amount of solids dissolved in the feed stream 18. Thus, it may be necessary to increase the pressure of the brine stream 16 to a higher pressure relative to the pressure of the feed stream 18. A motor-driven, interstage pump (not shown) may be included between the membrane arrays 12, 52 to increase the pressure of the brine stream 16 to this higher pressure. However, since the booster 152 is driven by the hydraulic energy in the brine stream 16, the booster 152 may consume less energy relative to the interstage pump. In addition, using the booster 152 may allow the pressure of the feed stream 18 to be reduced. Thus, the feed pump 20 and the motor 22 may be reduced in size since a reduced amount of pressure is required by them. In addition, the amount of energy consumed by the feed pump 20 and the motor 22 may be reduced.

SUMMARY

[0017] This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope or all of its features.

[0018] A reverse osmosis system according to an aspect of the present invention includes a pump, a first membrane array, a second membrane array, a hydraulic pressure booster, and an electric motor-generator. The pump is operable to pressurize a feed stream. The first membrane array is configured to receive the feed stream and to generate a first permeate stream and a first brine stream from the feed stream. The second membrane array is configured to receive the first brine stream and to generate a second permeate stream and a second brine stream from the first brine stream. The hydraulic pressure booster comprises a shaft, a pump that is coupled to and rotates with the shaft, a first variable area nozzle, and turbine that is coupled to and rotates with the shaft. The hydraulic pressure booster is configured to receive at least a first portion of the second brine stream and to use energy from the first portion of the second brine stream to increase pressure of at least one of the feed stream and the first brine stream. The electric motor-generator is coupled to the shaft of the hydraulic pressure booster and is operable to act as a motor to use electric power from a power supply to drive the shaft of the hydraulic pressure booster. The electric motor-generator is also operable to (i) convert hydraulic energy from the second brine stream into electrical energy and

(ii) return the electrical energy to the power supply; a first flow meter that measures a flow of the first permeate stream; a second flow meter that measures a flow of the first portion of the second brine stream, said flow of the first portion of the second brine stream less than a flow of the second brine stream; a first controller controls the first variable area nozzle based on the flow of the first permeate stream and based on the flow of the first portion of the second brine stream; and the first controller controls the first variable area nozzle to adjust the flow of the first portion of the second brine stream through the first hydraulic pressure booster and thereby adjust an amount by which the first hydraulic pressure booster increases the pressure of the feed stream.

[0019] A reverse osmosis system according to another aspect of the present invention includes a pump, a first membrane array, a second membrane array, a first hydraulic pressure booster, a second hydraulic pressure booster and an electric motor-generator. The pump is operable to pressurize a feed stream. The first membrane array is

configured to receive the feed stream and to generate a first permeate stream and a first brine stream from the feed stream. The second membrane array is configured to receive the first brine stream and to generate a second permeate stream and a second brine stream from the first brine stream. The first hydraulic pressure booster comprises a first shaft, a first pump that is coupled to and rotates with the first shaft, and a first turbine that is coupled to and rotates with the first shaft. The first hydraulic pressure booster is configured to receive a first portion of the second brine stream and to use energy from the first portion of the second brine stream to increase the pressure of the first brine stream, wherein the first hydraulic pressure booster includes a first variable area nozzle. The second hydraulic pressure booster comprises a second shaft, a second pump that is coupled to and rotates with the second shaft, and a second turbine that is coupled to and rotates with the second shaft. The second hydraulic pressure booster is configured to receive a second portion of the second brine stream and to use energy from the second portion of the second brine stream to increase the pressure of the feed stream, wherein the second hydraulic pressure booster includes a second variable area nozzle. The motor-generator is coupled to the second shaft of the second hydraulic pressure booster, and is (a) operable to act as a motor to use electric power from a power supply to drive the second shaft of the second hydraulic pressure booster, and (b) operable to (i) convert hydraulic energy from the second portion of the second brine stream into electrical energy and (ii) return the electrical energy to the power supply. The reverse osmosis system further comprises a controller operatively coupled to the first variable area nozzle, the second variable area nozzle and the motor-generator, said controller controlling the first area variable nozzle based on a flow of the first permeate stream, a flow of the first portion of the second brine stream and a flow of the second portion of the second brine stream, said controller controlling the second variable area nozzle in response to a flow of the second permeate stream, the flow of the second portion of the second brine stream, said controller adjusting torque output of the motor-generator based on the flow of the first permeate stream and the flow of the first portion of the second brine stream.

