

CLAIMS

1. An apparatus for recovering draw solution solutes from an osmotically driven membrane system, the apparatus comprising:
 - a first distillation column comprising:
 - a first inlet coupled to a first source of dilute draw solution for introducing a portion of dilute draw solution into a first end of the first distillation column;
 - a first heat transfer means coupled to the first distillation column at a second end, the first heat transfer means having an inlet coupled to a first source of thermal energy and an outlet coupled to the first distillation column for directing thermal energy to the first distillation column to cause the dilute draw solution solutes in the first distillation column to vaporize;
 - a first outlet for removing the vaporized dilute draw solution solutes from the first distillation column; and
 - a second outlet for removing a bottoms product from the first distillation column;
 - a compressor coupled to the first outlet of the first distillation column; and
 - a second distillation column comprising:
 - a first inlet coupled to a source of concentrated solution for introducing a portion of the concentrated solution into a first end of the second distillation column;
 - a second heat transfer means coupled to the second distillation column at a second end, the second heat transfer means having an inlet coupled to the compressor for receiving the vaporized dilute draw solution solutes for use as a second source of thermal energy, a first outlet coupled to the second distillation column for directing the second source of thermal energy to the second distillation column to cause any draw solutes in the second distillation column to vaporize, and a second outlet configured to return the vaporized dilute draw solution solutes from the first distillation column condensed within the second heat transfer means to the osmotically driven membrane system;

- a first outlet for removing the vaporized draw solutes from the second distillation column; and
- a second outlet for removing a bottoms product from the second distillation column.
2. The apparatus of claim 1, further comprising:
- a second compressor coupled to the first outlet of the second distillation column;
- and
- at least a third distillation column comprising:
- a first inlet coupled to a second source of dilute draw solution for introducing a portion of dilute draw solution into a first end of the third distillation column;
- a third heat transfer means coupled to the third distillation column at a second end, said third heat transfer means having an inlet coupled to the second compressor for receiving the vaporized draw solutes for use as a third source of thermal energy for use with the third distillation column, a first outlet coupled to the third distillation column for directing the third source of thermal energy to the third distillation column to cause the dilute draw solution solutes in the third distillation chamber to vaporize, and a second outlet configured to return the vaporized draw solutes from the second distillation column condensed within the third heat transfer means to the osmotically driven membrane system;
- a first outlet for removing the vaporized draw solution solutes from the third distillation column; and
- a second outlet for removing a bottoms product from the third distillation column.
3. The apparatus of claim 1, wherein the first and second distillation columns are configured for parallel operation and the first source of dilute draw solution and the source of concentrated solution are the osmotically driven membrane system.
4. The apparatus of claim 2, wherein the first and third distillation columns are configured for series operation and the second source of dilute draw solution is the bottoms product of the first distillation column.

5. An apparatus for recovering draw solutes from an osmotically driven membrane process, the apparatus comprising:
 - an osmotically driven membrane system comprising a source of dilute draw solution comprising thermally removable solutes; and
 - a separation module in fluid communication with the osmotically driven membrane system, the separation module comprising:
 - at least one of a membrane device or a distillation apparatus in fluid communication with the source of dilute draw solution; and
 - at least one heat pump coupled to the at least one of a membrane device or a distillation apparatus and configured to provide a source of thermal energy to the at least one of a membrane device and a distillation apparatus to vaporize the thermally removable solutes.
6. The apparatus of claim 5, wherein the at least one of a membrane device or a distillation apparatus comprises at least one membrane contactor configured to at least one of bring vaporized draw solutes in contact with an absorbing solution or strip draw solutes from the dilute draw solution.
7. The apparatus of claim 6, wherein the membrane contactor is a suspended liquid membrane.
8. The apparatus of claim 5, wherein the at least one of a membrane device or a distillation apparatus comprises a multi-stage solute recovery apparatus.
9. The apparatus of claim 8, wherein the multi-stage solute recovery apparatus comprises a multi-stage column distillation apparatus.
10. A method of recovering draw solutes from an osmotically driven membrane system, the method comprising the steps of:
 - providing a source of dilute draw solution from the osmotically driven membrane system, wherein the dilute draw solution comprises thermally removable solutes;
 - introducing at least a portion of the dilute draw solution to a separation system;
 - introducing a source of thermal energy to the separation system;
 - vaporizing the dilute draw solution solutes out of the dilute draw solution;
 - recovering the vaporized dilute draw solution solutes; and

recycling the draw solution solutes from the separation system to the osmotically driven membrane system.

11. The method of claim 10, wherein the step of vaporizing the dilute draw solution solutes comprises exposing the dilute draw solution solutes to the source of thermal energy via a membrane contactor to strip the solutes from the dilute draw solution.

