

WHAT IS CLAIMED IS:

1. A respiratory humidification system for providing humidification to gases that pass through a gas passage way before being provided to an airway of a patient, the respiratory humidification system comprising:

a liquid flow controller for providing a controlled flow of liquid;

a heating system including a heating surface configured to be located in a gases passage way and provide humidification to gases passing through the passage way, wherein the heating system receives the controlled flow of liquid, the heating system configured to maintain the heating surface at a predetermined temperature of between approximately 30 °C and approximately 99.9 °C; and

one or more hardware processors providing deterministic control of a humidity level of gases passing through the gas passage way by instructing the liquid flow controller to adjust the controlled flow of liquid received at the heating system.

2. The respiratory humidification system of Claim 1, wherein the liquid flow controller comprises a metering system.

3. The respiratory humidification system of any of Claims 1-2, wherein the liquid flow controller comprises a pump.

4. The respiratory humidification system of Claim 3, wherein pump comprises a positive displacement pump.

5. The respiratory humidification system of Claim 4, wherein the positive displacement pump comprises a piezoelectric diaphragm pump or peristaltic pump.

6. The respiratory humidification system of any of Claims 1-2, wherein the liquid flow controller comprises a gravity feed and a control valve.

7. The respiratory humidification system of any of Claims 1-6, wherein the liquid flow controller comprises a non-return valve.

8. The respiratory humidification system of any of Claims 1-7, wherein the liquid flow controller is configured to use a wicking or capillary action.

9. The respiratory humidification system of any of Claims 1-8, further comprising a liquid reservoir.

10. The respiratory humidification system of Claim 9, further comprising a flow restriction device positioned between the liquid reservoir and the liquid flow controller and configured to prevent gravity driven flow influencing a delivered flow of liquid.

11. The respiratory humidification system of any of Claims 1-10, wherein the liquid flow controller is a pump in an open loop configuration.

12. The respiratory humidification system of any of Claims 1-10, further comprising a flow sensor.

13. The respiratory humidification system of Claim 12, wherein the flow sensor is a thermal mass meter, drip feed counter, or a differential pressure flow sensor.

14. The respiratory humidification system of Claim 12 or 13, wherein the liquid flow controller is a pump or flow actuator in series with the flow sensor in a closed loop configuration.

15. The respiratory humidification system of any of Claims 1-14, wherein the flow controller provides a controlled flow of liquid with an accuracy of approximately $\pm 15\%$ of a desired liquid flow rate.

16. The respiratory humidification system of any of Claims 1-15, wherein the one or more hardware processors provides deterministic control of the humidity level based on one or more of the following:

- a flow rate of the gases;
- an evaporation rate of water from the heating surface;
- a temperature of the heating surface, wherein the temperature of the heater surface is maintained at a constant temperature;
- a temperature of the heating surface, wherein the temperature of the heater surface is controlled;
- an absolute or barometric pressure of gases at the inlet;
- a humidity level based on the dew point temperature of the gases at the inlet;
- a humidity level based on enthalpy provided by the heating surface;
- a temperature of the gases prior to interaction with the heating system;
- a humidity level based on the relative humidity of the gases prior to interaction with the heating system;

a pressure of the gases;
a function of gas velocity; and/or
a temperature of the liquid in the controlled flow of liquid.

17. The respiratory humidification system of any of Claims 1-16, further comprising one or more of the following: a water temperature sensor, a gas flow rate sensor at an outlet of the gases passage way, and a gas flow rate sensor at an inlet of the gases passage way.

18. The respiratory humidification system of any of Claims 1-17, further comprising a liquid flow rate determined by a model.

19. The respiratory humidification system of any of Claims 1-18, further comprising a gases flow rate determined by a model.

