CLAIMS

1. An electrodeionization apparatus having an anode compartment and a cathode compartment, comprising:

a first depleting compartment disposed between the anode compartment and the cathode compartment;

a concentrating compartment in ionic communication with the depleting compartment;

a second depleting compartment in ionic communication with the concentrating compartment; and

a first barrier cell in ionic communication with and disposed between the first depleting compartment and at least one of the anode compartment and the cathode compartment.

2. The electrodeionization apparatus of claim 1, wherein the first barrier cell is at least partially defined by a cation selective membrane disposed adjacent the first depleting compartment.

3. The electrodeionization apparatus of claim 2, wherein the first barrier cell is at least partially defined by an anion selective membrane and disposed adjacent the cathode compartment.

4. The electrodeionization apparatus of claim 3, wherein the first barrier cell contains a layer of media comprising a mixture of anion exchange media and cation exchange media.

5. The electrodeionization apparatus of claim 4, wherein the cathode compartment contains a mixture of anion exchange media and cation exchange media.

6. The electrodeionization apparatus of claim 1, further comprising a second barrier cell in ionic communication with the second depleting compartment, wherein

the second barrier cell is disposed between the anode compartment and the second depleting compartment.

7. The electrodeionization apparatus of claim 6, wherein the second barrier cell is at least partially defined by an anion selective membrane disposed adjacent the second depleting compartment.

8. The electrodeionization apparatus of claim 7, wherein the second barrier cell further comprises a cation selective membrane disposed adjacent the anode compartment.

9. The electrodeionization apparatus of claim 8, wherein the second barrier cell contains a layer of media comprising a mixture of anion exchange media and cation exchange media.

10. The electrodeionization apparatus of claim 8, wherein the anode compartment contains cation exchange media.

11. An electrodeionization apparatus comprising:

a depleting compartment; and

a first concentrating compartment in ionic communication with the depleting compartment, and defined at least partially by an anion selective membrane and a cation selective membrane, the first concentrating compartment containing at least partially a first zone comprising substantially of cation exchange media that is substantially separated from the anion selective membrane by a second zone comprising substantially of anion exchange media.

12. The electrodeionization apparatus of claim 11, further comprising a second concentrating compartment in ionic communication with the depleting compartment, the second concentrating compartment defined at least partially by a cation selective membrane and an anion selective membrane and containing a first portion comprising

ion exchange media and a second portion comprising ion exchange media, each of the first and second portions partially fills a lengthwise segment of the second concentrating compartment.

13. The electrodeionization apparatus of claim 12, wherein the first portion is predominantly comprised of cation exchange media and is disposed adjacent the cation selective membrane of the second concentrating compartment.

14. The electrodeionization apparatus of claim 13, wherein the second portion is substantially comprised of anion exchange media and is substantially separated from the cation selective membrane of the second compartment by the first portion of cation exchange media.

15. The electrodeionization apparatus of claim 11, wherein at least one of the first and second concentrating compartments further comprises electrochemically inert media.

16. The electrodeionization apparatus of claim 11, further comprising a source of an acidic solution in fluid communication with an inlet of the first concentrating compartment.

17. The electrodeionization apparatus of claim 11, wherein the cation exchange media comprises weak acid cation exchange resin.

18. The electrodeionization apparatus of claim 11, wherein the anion exchange media comprises weak base anion exchange resin.

19. An electrodeionization apparatus comprising:
a depleting compartment;

a first concentrating compartment in ionic communication with the depleting compartment, the first concentrating compartment comprising media with a first effective current resistance; and

a second concentrating compartment in ionic communication with the depleting compartment, wherein a portion of the second concentrating compartment comprising media with a second effective current resistance greater than the first effective current resistance.

20. The electrodeionization apparatus of claim 19, wherein the effective resistance of the at least a portion of the second concentrating compartment is at least two times greater than the first effective resistance.

