CLAIMS

1. A reverse-osmosis system comprising:

multiple reverse-osmosis assemblies, each reverse-osmosis assembly comprising:

a reverse-osmosis stage having a semi-permeable membrane, a feed inlet, a permeate outlet and a concentrate outlet, wherein the feed inlet is configured to receive feed water having a feed-water flow rate;

a concentrate valve configured to control the pressure of the concentrate outlet;

a liquid-monitoring sensor array having:

a feed pressure sensor;

at least one of: a feed salinity and a conductivity sensor;

a feed temperature sensor;

at least two flow sensors configured to measure at least two of: feed flow, permeate flow, and concentrate flow;

at least one of: a permeate salinity and a conductivity sensor;

a differential pressure sensor configured to measure the difference between the feed pressure and the concentrate pressure; and

a permeate pressure sensor; and

a controller configured:

to receive information from the liquid monitoring sensor arrays;

to calculate, from the received information, one or more of: an A-Value, a B-value and a normalized differential pressure value, for each reverse-osmosis stage, wherein the A-Value is a measure of a water permeability of the semi-permeable membrane, and the B-Value is a measure of a salt diffusion rate through the semi-permeable membrane;

to determine a fouling parameter for each reverse-osmosis stage based on one or more of: the A-Value, the B-Value, and the normalized differential pressure value; and

to individually control flow through each of the reverse-osmosis assemblies to meet a predetermined criterion for total permeate production for the reverse-osmosis system,

wherein the control comprises alternating each of the reverse-osmosis stages between a production mode and an anti-fouling mode based on the determined fouling parameter, wherein the production mode has increased permeate flow through the semi-permeable membrane and decreased concentrate flow as compared to that of the anti-fouling mode and is configured to permit fouling of the semi-permeable membrane, and the anti-fouling mode has decreased flow through the semi-permeable membrane and increased concentrate flow as compared to that of the production mode and is configured to at least partially remove fouling of the semi-permeable membrane, and

wherein, in both the production and anti-fouling modes, each stage continues to produce cleaned permeate water at the respective permeate outlet.

2. The system of claim 1, wherein the controller is configured to control the flow through each of the reverse-osmosis assemblies comprises by individually adjusting a recovery ratio of each of the reverse-osmosis assemblies.

3. The system according to any one of claims 1-2, wherein the controller is configured to control the flow through each of the reverse-osmosis assemblies comprises by adjusting feed flow provided to each of the reverse-osmosis assemblies.

4. The system according to any one of claims 1-3, wherein the controller is configured to use machine learning to predict the response of controlling the flow through each of the reverse-osmosis assemblies.

5. The system according to any one of claims 1-4, wherein the controller is configured to enable control of flow through each of the reverse-osmosis assemblies based on the received information and on previous behaviour of the system to meet predetermined permeate flow and permeate salinity criteria and to reduce energy consumption.

6. The system according to any one of claims 1-5, wherein the controller is configured to increase permeate production of the reverse-osmosis assemblies which have a fouling parameter indicative of less

fouling and increase concentrate production of the reverse-osmosis assemblies which have a fouling parameter indicative of more fouling.

7. The system according to any one of claims 1-6, wherein the controller is configured to control the flows through the reverse osmosis assemblies in real time to meet predetermined total permeate flow and total permeate salinity criteria and to reduce cleaning.

8. The system according to any one of claims 1-7, wherein the reverse-osmosis system comprises an energy sensor configured to measure the energy consumption of the system.

9. The system according to any one of claims 1-8, wherein the concentrate flow comprises a cross flow that passes along an inlet side of the semi-permeable membrane.

10. The system according to claim 9, wherein, in the anti-fouling mode, the cross flow flushes away concentrated fouling material from the inlet side of the semi-permeable membrane to the concentrate outlet to at least partially remove the fouling from the semi-permeable membrane.

11. A method of controlling a reverse-osmosis system comprising multiple reverse-osmosis assemblies, each reverse-osmosis assembly comprising:

a reverse-osmosis stage comprising a semi-permeable membrane, a feed inlet, a permeate outlet and a concentrate outlet, wherein the feed inlet is configured to receive feed water powered by a feed pump; and

a concentrate valve configured to control the pressure of the concentrate outlet flow;

the method comprising:

measuring a feed pressure;

measuring a feed salinity and/or conductivity;

measuring a feed temperature;

measuring at least two of: feed flow, permeate flow, and concentrate flow;

measuring a permeate salinity and/or conductivity;

measuring a differential pressure configured to measure the difference between the feed pressure and the concentrate pressure;

