Claims

[Claim 1]
A water treatment apparatus comprising:
a forward osmosis unit configured to allow a diluted draw solution to flow out, the diluted draw solution being obtained by causing water to move to a draw solution having a cloud point from a water-containing solution containing water as a solvent via a semipermeable membrane to dilute the draw solution, and configured to discharge the water-containing solution as a concentrated water-containing solution that is concentrated;
a heating unit configured to heat the diluted draw solution to a temperature equal to or higher than the cloud point;
a water separation unit configured to separate the diluted draw solution heated by the heating unit into a water-rich solution and the draw solution having water content lower than that of the water-rich solution;
a cooling unit configured to cool a liquid and allow the liquid to flow out as a coolant;
an inflow side heat exchange unit configured to perform heat exchange between the coolant flowed out from the cooling unit and the draw solution flowed out from the water separation unit;
an outflow side heat exchange unit configured to perform heat exchange between the diluted draw solution flowed out from the forward osmosis unit and the water-rich solution flowed out from the water separation unit; and
a circulation flow passage configured to cause a downstream side of the water separation unit and an upstream side of the forward osmosis unit along a flowing direction of the draw solution to communicate with an upstream side of the heating unit and a downstream side of the forward osmosis unit along a flowing direction of the diluted draw solution.

[Claim 2]
The water treatment apparatus according to claim 1, further comprising a separation treatment unit configured to obtain generated water from the water-rich solution.

[Claim 3]
The water treatment apparatus according to claim 2, further comprising a heat exchange unit before final treatment disposed on a downstream side of the outflow side heat exchange unit and an upstream side of the separation treatment unit along a flowing direction of the water-rich solution, the heat exchange unit before final treatment configured to perform heat exchange between the water-rich solution flowed out from the water separation unit and the coolant flowed out from the cooling unit.

[Claim 4]
The water treatment apparatus according to claim 2 or 3, wherein the separation treatment unit is configured to supply, to the cooling unit, separation treatment effluent separated from the generated water.

[Claim 5]
The water treatment apparatus according to any one of claims 1 to 4, further comprising a succeeding stage heat exchange unit configured to perform heat exchange between the draw solution flowed out from the water separation unit and the diluted draw solution flowed out from the forward osmosis unit.

[Claim 6]

The water treatment apparatus according to any one of claims 1 to 5, further comprising a preceding stage heat exchange unit disposed on an upstream side of the outflow side heat exchange unit along a flowing direction of the diluted draw solution, the preceding stage heat exchange unit configured to perform heat exchange between the draw solution flowed out from the water separation unit and the diluted draw solution flowed out from the forward osmosis unit.

[Claim 7]
The water treatment apparatus according to any one of claims 1 to 6, the water treatment apparatus is configured to circulate the coolant between the cooling unit and the inflow side heat exchange unit.

[Claim 8]
The water treatment apparatus according to any one of claims 1 to 7, the water treatment apparatus is configured to cause the diluted draw solution flowed out from the forward osmosis unit to diverge to be heat-exchanged by a parallel heat exchange unit in which at least two heat exchangers are arranged in parallel, and configured to cause diverged diluted draw solutions heat-exchanged by the parallel heat exchange unit to converge on an upstream side of the heating unit.

[Claim 9]
The water treatment apparatus according to claim 8, wherein the parallel heat exchange unit is configured such that one of the diverged diluted draw solutions is heat-exchanged with the water-rich solution flowed out from the water separation unit, and the other one of the diverged diluted draw solutions is

heat-exchanged with the draw solution flowed out from the water separation unit.

[Claim 10]
The water treatment apparatus according to claim 1, further comprising
a diluted draw storage unit configured to store the diluted draw solution flowed out from the forward osmosis unit, and
an upstream side bypass flow passage configured to cause the diluted draw storage unit to communicate with a downstream side of the water separation unit and an upstream side of the forward osmosis unit along a flowing direction of the draw solution.