21. The electrodeionization apparatus of claim 19, wherein the second concentrating compartment comprises inert media.

22. An electrodeionization apparatus comprising:

a depleting compartment; and

a concentrating compartment in ionic communication with the depleting compartment, the concentrating compartment comprising a mixture of anion exchange resin and cation exchange resin,

wherein amounts of the anion exchange resin and cation exchange resin in the mixture varies relative to a flow path length of the concentrating compartment.

23. The electrodeionization apparatus of claim 22, wherein the relative amount of anion exchange resin increases along the flow path of the concentrating compartment.

24. The electrodeionization apparatus of claim 22, wherein the relative amount of cation exchange resin increases along the flow path of the concentrating compartment.

25. An electrodeionization apparatus having at least one compartment with at least one outlet port defined by a distributor having a plurality of apertures, comprising:

a first layer of particles in the compartment bounded by ion selective membranes, the particles comprising media having a first effective diameter less than the smallest dimension of the apertures; and

a second layer of particles in the compartment downstream of the first layer, the second layer of particles having a second effective diameter greater than the first effective diameter and greater than the smallest dimension of the apertures.

26. The electrodeionization apparatus of claim 25, further comprising a third layer of particles disposed upstream of the first layer of particles.

27. The electrodeionization apparatus of claim 26, wherein the third layer comprises particles having about the same effective diameter as the particles of the second layer.

28. The electrodeionization apparatus of claim 25, wherein the second layer comprises ion exchange resin.

29. The electrodeionization apparatus of claim 25, wherein the first layer comprises an ion exchange resin.

30. The electrodeionization apparatus of claim 25, wherein the third layer comprises ion exchange resin.

31. An electrodeionization system comprising:

a source of water to be treated;

a treating module comprising a depleting compartment and a concentrating compartment, the treating module fluidly connected to the source of water to be treated;

an electrolytic module comprising an acid-generating compartment, the electrolytic module fluidly connected upstream of the concentrating compartment; and

a source of a brine solution fluidly connected to an inlet of the acid-generating compartment of the electrolytic module.

32. The electrodeionization system of claim 31, wherein an outlet of the depleting compartment is fluidly connected to the inlet of the acid-generating compartment.

33. The electrodeionization system of claim 32, wherein the electrolytic module further comprises a base-generating compartment in ionic communication with the acid-generating compartment.

34. The electrodeionization system of claim 33, wherein an outlet of the concentrating compartment is fluidly connected to an outlet of the base-generating compartment.

35. An electrodeionization apparatus comprising a compartment containing a mixture of anion exchange resins and cation exchange resins, the anion exchange resins having an average diameter at least 1.3 times greater than an average diameter of the cation exchange resins.

36. An electrodeionization apparatus comprising a compartment containing a mixture of anion exchange resins and cation exchange resins, the cation exchange resins having an average diameter at least 1.3 times greater than an average diameter of the anion exchange resins.

37. A water treatment system comprising:

a source of water to be treated;

an electrodeionization device comprising a plurality of concentrating and depleting compartments and fluidly connected to the source of water to be treated;

a chiller in thermal communication with the water to be introduced into at least one concentrating compartment of the electrodeionization device;

a sensor disposed to provide a representation of a temperature of at least one of water to be introduced into the concentrating compartment and water exiting the concentrating compartment; and

a controller configured to receive the temperature representation and generate a signal that promotes cooling the water to be introduced into the concentrating compartment.

38. The water treatment system of claim 37, wherein the controller is configured to regulate the temperature of the water to be introduced into the concentrating compartment to a target temperature.

39. The water treatment system of claim 38, wherein the controller is configured to calculate an effective Langelier Saturation Index (LSI) value of at least one of the water introduced into the concentrating compartment and the water exiting the concentrating compartment, and derive the target temperature based at least partially on the calculated LSI value.