20. The respiratory humidification system of any of Claims 1-19, further comprising a gases pre-heater.

21. The respiratory humidification system of any of Claims 1-20, further comprising one or more of the following:

- an ambient pressure sensor;
- a pressure sensor positioned at or near the heater surface;
- a heating surface temperature sensor;
- an ambient dew point temperature sensor or ambient humidity sensor positioned upstream of a humidification region;
- an ambient dew point temperature sensor positioned upstream from a gases pre-heater;
- an ambient dew point temperature sensor positioned downstream from a gases pre-heater; and/or
- an ambient dew point temperature sensor positioned downstream from the gases pre-heater and combined with a temperature sensor at a gases passage way inlet.

22. The respiratory humidification system of any of Claims 1-21, further comprising at least one temperature sensor forming part of the heating system.

23. The respiratory humidification system of Claim 22, wherein the at least one temperature sensor is utilized to determine a proportion of the heater that is saturated with a liquid.

24. The respiratory humidification system of any of Claims 20-23, wherein a temperature of the gases at a gases passage way inlet is controlled in an open loop fashion via control of a power to the pre-heater.

25. The respiratory humidification system of any of Claims 1-24, further comprising a liquid pre-heater.

26. The respiratory humidification system of any of Claims 1-25, wherein the heating surface comprises a wicking surface.

27. A high efficiency respiratory humidification system for providing heated and humidified respiratory gases to a patient, the system comprising:

- a respiratory gas passage way having an inlet and an outlet, where gases flow from the inlet to the outlet during operation;

- a pre-heater configured to heat a gas flow;

- a heating surface separate from the pre-heater and located downstream from the pre-heater, the heating surface including wicking features configured to wick a liquid across a face of the heating surface, the heating surface further configured to heat the liquid during and/or after wicking.

28. The respiratory humidification system of Claim 27, further comprising a gas flow generator.

29. The respiratory humidification system of any of Claims 27-28, wherein the pre-heater comprises a gas heating element.

30. The respiratory humidification system of Claim 29, wherein the gas heating element is one of a PCB including resistive elements, an etched foil film, a heating coil, or a PTC element.

31. The respiratory humidification system of any of Claims 27-30, further comprising a temperature sensor positioned downstream from the pre-heater.

32. The respiratory humidification system of Claim 31, wherein a power provided to the gas heating element is controlled according to a measurement obtained from the downstream temperature sensor.

33. The respiratory humidification system of any of Claims 27-32, further comprising a temperature sensor positioned upstream from the pre-heater.

34. The respiratory humidification system of Claim 33, wherein a power provided to the gas heating element is controlled according to a gas flow rate and a measurement obtained from the upstream temperature sensor.

35. The respiratory humidification system of any of Claims 29-34, wherein a characterization of the gas heating element is used as a temperature sensor.

36. The respiratory humidification system of any of Claims 27-35, wherein a desired downstream temperature is set according to an evaporation rate of the heating surface.

37. The respiratory humidification system of any of Claims 27-36, wherein the desired downstream temperature is set in order to ensure substantially all sensible heat is supplied to the gas flow by the pre-heater.

38. The respiratory humidification system of any of Claims 27-37, wherein the desired downstream temperature is set between 0 °C and approximately 5 °C above an output dew point temperature.

39. The respiratory humidification system of any of Claims 27-38, wherein the desired downstream temperature is set to obtain a pre-determined output relative humidity.

40. The respiratory humidification system of any of Claims 27-39, wherein the desired downstream temperature is set to obtain a pre-determined output absolute humidity.

41. The respiratory humidification system of any of Claims 27-40, wherein the desired downstream temperature is set to approximately 25 °C to 43 °C, approximately 31 °C to 43 °C, approximately 31 °C to 41 °C, approximately 31 °C to 37 °C, or approximately 37 °C.

42. The respiratory humidification system of any of Claims 27-41, further comprising a liquid flow generator for generating a liquid flow.

43. The respiratory humidification system of any of Claims 27-42, further comprising an apparatus for pre-heating the liquid flow.

44. The respiratory humidification system of Claim 43, wherein the apparatus for pre-heating the liquid flow is incorporated into the heater-surface structure by increasing a number of heating tracks at a location where the water is introduced.