measuring a permeate pressure; and

determining a fouling parameter for each reverse-osmosis stage based on one or more of: an A-Value, a B-value and a normalized differential pressure value; wherein the A-Value is a measure of a water permeability of the semi-permeable membrane; and the B-Value is a measure of a salt diffusion rate through the semi-permeable membrane; and

individually controlling the flow through each of the reverse-osmosis assemblies to meet a predetermined criterion for total permeate production for the reverse-osmosis system,

wherein the controlling the flow through each of the reverse-osmosis assemblies comprises alternating each of the reverse-osmosis stages between a production mode and an anti-fouling mode based on the determined fouling parameter, wherein the production mode has increased permeate flow through the semi-permeable membrane and decreased concentrate flow as compared to that of the anti-fouling mode and is configured to permit fouling of the semi-permeable membrane, and the anti-fouling mode has decreased flow through the semi-permeable membrane and increased concentrate flow as compared to that of the production mode and is configured to at least partially remove fouling of the semi-permeable membrane, and

wherein, in both the production and anti-fouling modes, each stage continues to produce cleaned permeate water at the respective permeate outlet.

12. A non-transitory medium comprising a computer program, the computer program comprising computer program code configured to run on a computer in conjunction with a reverse-osmosis system comprising multiple reverse-osmosis assemblies, each reverse-osmosis assembly comprising:

a reverse-osmosis stage comprising a semi-permeable membrane, a feed inlet, a permeate outlet and a concentrate outlet, wherein the feed inlet is configured to receive feed water powered a feed pump;

a concentrate valve configured to control the pressure of the concentrate outlet flow;

a liquid-monitoring sensor array having:

a feed pressure sensor;

a feed salinity and/or conductivity sensor;

a feed temperature sensor;

at least two flow sensors configured to measure at least two of: feed flow, permeate flow, and concentrate flow;

a permeate salinity and/or conductivity sensor;

a differential pressure sensor configured to measure the difference between the feed pressure and the concentrate pressure;

a permeate pressure sensor;

wherein the computer program code is configured to control the computer to enable:

receiving information from the liquid-monitoring sensor array;

determining a fouling parameter for each reverse-osmosis stage based on one or more of: an A-Value, a B-value and a normalized differential pressure, wherein the A-Value is a measure of a water permeability of the semi-permeable membrane; and

individually controlling flow through each of the reverse-osmosis assemblies to meet a predetermined criterion for total permeate production for the reverse-osmosis system,

wherein the controlling comprises alternating each of the reverse-osmosis stages between a production mode and an anti-fouling mode based on the determined fouling parameter, wherein the production mode has increased permeate flow through the semi-permeable membrane and decreased concentrate flow as compared to that of the anti-fouling mode and is configured to permit fouling of the semi-permeable membrane, and the anti-fouling mode has decreased concentrate flow through the semi-permeable membrane and increased concentrate flow as compared to that of the production mode and is configured to at least partially remove fouling of the semi-permeable membrane, and

wherein, in both the production and anti-fouling modes, each stage continues to produce cleaned permeate water at the respective permeate outlet.

13. A reverse-osmosis system comprising:

a reverse-osmosis stage having a semi-permeable membrane, a feed inlet, a permeate outlet and a concentrate outlet, wherein the feed inlet is configured to receive feed water having a feed-water flow rate;

a concentrate valve configured to control the pressure of the concentrate outlet;

a liquid-monitoring sensor array configured to monitor parameters of the liquid flowing through each stage, the liquid-monitoring sensor array having:

a feed pressure sensor;

at least one of: a feed salinity and a conductivity sensor;

a feed temperature sensor;

at least two flow sensors configured to measure at least two of: feed flow, permeate flow, and concentrate flow;

at least one of: a permeate salinity and a conductivity sensor;

a differential pressure sensor configured to measure the difference between the feed pressure and the concentrate pressure; and

a permeate pressure sensor; and

a controller configured:

to receive liquid-monitoring information from the liquid-monitoring sensor array on the monitored parameters of the liquid flowing through each stage;

to calculate, from the received liquid-monitoring information, one or more of: an A-Value, a B-value and a normalized differential pressure value, for each reverse-osmosis stage, wherein the A-Value is a measure of a water permeability of the semi-permeable membrane, and the B-Value is a measure of a salt diffusion rate through the semi-permeable membrane;

to determine a fouling parameter based on one or more of: the A-Value, the B-value and the normalized differential pressure; and

to calculate how the fouling parameter would change as a function of permeate production for various flow rates through the feed inlet and recovery ratios, based on previous parameters monitored by the liquid-

monitoring sensor array, wherein calculating how the fouling parameter would change comprises calculating an estimate of when an inflection point will occur in the fouling parameter as a function of cumulative permeate flow due to membrane fouling based on previous behaviour of the system.