[0020] A method for operating a reverse osmosis system according to another aspect of the present invention comprises a first hydraulic pressure booster comprising a shaft, a pump that is coupled to and rotates with the shaft, a first variable area nozzle and a turbine that is coupled to and rotates with the shaft and includes directing a pressurized feed stream to a first membrane array to separate the pressurized feed stream into a first permeate stream and a first brine stream, directing the first brine stream to a second membrane array to separate the first brine stream into a second permeate stream and a second brine stream, receiving, at the first hydraulic pressure booster, at least a first portion of the second brine stream; using energy from the first portion of the second brine stream to increase a pressure of at least one of the feed stream and the first brine stream; operating an electric motor-generator coupled to the shaft, (a) to act as a motor to use electric power from a power supply to drive the shaft of the first hydraulic pressure booster, and (b) (i) to convert hydraulic energy from the second brine stream into electrical energy and (ii) to return the electrical energy to the power supply; measuring a flow of the first permeate stream at a first flow meter; measuring a flow of the first portion of the second brine stream at a second flow meter, said flow of the first portion less than a flow of the second brine stream; controlling, by a first controller, the first variable area nozzle based on the flow of the first permeate stream and based on the flow of the first portion of the second brine stream; and controlling, by the first controller, the first variable area nozzle to adjust the flow of the first portion of the second brine stream through the first hydraulic pressure booster and thereby adjust an amount by which the first hydraulic pressure booster increases the pressure of the feed stream.

[0021] Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

DRAWINGS

[0022] The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations, and are not intended to limit the scope of the present disclosure.

[0023] FIG. 1 is a schematic view of a first reverse osmosis system according to the prior art;

[0024] FIG. 2 is a schematic view of a second reverse osmosis system according to the prior art;

[0025] FIG. 3 is a schematic view of a third reverse osmosis system according to the prior art;

CLAIMS

What is claimed is:

1. A reverse osmosis system comprising:

a pump operable to pressurize a feed stream;

a first membrane array configured to receive the feed stream and to generate a first permeate stream and a first brine stream from the feed stream;

a second membrane array configured to receive the first brine stream and to generate a second permeate stream and a second brine stream from the first brine stream;

a first hydraulic pressure booster comprising a shaft, a pump that is coupled to and rotates with the shaft, a first variable area nozzle, and turbine that is coupled to and rotates with the shaft, the first hydraulic pressure booster configured to receive at least a first portion of the second brine stream and to use energy from the first portion of the second brine stream to increase a pressure of at least one of the feed stream and the first brine stream;

an electric motor-generator coupled to the shaft of the first hydraulic pressure booster, (a) operable to act as a motor to use electric power from a power supply to drive the shaft of the first hydraulic pressure booster, and (b) operable to (i) convert hydraulic energy from the second brine stream into electrical energy and (ii) return the electrical energy to the power supply;

a first flow meter that measures a flow of the first permeate stream;

a second flow meter that measures a flow of the first portion of the second brine stream, said flow of the first portion of the second brine stream less than a flow of the second brine stream;

a first controller controls the first variable area nozzle based on the flow of the first permeate stream and based on the flow of the first portion of the second brine stream; and

the first controller controls the first variable area nozzle to adjust the flow of the first portion of the second brine stream through the first hydraulic pressure booster and thereby adjust an amount by which the first hydraulic pressure booster increases the pressure of the feed stream.

2. The reverse osmosis system of claim 1 wherein the first membrane array is configured to receive the feed stream directly from the pump.

3. The reverse osmosis system of claim 1 wherein the first hydraulic pressure booster is configured to increase the pressure of the feed stream, and the first membrane array is configured to receive the feed stream after the feed stream flows through the first hydraulic pressure booster.

4. The reverse osmosis system of claim 3 further comprising a variable frequency drive operable to adjust at least one of an amount of power supplied to the electric motor-generator and an amount of load placed on the shaft by the electric motor-generator to increase the pressure of the feed stream by a desired amount.

5. The reverse osmosis system of claim 3 wherein the first controller further controls a variable frequency drive to adjust at least one of an amount of power supplied to the electric motor-generator and an amount of load placed on the electric motor-generator.

6. The reverse osmosis system of claim 1 further comprising a second hydraulic pressure booster configured to receive a second portion of the second brine stream and to use energy from the second portion of the second brine stream to increase the pressure of the first brine stream.

7. The reverse osmosis system of claim 6 wherein the second hydraulic pressure booster includes a second variable area nozzle.

8. The reverse osmosis system of claim 7 further comprising a second controller that controls the second variable area nozzle to adjust the flow of the second portion of the second brine stream through the second hydraulic pressure booster and thereby adjust an amount by which the second hydraulic pressure booster increases the pressure of the first brine stream.

9. The reverse osmosis system of claim 8 further comprising a first flow meter that measures the flow of the second permeate stream, wherein the second controller controls the second variable area nozzle based on the flow of the second permeate stream.

10. The reverse osmosis system of claim 9 further comprising a second flow meter that measures the flow of the second portion of the second brine stream, wherein the second controller controls the second variable area nozzle based on the flow of the second portion of the second brine stream.

11. The reverse osmosis system of claim 10 wherein the first controller controls the first variable area nozzle based on the flow of the second portion of the second brine stream.