45. The respiratory humidification system of Claim 44, wherein the apparatus for pre-heating the liquid flow is in a water supply line.

46. The respiratory humidification system of any of Claims 27-45, wherein the wicking features are one or more of an absorptive fabric or paper, micro-channels, a hydrophilic coated surface, capillary or contact wicks, or thin porous media.

47. The respiratory humidification system of any of Claims 27-46, wherein the wicking features comprise a coupling configured to distribute a liquid.

48. The respiratory humidification system of any of Claims 27-47, wherein the heating surface is maintained at a temperature of between approximately 30 °C and approximately 99.9 °C, between approximately 35 °C and approximately 90 °C, between approximately 40 °C and approximately 80 °C, between approximately 45 °C and approximately 70 °C, between approximately 45 °C and 60 °C, between approximately 50 °C and approximately 60 °C, or at approximately 50 °C.

49. The respiratory humidification system of any of Claims 27-48, wherein the humidification system is configured to be within, or as part of, an inspiratory tube for delivering gas to a patient.

50. The respiratory humidification system of any of Claims 27-49, further comprising a filter.

51. The respiratory humidification system of Claim 50, wherein the filter is in a liquid delivery line.

52. The respiratory humidification system of any of Claims 50-51, wherein the filter is positioned downstream from a pump.

53. The respiratory humidification system of any of Claims 50-52, wherein the filter is positioned at an inlet to the heating surface.

54. The respiratory humidification system of any of Claims 50-53, wherein the filter is a biologic filter.

55. The respiratory humidification system of any of Claims 27-54, further comprising a UV source for sterility.

56. A respiratory humidification system for providing heated and humidified respiratory gases to a patient, the system comprising:

a liquid flow controller providing a controlled flow of liquid;

a heating system including a heating surface configured to receive the controlled flow of liquid and provide humidification to gases passing through the humidification system;

one or more temperature sensors measuring a surface temperature of the heating surface;

one or more hardware processors providing deterministic control of a humidity level of gases passing through the respiratory system by instructing the liquid flow controller to adjust the controlled flow of liquid received at the heating system and instructing the heating system to adjust the surface temperature of the heating surface, wherein adjusting the surface temperature of the heating surface provides control to produce a known evaporative area; and

one or more liquid sensors configured to detect whether the heating surface is wetted in at least one region.

57. The respiratory humidification system of Claim 56, wherein the one or more liquid sensors comprises at least two liquid sensors configured to detect whether the heating surface is wetted at two or more regions of the heating surface.

58. The respiratory humidification system of any of Claims 56-57, wherein the one or more liquid sensors are located at, on, adjacent, or proximal the heating surface.

59. The respiratory humidification system of any of Claims 56-58, wherein the liquid flow controller comprises a metering system.

60. The respiratory humidification system of any of Claims 56-59, wherein the liquid flow controller is a pump in an open loop configuration.

61. The respiratory humidification system of any of Claims 56-59, wherein the liquid flow controller is a pump or flow actuator in series with a flow sensor in a closed loop configuration.

62. The respiratory humidification system of any of Claims 56-61, further comprising at least one temperature sensor forming part of the heating system.

63. The respiratory humidification system of Claim 62, wherein the at least one temperature sensor is utilized to determine a proportion of the heater that is saturated with a liquid.

64. The respiratory humidification system of any of Claims 56-63, wherein the one or more liquid sensors are used to prevent overflow of liquid onto the heating surface.

65. The respiratory humidification system of any of Claims 56-64, wherein the one or more liquid sensors are used by the one or more hardware processors to adjust the deterministic control of the humidity level of gases passing through the respiratory system.

66. The respiratory humidification system of any of Claims 56-65, wherein the one or more liquid sensors are used by the one or more hardware processors to adjust the evaporative area of the heating surface.

67. The respiratory humidification system of any of Claims 56-66, wherein the one or more liquid sensors are temperature sensors.