[Claim 11]
The water treatment apparatus according to claim 1 or 10, further comprising
a diluted draw storage unit configured to store the diluted draw solution flowed out from the forward osmosis unit, and
a downstream side bypass flow passage configured to cause the diluted draw storage unit to communicate with a downstream side of the water separation unit along a flowing direction of the water-rich solution.

[Claim 12]
A water treatment method comprising:
a forward osmosis process of allowing a diluted draw solution to flow out, the diluted draw solution being obtained by causing water to move to a draw solution having a cloud point from a water-containing solution containing water as a solvent via a semipermeable membrane to dilute the draw solution, and

discharging the water-containing solution as a concentrated water-containing solution that is concentrated;
a heating process of heating the diluted draw solution to a temperature equal to or higher than the cloud point;
a water separation process of separating the diluted draw solution heated in the heating process into a water-rich solution and the draw solution having water content lower than that of the water-rich solution;
a coolant generation process of cooling a liquid to generate a coolant;
an inflow side heat exchange process of performing heat exchange between the coolant obtained in the coolant generation process and the draw solution obtained in the water separation process; and
an outflow side heat exchange process of performing heat exchange between the diluted draw solution obtained in the forward osmosis process and the water-rich solution obtained in the water separation process,
wherein the water treatment method is performed using the apparatus of claim 1.

[Claim 13]
The water treatment method according to claim 12, further comprising a separation treatment process of obtaining generated water from the water-rich solution.

[Claim 14]
The water treatment method according to claim 13, further comprising, before the separation treatment process, a heat exchange process before final treatment of performing heat exchange between the water-rich solution obtained in the water

separation process and the coolant obtained in the coolant generation process.

[Claim 15]
The water treatment method according to claim 13 or 14, wherein separation treatment effluent separated from the generated water through the separation treatment process is used for the coolant generation process.

[Claim 16]
The water treatment method according to any one of claims 12 to 15, further comprising, before the outflow side heat exchange process, a preceding stage heat exchange process of performing heat exchange between the diluted draw solution obtained in the forward osmosis process and the draw solution obtained in the water separation process.

[Claim 17]
The water treatment method according to any one of claims 12 to 16, further comprising a succeeding stage heat exchange process of performing heat exchange between the draw solution obtained in the water separation process and the diluted draw solution that is heat-exchanged in the outflow side heat exchange process.

[Claim 18]
The water treatment method according to any one of claims 12 to 17, wherein the coolant after being heat-exchanged in the inflow side heat exchange process is cooled in the coolant generation process.

[Claim 19]
The water treatment method according to any one of claims 12 to 18, further comprising a parallel heat exchange process of causing the diluted draw solution obtained in the forward osmosis process to diverge, and performing heat exchange between diverged diluted draw solutions by at least two heat exchangers in parallel, wherein
the diverged diluted draw solutions are caused to converge after the parallel heat exchange process and before the heating process.

[Claim 20]
The water treatment method according to claim 19, wherein, in the parallel heat exchange process, one of the diverged diluted draw solutions is heat-exchanged with the water-rich solution obtained in the water separation process, and the other one of the diverged diluted draw solutions is heat-exchanged with the draw solution obtained in the water separation process.

[Claim 21]
A method of starting a water treatment apparatus, the water treatment apparatus including:
a forward osmosis unit configured to allow a diluted draw solution to flow out, the diluted draw solution being obtained by causing water to move to a draw solution having a cloud point from a water-containing solution containing water as a solvent via a semipermeable membrane to dilute the draw solution, and configured to discharge the water-containing solution as a concentrated water-containing solution that is concentrated;
a heating unit configured to heat the diluted draw solution to a temperature equal to or higher than the cloud point;