12. A reverse osmosis system comprising:

a pump operable to pressurize a feed stream;

a first membrane array configured to receive the feed stream and to generate a first permeate stream and a first brine stream from the feed stream;

a second membrane array configured to receive the first brine stream and to generate a second permeate stream and a second brine stream from the first brine stream;

a first hydraulic pressure booster comprising a first shaft, a first pump that is coupled to and rotates with the first shaft, and a first turbine that is coupled to and rotates with the first shaft, the first hydraulic pressure booster configured to receive a first portion of the second brine stream and to use energy from the first portion of the second brine stream to increase the pressure of the first brine stream, wherein the first hydraulic pressure booster includes a first variable area nozzle;

a second hydraulic pressure booster comprising a second shaft, a second pump that is coupled to and rotates with the second shaft, and a second turbine that is coupled to and rotates with the second shaft, the second hydraulic pressure booster configured to receive a second portion of the second brine stream and to use energy from the second portion of the second brine stream to increase the pressure of the feed stream, wherein the second hydraulic pressure booster includes a second variable area nozzle;

a motor-generator coupled to the second shaft of the second hydraulic pressure booster, the motor-generator (a) operable to act as a motor to use electric power from a power supply to drive the second shaft of the second hydraulic pressure booster, and (b) operable to (i) convert hydraulic energy from the second portion of the second brine stream into electrical energy and (ii) return the electrical energy to the power supply; and

a controller operatively coupled to the first variable area nozzle, the second variable area nozzle and the motor-generator, said controller controlling the first area variable nozzle based on a flow of the first permeate stream, a flow of the first portion of the second brine stream and a flow of the second portion of the second brine stream, said controller controlling the second variable area nozzle in response to a flow of the second permeate stream, the flow of the second portion of the second brine stream, said controller adjusting torque output of the motor-generator based on the flow of the first permeate stream and the flow of the first portion of the second brine stream.

13. The reverse osmosis system of claim 12wherein the controller controls the first variable area nozzle to adjust flow of the first portion of the second brine stream through the first hydraulic pressure booster and thereby adjust a first amount by which the first hydraulic pressure booster increases the pressure of the feed stream.

14. The reverse osmosis system of claim 12 wherein the controller controls the second variable area nozzle to adjust flow of the second portion of the second brine stream through the second hydraulic pressure booster and thereby adjust a second amount by which the second hydraulic pressure booster increases the pressure of the first brine stream.

15. A method for operating a reverse osmosis system comprising a first hydraulic pressure booster comprising a shaft, a pump that is coupled to and rotates with the shaft, a first variable area nozzle and a turbine that is coupled to and rotates with the shaft, the method comprising:

directing a pressurized feed stream to a first membrane array to separate the pressurized feed stream into a first permeate stream and a first brine stream;

directing the first brine stream to a second membrane array to separate the first brine stream into a second permeate stream and a second brine stream;

receiving, at the first hydraulic pressure booster, at least a first portion of the second brine stream;

using energy from the first portion of the second brine stream to increase a pressure of at least one of the feed stream and the first brine stream;

operating an electric motor-generator coupled to the shaft, (a) to act as a motor to use electric power from a power supply to drive the shaft of the first hydraulic pressure booster, and (b) (i) to convert hydraulic energy from the second brine stream into electrical energy and (ii) to return the electrical energy to the power supply;

measuring a flow of the first permeate stream at a first flow meter;

measuring a flow of the first portion of the second brine stream at a second flow meter, said flow of the first portion less than a flow of the second brine stream;

controlling, by a first controller, the first variable area nozzle based on the flow of the first permeate stream and based on the flow of the first portion of the second brine stream; and

controlling, by the first controller, the first variable area nozzle to adjust the flow of the first portion of the second brine stream through the first hydraulic pressure booster and thereby adjust an amount by which the first hydraulic pressure booster increases the pressure of the feed stream.

16. The method of claim 15 further comprising directing at least a first portion of the second brine stream through the first hydraulic pressure booster to increase the pressure of the feed stream by a first desired amount.

17. The method of claim 16 further comprising

controlling a torque output of the motor-generator based on the flow of the at least one of the first permeate stream and the first portion of the second brine stream.

18. The method of claim 15 further comprising directing a second portion of the second brine stream though a second hydraulic pressure booster to increase the pressure of the first brine stream by a second desired amount.

19. The method of claim 18 further comprising measuring flow of at least one of the second permeate stream and the second portion of the second brine stream and controlling a second variable area nozzle of the second hydraulic pressure booster based on the flow of the at least one of the second permeate stream and the second portion of the second brine stream.

20. The method of claim 19 further comprising controlling the first variable area nozzle of the first hydraulic pressure booster based on the flow of the at least one of the second permeate stream and the second portion of the second brine stream.