68. The respiratory humidification system of any of Claims 56-67, wherein the one or more liquid sensors are resistive or capacitive sensors.

69. A heater plate for a respiratory humidification system comprising a printed circuit board (PCB) or etched foil over-molded with a surface comprising micro-channels.

70. The heater plate of Claim 69, wherein the surface has micro-channels that extend in only a single direction.

71. The heater plate of any of Claims 68-69, wherein the micro-channels include a first set of distribution channels connected to a second set of main channels.

72. The heater plate of Claim 71, wherein the number of distribution channels is less than the number of main channels.

73. The heater plate of any of Claims 68-72, wherein the micro-channels are distributed radially from a single point.

74. The respiratory humidification system of any of Claims 1-68, wherein the heating system includes the heater plate of any of Claims 68-73.

75. A respiratory humidification system for providing humidification to gases that pass through a gas passage way before being provided to an airway of a patient, the respiratory humidification system comprising:

a liquid flow controller providing a controlled flow of liquid;

a heating system including a heating surface configured to receive the controlled flow of liquid and provide humidification to gases passing through the humidification system, wherein the heating surface is configured to wick liquid across the surface thereof; and

a gas pre-heater arranged in the gas passage way upstream of the heating system.

76. The respiratory humidification system of Claim 75, further comprising a coupling configured to receive the controlled flow of liquid from the liquid control and distribute the liquid onto the heating surface.

77. The respiratory humidification system of Claim 75 or 76, wherein the respiratory humidification system is configured to be in-line with an inspiratory tube for delivering gases to a patient.

78. The respiratory humidification system of Claim 77, wherein the respiratory humidification system is configured to be at least partially within the inspiratory tube.

79. The respiratory humidification system of any of Claims 75-78, further comprising a filter.

80. The respiratory humidification system of any of Claims any of Claims 75-79, further comprising a UV source for sterility.

81. The respiratory humidification system of Claim 75-80, wherein the liquid flow controller comprises a metering system.

82. The respiratory humidification system of any of Claims 75-81, wherein the liquid flow controller comprises a pump.

83. The respiratory humidification system of any of Claims 75-82, further comprising a safety valve to prevent flow of liquids if the pump fails.

84. The respiratory humidification system of any of Claims 75-83, further comprising a water reservoir.

85. The respiratory humidification system of Claim 84, further comprising a flow restriction device positioned between the water reservoir and the liquid flow controller and configured to prevent gravity driven flow influencing a delivered flow of liquid.

86. The respiratory humidification system of any of Claims 75-85, wherein the liquid flow controller is a pump in an open loop configuration.

87. The respiratory humidification system of any of Claims 75-85, wherein the liquid flow controller is a pump or flow actuator in series with a flow sensor in a closed loop configuration.

88. The respiratory humidification system of claim 87, wherein the pump is a piezoelectric micro pump and the flow sensor is a thermal mass meter.

89. The respiratory humidification system of any of Claims 75-88, wherein the heating system includes heater plate comprising a printed circuit board (PCB) or etched foil over-molded with a surface comprising micro-channels.

90. The respiratory humidification system of any of Claims 76-89, wherein the coupling is a fibrous, porous, or sintered polymer.

91. The respiratory humidification system of any of Claims 75-90, wherein the heating surface is immersed in the gas flow.

92. The respiratory humidification system of any of Claims 75-91, wherein the heating surface includes modular zones.

93. A respiratory humidification system comprising:

a liquid flow controller providing a controlled flow of liquid;

a heating system including a heating surface configured to be located in a gases passage way and provide humidification to gases passing through the passage way, wherein the heating system receives the controlled flow of liquid, the heating system configured to maintain the heating surface at a predetermined temperature of between approximately 30 °C and 99.9 C°; and

wherein approximately 80%-99.9% of the power output of the system is transferred into heat in the water.

94. The respiratory humidification system of Claim 93, wherein the heating surface is configured to be maintained at a temperature of between approximately 35 and

approximately 90 °C, between approximately 50 and approximately 60 °C or approximately 50 °C.

