one filter membrane and produce an output permeate stream, the method comprising:~~

~~causing a first driving signal to be provided to the at least one pump to cause output of the output permeate stream at substantially a target recovery rate during a first period of time, the target recovery rate being greater than a maximum non-scaling recovery rate for the at least one filter membrane, and the first driving signal to increase the generated pressure of the at least one pump to an amount exceeding osmotic pressure of the at least one filter membrane to maintain output of the output permeate stream at substantially the target recovery; and~~

~~causing one or a plurality of antiscalant doses to be introduced into the at least one filter membrane at a predetermined moment during the first period of time.~~

~~69. The method of claim 68, wherein the predetermined moment delineates the first period of time into a first induction period occurring prior to the predetermined moment and a second induction period occurring after the predetermined moment at which the one or plurality of antiscalant doses are introduced, the first induction period being a period of time operating before scaling and/or fouling occurs, the second induction period being a period of time measured from when the one or plurality of antiscalant doses are introduced to when scaling and/or fouling occurs.~~