40. An electrodeionization apparatus comprising:

a depleting compartment at least partially defined by a cation selective membrane and an anion selective membrane; and

a concentrating compartment at least partially defined by the anion selective membrane and containing a first layer of anion exchange media and a second layer of media disposed downstream of the first layer, the second layer comprising anion exchange media and cation exchange media.

41. The electrodeionization apparatus of claim 40, wherein the second layer comprises a first zone comprising cation exchange media that is substantially separated from the anion selective membrane by a second zone comprising anion exchange media.

42. The electrodeionization apparatus of claim 40, wherein the second layer is disposed downstream of the first layer.

43. A method of treating water in an electrodeionization device having a depleting compartment and a concentrating compartment, comprising:

measuring one of a temperature of a stream in the concentrating compartment, a temperature of a stream to be introduced into the concentrating compartment, and a temperature of a stream exiting from the concentrating compartment;

reducing the temperature of the water to be introduced into the concentrating compartment to a predetermined temperature;

introducing water to be treated into the depleting compartment; and

removing at least a portion of at least one undesirable species from the water to be treated in the electrodeionization device.

44. The method of claim 43, further comprising maintaining the temperature of the stream to be introduced into the concentrating compartment at a target value.

45. The method of claim 44, further comprising determining a Langelier Saturation Index (LSI) value of at least one of the stream to be introduced into the concentrating compartment and the stream exiting the concentrating compartment, and determining the target value based at least partially on the LSI value.

46. A method of treating water in an electrodeionization device, comprising:

introducing water having anionic and cationic species into a depleting compartment of the electrodeionization device;

promoting transport of at least a portion of the cationic species into a first barrier cell disposed between the depleting compartment and a cathode compartment of the electrodeionization device; and

promoting transport of at least a portion of the anionic species into a second barrier cell disposed between the depleting compartment and an anode compartment of the electrodeionization device.

47. The method of claim 46, wherein promoting transport of at least a portion of the cationic species comprises inhibiting transport of the cationic species from the first barrier cell into the cathode compartment.

48. The method of claim 47, wherein promoting transport of at least a portion of the anionic species comprises inhibiting transport of the anionic species from the second barrier cell into the anode compartment.

49. The method of claim 48, further comprising introducing at least a portion of water leaving the depleting compartment into at least one of the cathode compartment and the anode compartment.

50. The method of claim 46, further comprising maintaining a fluid flow velocity of greater than 2 gallons per minute per square foot through the concentrating compartment.

51. A method of treating water in an electrodeionization device having a depleting compartment and a concentrating compartment, comprising:

introducing water to be treated into the depleting compartment of the electrodeionization device;

promoting transport of an undesirable species from the depleting compartment into the concentrating compartment of the electrodeionization device, the concentrating compartment containing a first layer of anion exchange media and a second layer of media disposed downstream of the first layer, the second layer comprising a mixture of anion exchange media and cation exchange media.

52. A method of treating water comprising:

introducing water to be treated into a depleting compartment of an electrodeionization device, the depleting compartment having at least one layer of ion exchange media; and

promoting transport of at least a portion of anionic species from the water introduced into the depleting compartment from a first layer of ion exchange media into a first concentrating compartment to produce water having a first intermediate quality, the first concentrating compartment defined at least partially by an anion selective membrane and a cation selective membrane, the first concentrating compartment containing at least partially a first zone comprising cation exchange media that is substantially separated from the anion selective membrane by a second zone comprising anion exchange media.

53. The method of claim 52, further comprising maintaining a fluid flow velocity of greater than 2 gallons per minute per square foot through the first concentrating compartment.

54. A method of treating water in an electrodeionization device comprising:

introducing water to be treated comprising undesirable species into a depleting compartment of the electrodeionization device;

promoting transport of the undesirable species from the depleting compartment to a concentrating compartment of the electrodeionization device to produce the treated water;

electrolytically generating an acid solution in the ancillary module; and

introducing at least a portion of the acid solution into the concentrating compartment.