95. The respiratory humidification system of any of Claims 93-94, wherein approximately 95%- 99.99% of the power output of the system is transferred into heat in the water.

96. The respiratory humidification system of any of Claims 93-94, wherein approximately 98% of the power output of the system is transferred into heat in the water.

97. The respiratory humidification system of any of Claims 93-96, wherein the respiratory humidification system comprises the respiratory humidification system of any of Claims 1-68 or 75-92.

98. A respiratory humidification system for providing humidification to gases that pass through a gas passage way before being provided to an airway of a patient, the respiratory humidification system comprising:

an apparatus for heating a gas flow and positioned upstream of a humidification region;

a liquid flow generator; and

a heating system including a heating surface configured to be located in a gases passage way and provide humidification to gases passing through the passage way, wherein the heating system is configured to maintain a heating surface at a predetermined temperature of between approximately 30 °C and 99.9 °C.

99. The respiratory humidification system of Claim 98, wherein the heating system is configured to maintain the heating surface at a predetermined temperature of between approximately 35 °C and 90 °C.

100. The respiratory humidification system of Claim 98, wherein the heating system is configured to maintain the heating surface at a predetermined temperature of between approximately 40 °C and approximately 80 °C, or between approximately 45 °C and approximately 70 °C, or between approximately 45 °C and approximately 60 °C, or approximately between 50 °C and approximately 60 °C, or approximately 50 °C.

101. The respiratory humidification system of Claims 98-100, wherein the apparatus is a pre-heater.

102. The respiratory humidification system of Claim 101, wherein the pre-heater comprises a gas heating element.

103. The respiratory humidification system of Claim 102, wherein the gas heating element is one of a PCB including resistive elements, an etched foil film, a heating coil, or a PTC element.

104. A method to deterministically deliver gases having a predetermined outlet dew point temperature to an outlet of a respiratory humidification system, said respiratory humidification system including:

- a gases channel through which gases may flow, said gases channel extending between an inlet location and an outlet location and including a humidification location between said inlet and outlet locations,

- a fluid reservoir configured to hold a fluid,

- a heating surface in fluid communication with said gases channel at said humidification location, said heating surface having a wicking element,

- a metering arrangement, in fluid communication with said fluid reservoir and with said wicking element, said metering arrangement configured to meter said fluid from said fluid reservoir to said wicking element,

- said wicking element configured to distribute said metered fluid to at least a portion of said heating surface,

- said heating surface configured to provide a latent heat energy to vaporize said distributed fluid,

- the method comprising deterministically controlling, with a controller, said metering arrangement so as to deliver said gases to said outlet location at said predetermined outlet dew point temperature.

105. The method of Claim 104, further comprising receiving, by the controller from an inlet dew point temperature sensor, an inlet dew point temperature measurement of a gases supply, said gases supply provided at said inlet of said respiratory humidification system, and controlling said metering arrangement based on the received inlet dew point temperature measurement of the gases supply.

106. The method of any of Claims 104-105, further comprising receiving, by the controller from an inlet gases flow sensor, an inlet gases flow rate measurement of said gases supply, and controlling said metering arrangement based on the received gases flow rate measurement of the gases supply.

107. The method of any of Claims 104-106, further comprising receiving, by the controller from a pressure sensor disposed within said gases channel between said inlet and humidification locations, a gases channel pressure level measurement, and controlling said metering arrangement based on the received gases channel pressure level measurement.

CLAIMS:

1. A respiratory humidification system for providing humidification to gases that pass through a gases passage way before being provided to an airway of a patient, the respiratory humidification system comprising:

a liquid flow controller for providing a controlled flow of liquid;

a heating system including a heating surface configured to be located in a gases passage way and provide humidification to gases passing through the passage way, wherein the heating system receives the controlled flow of liquid, the heating system configured to maintain the heating surface at a temperature of between 30 °C and 99.9 °C; and

one or more hardware processors providing deterministic control of a humidity level of gases passing through the gases passage way by instructing the liquid flow controller to adjust the controlled flow of liquid received at the heating system based on a flow rate of gases through the gases passage way, and an evaporation rate of said controlled flow of liquid from the heating surface.