12. The method of claim 10, wherein the step of recovering the vaporized draw solution solutes comprises exposing the vaporized draw solution solutes to an absorbing solution via a membrane contactor.

13. The method of claim 10, wherein the step of vaporizing the dilute draw solution solutes comprises exposing the dilute draw solution to a multi-stage solute recovery process.

14. The method of claim 13, wherein the dilute draw solution and source of thermal energy flow in series through at least a first distillation column and a second distillation column.

15. The method of claim 10, wherein the step of vaporizing the dilute draw solution solutes comprises assisting the source of thermal energy with a compressor.

CLAIMS

1. An apparatus for recovering draw solution solutes from an osmotically driven membrane system, the apparatus comprising:

an osmotically driven membrane system comprising a semi-permeable membrane having a first side in fluid communication with a first solution and a second side in fluid communication with a source of concentrated draw solution, where the osmotically driven membrane system receives the first solution and the concentrated draw solution and outputs a concentrated first solution and a dilute draw solution;

a first distillation apparatus in fluid communication with the second side of the semi-permeable membrane, the apparatus comprising:

a first inlet coupled to a first source of the dilute draw solution for introducing a portion of the dilute draw solution into a first end of the first distillation apparatus;

a first heat transfer means coupled to the first distillation apparatus at a second end, the first heat transfer means having an inlet coupled to a first source of thermal energy and an outlet coupled to the first distillation apparatus for directing thermal energy to the first distillation apparatus to cause draw solutes within the dilute draw solution in the first distillation apparatus to vaporize;

a first outlet for removing the vaporized draw solution solutes from the first distillation apparatus; and

a second outlet for removing a bottoms product from the first distillation apparatus;

a compressor coupled to the first outlet of the first distillation apparatus for receiving the vaporized draw solution solutes; and

a second distillation apparatus in fluid communication with the first side of the semi-permeable membrane and configured for parallel operation with the first distillation apparatus, the second distillation apparatus comprising:

a first inlet coupled to a source of the concentrated first solution for introducing a portion of the concentrated first solution into a first end of the second distillation apparatus;

a second heat transfer means coupled to the second distillation apparatus at a second end, the second heat transfer means having an inlet coupled to the compressor for receiving the

compressed vaporized draw solution solutes therefrom for use as a second source of thermal energy, a first outlet coupled to the second distillation apparatus for directing the second source of thermal energy to the second distillation apparatus to cause any draw solution solutes in the second distillation apparatus to vaporize, and a second outlet configured to return the vaporized draw solution solutes from the first distillation apparatus condensed within the second heat transfer means to the osmotically driven membrane system;

a first outlet for removing the vaporized draw solution solutes from the second distillation apparatus; and

a second outlet for removing a bottoms product from the second distillation apparatus.

2. The apparatus of claim 1, further comprising:

a second compressor coupled to the first outlet of the second distillation column; and

at least a third distillation apparatus in fluid communication with the second side of the semi-permeable membrane, the apparatus comprising:

a first inlet coupled to a second source of the dilute draw solution for introducing a portion of dilute draw solution into a first end of the third distillation column;

a third heat transfer means coupled to the third distillation column at a second end, the third heat transfer means having an inlet coupled to the second compressor for receiving the vaporized draw solutes therefrom for use as a third source of thermal energy for use with the third distillation column, a first outlet coupled to the third distillation column for directing the third source of thermal energy to the third distillation column to cause draw solutes within the dilute draw solution in the third distillation chamber to vaporize, and a second outlet configured to return the vaporized draw solutes from the second distillation column condensed within the third heat transfer means to the osmotically driven membrane system;

a first outlet for removing the vaporized draw solution solutes from the third distillation column; and

a second outlet for removing a bottoms product from the third distillation column.

3. The apparatus of claim 2, wherein the first and third distillation apparatus are configured for series operation and the second source of the dilute draw solution is the bottoms product of

the first distillation column.

4. The apparatus of claim 1, wherein at least one of the first distillation apparatus or the second distillation apparatus comprises a membrane distillation apparatus.
5. The apparatus of claim 1 further comprising at least one recycling system disposed downstream of at least one of the first distillation apparatus or the second distillation apparatus.
6. The apparatus of claim 5, wherein the at least one recycling system comprises at least one of a compressor or an eductor.
7. The apparatus of claim 5, wherein the at least one recycling system comprises an absorbing system.
8. The apparatus of claim 7, wherein the absorbing system comprises at least one of a membrane contactor or a packed column.
9. The apparatus of claim 7, wherein the absorbing system comprises an absorbent comprising at least one of dilute draw solution or a product solvent.
10. The apparatus of claim 7, wherein the absorbing system comprises a catalyst.