55. The method of claim 54, wherein electrolytically generating the acid solution comprises introducing a halide salt solution into the ancillary module.

56. The method of claim 55, further comprising generating a basic solution in the ancillary module while generating the acid solution.

57. The method of claim 56, further comprising neutralizing an outlet stream from the concentrating compartment with the basic solution.

58. The method of claim 57, further comprising mixing a portion of the treated water with the brine solution and introducing the mixture into the ancillary module.

59. The method of claim 58, wherein introducing the acid solution into the concentrating compartment comprises introducing an acidic solution having a pH of less than 4.3 into the concentrating compartment.

60. The method of claim 59, further comprising degasifying at least a portion of the liquid in the concentrating compartment.

61. A water treatment system comprising:

a source of a water to be treated; and

an electrodeionization device comprising a first depleting compartment and a second depleting compartment, each of the first and second depleting compartment fluidly connected to the source of water to be treated in a parallel flow configuration; and a first concentrating compartment in ionic communication with the first depleting compartment and a second concentrating compartment fluidly connected to downstream of the first concentrating compartment.

62. The system of claim 61, wherein the electrodeionization device further comprises a first electrode compartment fluidly connected upstream of the first concentrating compartment.

63. An electrodeionization apparatus comprising:

a plurality of depleting compartments configured to have liquid flowing therein along parallel flow paths; and

a plurality of concentrating compartments in ionic communication with at least one depleting compartment, wherein at least portion of the concentrating compartments are arranged serially.

64. The electrodeionization apparatus of claim 63, wherein the plurality of concentrating compartment define a single flow path through the electrodeionization apparatus.

Claims

1. An electrodeionization apparatus comprising:

a depleting compartment defined by a cation selective membrane (CEM) and an anion selective membrane (AEM) and containing a first layer of anion exchange media (A) and a second layer of a mixture of anion exchange media and cation exchange media (MB), the second layer (MB) of the depleting compartment being downstream of the first layer (A) of the depleting compartment; and

a concentrating compartment defined by the anion selective membrane (AEM) and a further cation selective membrane (CEM) and containing a first layer of anion exchange media (A) and a second layer of media (MB+) disposed downstream of the first layer (A), the second layer (MB+) comprising anion exchange media and cation exchange media,

wherein the second layer (MB) of the concentrating compartment comprises a mixture of anion exchange media and cation exchange media, wherein the first layer (A) of the depleting compartment extends further downstream than the first layer (A) of the concentrating compartment.

2. An electrodeionization apparatus comprising:

a depleting compartment defined by a cation selective membrane (CEM) and an anion selective membrane (AEM) and containing a first layer of anion exchange media (A) and a second layer of a mixture of anion exchange media and cation exchange media (MB), the second layer (MB) of the depleting compartment being downstream of the first layer (A) of the depleting compartment; and

a concentrating compartment defined by the anion selective membrane (AEM) and a further cation selective membrane (CEM) and containing a first layer of anion exchange media (A) and a second layer of media (A1, C) disposed downstream of the first layer (A), the second layer (A1, C) comprising anion exchange media and cation exchange media,

wherein the second layer (A1, C) of the concentrating compartment comprises a first zone comprising cation exchange media (C) that is separated from the anion selective membrane (AEM) by a second zone comprising anion exchange media (A1), wherein said zones (A1, C) extend from the bottom of the concentrating compartment to the above first layer (A) of the concentrating compartment,

wherein the a first layer (A) of the depleting compartment extends further downstream than the a first layer (A) of the concentrating compartment.

3. A method of treating water in an electrodeionization apparatus according to claim 1 or claim 2 comprising:

introducing water to be treated into the depleting compartment of the electrodeionization apparatus and also introducing water into the concentrating compartment of the electrodeionization apparatus;

passing an electrical current through the electrodeionization apparatus to promote transport of an undesirable species from the depleting compartment into the concentrating compartment of the electrodeionization apparatus.