2. The respiratory humidification system of Claim 1, wherein the deterministic control of the humidity level of gases is based on one or more of:

control of a temperature of the heating surface,

control of an evaporative area of the heating surface,

the flow of liquid received at the heating system.

3. The respiratory humidification system of Claim 1 or 2, wherein the controlled flow of liquid is configured to be provided to the heating surface so as to cover the heating surface as a film.

4. The respiratory humidification system of any one of Claim 1-3, wherein the liquid flow controller comprises a metering system.

5. The respiratory humidification system of any one of Claims 1-4, wherein the liquid flow controller comprises a pump, optionally the pump is a positive displacement pump, or a gravity feed and a control valve.

6. The respiratory humidification system of any one of Claims 1-5, wherein the liquid flow controller comprises a non-return valve.

7. The respiratory humidification system of any one of Claims 1-6, further comprising a liquid reservoir.

8. The respiratory humidification system of any one of Claims 1-7, wherein the liquid flow controller is a pump in an open loop configuration.

9. The respiratory humidification system of any one of Claims 1-8, further comprising a flow sensor, wherein the flow sensor is configured to measure the controlled flow of liquid.

10. The respiratory humidification system of Claim 9, wherein the liquid flow controller is a pump or flow actuator in series with the flow sensor in a closed loop configuration.

11. The respiratory humidification system of any one of Claims 1 to 10, wherein the one or more hardware processors provides deterministic control of the humidity level based on one or more of:

- a relative humidity level of the gases prior to interaction with the heating system;

- a temperature of the gases prior to interaction with the heating system;

- an absolute or barometric pressure of gases at the inlet.

12. The respiratory humidification system of any one of Claims 1-11, wherein the one or more hardware processors provides deterministic control of the humidity level based on one or more of the following:

- a humidity level based on the dew point temperature of the gases at the inlet;

- a humidity level based on enthalpy provided by the heating surface;

- a pressure of the gases;

- a function of gas velocity; and/or

- a temperature of the liquid in the controlled flow of liquid.

13. The respiratory humidification system of any one of Claims 1-12, further comprising one or more of the following: a water temperature sensor, a gas flow rate sensor at an outlet of the gases passage way, and a gas flow rate sensor at an inlet of the gases passage way.

14. The respiratory humidification system of any one of Claims 1-13, further comprising a gases pre-heater.

15. The respiratory humidification system of Claim 14, wherein the gases pre-heater is controlled to heat the gases to a desired downstream temperature after the pre-heater, the desired downstream temperature set to be between 0 °C and 5 °C above a gases output temperature.

16. The respiratory humidification system of any one of Claims 1-15, further comprising one or more of the following:

an ambient pressure sensor;

a pressure sensor positioned at or near the heater surface;

a heating surface temperature sensor;

an ambient dew point temperature sensor or ambient humidity sensor positioned upstream of a humidification region;

an ambient dew point temperature sensor positioned upstream from a gases pre-heater;

an ambient dew point temperature sensor positioned downstream from a gases pre-heater; and/or

an ambient dew point temperature sensor positioned downstream from the gases pre-heater and combined with a temperature sensor at a gases passage way inlet.

17. The respiratory humidification system of any one of Claims 1-16, further comprising at least one temperature sensor forming part of the heating system, optionally said at least one temperature sensor is in thermal contact with the heating surface.

18. The respiratory humidification system of Claim 17, wherein the at least one temperature sensor is utilized to determine a proportion of the heater that is saturated with a liquid.

19. The respiratory humidification system of any one of Claims 1-18, further comprising a liquid pre-heater.

20. The respiratory humidification system of any one of Claims 1-19, wherein the heating surface comprises a wicking surface.