14. The system according to claim 13, wherein calculating how the fouling parameter would change comprises calculating an estimate of when an inflection point will occur in the fouling parameter as a function of cumulative permeate flow due to membrane fouling based on previous parameters of the liquid flowing through the reverse-osmosis stage monitored by the liquid-monitoring sensor array.

15. The reverse-osmosis system of claim 14, wherein the system is configured to calculate a future energy consumption of the reverse-osmosis system based on the estimated inflection point; and to determine the optimum time to clean the reverse-osmosis stage, based on the calculated future energy consumption.

16. The reverse-osmosis system according to any one of claims 13-15, wherein the system is configured to calculate an estimate of when a change will occur in the rate of change of fouling parameter as a function of cumulative permeate flow due to membrane fouling based on previous behaviour of the system.

17. The reverse-osmosis system according to any one of claims 13-16, wherein the calculation of how the fouling parameter would change as a function of permeate production is based on one or more of: the feed salinity and the feed conductivity.

18. The reverse-osmosis system according to any one of claims 13-17, wherein the calculation of how the fouling parameter would change as a function of permeate production is based on the feed temperature.

19. A method of controlling a reverse-osmosis system, the reverse-osmosis system comprising:

a reverse-osmosis stage having a semi-permeable membrane, a feed inlet, a permeate outlet and a concentrate outlet, wherein the feed inlet is configured to receive feed water having a feed-water flow rate; and

a concentrate value configured to control the pressure of the concentrate outlet;

the method comprising:

measuring a feed pressure;

measuring a feed salinity and/or conductivity;

measuring a feed temperature;

measuring at least two of: feed flow, permeate flow, and concentrate flow;

measuring a permeate salinity and/or conductivity;

measuring a differential pressure configured to measure the difference between the feed pressure and the concentrate pressure;

measuring a permeate pressure;

calculating, from the measured information, one or more of: an A-Value, a B-value and a normalized differential pressure value, for the reverse-osmosis stage, wherein the A-Value is a measure of a water permeability of the semi-permeable membrane, and the B-Value is a measure of a salt diffusion rate through the semi-permeable membrane;

determining a fouling parameter based on one or more of: the A-Value, the B-value and the normalized differential pressure; and

calculating how the fouling parameter would change as a function of permeate production for various flow rates through the feed inlet and recovery ratios, based on previous parameters monitored by a liquid-monitoring sensor array of the reverse-osmosis stage configured to monitor parameters of liquid flowing through the reverse-osmosis stage, wherein calculating how the fouling parameter would change comprises calculating an estimate of when an inflection point will occur in the fouling parameter as a function of cumulative permeate flow due to membrane fouling based on previous behaviour of the system.

20. A non-transitory medium comprising a computer program, the computer program comprising computer program code configured to run on a computer in conjunction with a reverse-osmosis system, the reverse-osmosis system comprising:

a reverse-osmosis stage having a semi-permeable membrane, a feed inlet, a permeate outlet and a concentrate outlet, wherein the feed inlet is configured to receive feed water having a feed-water flow rate;

a concentrate value configured to control the pressure of the concentrate outlet;

a liquid-monitoring sensor array configured to monitor parameters of the liquid flowing through each stage, the liquid-monitoring sensor array having:

a feed pressure sensor;

at least one of: a feed salinity and a conductivity sensor;

a feed temperature sensor;

at least two flow sensors configured to measure at least two of: feed flow, permeate flow, and concentrate flow;

at least one of: a permeate salinity and a conductivity sensor;

a differential pressure sensor configured to measure the difference between the feed pressure and the concentrate pressure; and

a permeate pressure sensor, and

wherein the computer program code is configured to control the computer to enable:

receiving liquid-monitoring information from the liquid-monitoring sensor array on the monitored parameters of the liquid flowing through each stage; and

calculating, from the received liquid-monitoring information, one or more of: an A-Value, a B-value and a normalized differential pressure value, for each reverse-osmosis stage, wherein the A-Value is a measure of a water permeability of the semi-permeable membrane, and the B-Value is a measure of a salt diffusion rate through the semi-permeable membrane;

determining a fouling parameter based on one or more of: the A-Value, the B-value and the normalized differential pressure; and

calculating how the fouling parameter would change as a function of permeate production for various flow rates through the feed inlet and recovery ratios, based on previous parameters monitored by the liquid-monitoring sensor array, wherein calculating how the fouling parameter would change comprises calculating an estimate of when an inflection point will occur in the fouling parameter as a function of cumulative permeate flow due to membrane fouling based on previous behaviour of the system.