a water separation unit configured to separate the diluted draw solution heated by the heating unit into a water-rich solution and the draw solution having water content lower than that of the water-rich solution;
a cooling unit configured to cool a liquid and allow the liquid to flow out as a coolant;
an inflow side heat exchange unit configured to perform heat exchange between the coolant flowed out from the cooling unit and the draw solution flowed out from the water separation unit; and
an outflow side heat exchange unit configured to perform heat exchange between the diluted draw solution flowed out from the forward osmosis unit and the water-rich solution flowed out from the water separation unit,
the method comprising:
a separation and circulation process of supplying the draw solution stored in the water separation unit to the heating unit to be heated to a temperature equal to or higher than the cloud point through a circulation flow passage that causes a downstream side of the water separation unit and an upstream side of the forward osmosis unit along a flowing direction of the draw solution to communicate with an upstream side of the heating unit and a downstream side of the forward osmosis unit along a flowing direction of the diluted draw solution.

[Claim 22]
The method of starting the water treatment apparatus according to claim 21, wherein
the water treatment apparatus further comprises a diluted draw storage unit configured to store the diluted draw solution flowed out from the forward osmosis unit, and an upstream side

bypass flow passage configured to cause the diluted draw storage unit to communicate with a downstream side of the water separation unit and an upstream side of the forward osmosis unit along a flowing direction of the draw solution, and
the method further comprises, after the separation and circulation process, an upstream side bypass process of supplying the draw solution stored in the water separation unit to the diluted draw storage unit through the upstream side bypass flow passage.

[Claim 23]
The method of starting the water treatment apparatus according to claim 21 or 22, wherein
the water treatment apparatus further comprises a diluted draw storage unit configured to store the diluted draw solution flowed out from the forward osmosis unit, and a downstream side bypass flow passage configured to cause the diluted draw storage unit to communicate with a downstream side of the water separation unit along a flowing direction of the water-rich solution, and
the method further comprises, after the separation and circulation process, a downstream side bypass process of supplying the water-rich solution flowed out from the water separation unit to the diluted draw storage unit through the downstream side bypass flow passage.

[Claim 24]
The method of starting the water treatment apparatus according to claim 22 or 23, further comprising an outflow side temperature raising process of performing heat exchange between the draw solution flowed out from the diluted draw storage unit

and the water-rich solution flowed out from the water separation unit by the outflow side heat exchange unit to raise a temperature of the draw solution flowed out from the diluted draw storage unit.

[Claim 25]
The method of starting the water treatment apparatus according to claim 24, further comprising, after the outflow side temperature raising process, a heating process of heating the draw solution flowed out from the diluted draw storage unit by the heating unit.

[Claim 26]
The method of starting the water treatment apparatus according to any one of claims 22 to 25, wherein
the water treatment apparatus further comprises a succeeding stage heat exchange unit configured to perform heat exchange between the diluted draw solution flowed out from the diluted draw storage unit and the draw solution flowed out from the water separation unit, and
the method further comprises a succeeding stage temperature raising process of performing heat exchange between the draw solution flowed out from the diluted draw storage unit and the draw solution flowed out from the water separation unit by the succeeding stage heat exchange unit to raise a temperature of the draw solution flowed out from the diluted draw storage unit.

[Claim 27]
The method of starting the water treatment apparatus according to claim 25 or 26, wherein
the water treatment apparatus is configured to cause the diluted

draw solution flowed out from the diluted draw storage unit to diverge to be heat-exchanged by a parallel heat exchange unit in which at least two heat exchange units are arranged in parallel, and configured to cause diverged diluted draw solutions heat-exchanged by the parallel heat exchange unit to converge on an upstream side of the heating unit, and
the method further comprises a parallel heat exchange process of performing heat exchange between the draw solution flowed out from the diluted draw storage unit and the water-rich solution flowed out from the water separation unit by one of the at least two heat exchange units, and performing heat exchange between the draw solution flowed out from the diluted draw storage unit and the draw solution flowed out from the water separation unit by the other one of the at least two heat exchange units.

[Claim 28]
The method of starting the water treatment apparatus according to claim 27, further comprising, after the parallel heat exchange process, a heating process of heating, by the heating unit, converged draw solution flowed out from the diluted draw storage unit.