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(54) AN APPARATUS AND A METHOD FOR HUMIDIFYING A GAS

(57) An apparatus (10) for humidifying a gas comprises a gas flow passage (20) along a top-to-bottom direction (D), with a gas inlet (22) opening towards a gas outlet (24), a heat exchange structure (34) between the gas inlet and outlet, a heat source (32) configured for heating the heat exchange structure (34), a liquid pouring device (50) within the gas flow passage between the gas inlet and the heat exchange structure for pouring a liquid downwards onto an upper end (52) of the heat exchange structure (34) such that said liquid wets the heat exchange structure where the latter delimits portions (36) of the gas flow passage, and a liquid inlet (54) for supplying the liquid pouring device with said liquid. The apparatus enables evaporation of at least part of the liquid into said gas within the portions of the gas flow passage delimited by the heat exchange structure.

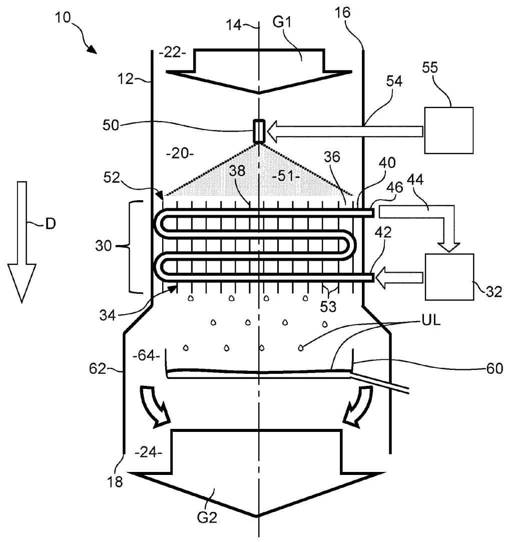

FIG. 1

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Description

TECHNICAL FIELD

[0001] The present invention relates to an apparatus and a method for humidifying a gas. Although humidification usually refers to adding water vapor in a flow of air or other gases, the present invention is not limited to the use of water as liquid to evaporate. In other words, the apparatus and method according to the invention aim at increasing the concentration of a substance (which can be water or another substance) in the gas phase within a gas flow (which can be air or another gas). For the sake of simplicity, most of the following description takes water and air as an example but can be easily transposed to other substances to evaporate and other gases.

BACKGROUND ART

[0002] Many thermodynamic processes use the water vapor contained in moist air for heating and cooling purposes.

[0003] The concentration of water, also known as absolute humidity, plays an important role in the process efficiency. Indeed, a higher concentration directly increases the potential energy of the moist air because water specific enthalpy is higher in gaseous phase (vapor) than in liquid or solid phase. The phase change enthalpy of water vapor to liquid/solid can thus be used for heat generation at a relatively low temperature (less than 100°C), for instance through condensation, sorption, or deposition.

[0004] Conventional air humidifiers are made of a wetted material through which a flow of air is circulated. Evaporation of the water into said air flow leads to lowering the temperature thereof down to the dew point, which may thereby stop the humidification process.

[0005] There is therefore a need to improve such gas humidifiers.

SUMMARY OF THE INVENTION

[0006] To this end, an object of the present invention is an apparatus according to claim 1 and a method according to claim 10.

[0007] Since the maximum absolute humidity increases with temperature, a higher humidification is made possible by using heat provided by the heat exchanger to compensate for the cooling effect of the liquid evaporation.

[0008] The invention provides the crucial advantage of combining the humidification process and the heat compensation at a same location, namely on wetted surfaces of the heat exchange structure delimiting said portions of the gas flow passage.

[0009] This makes it possible to avoid or at least limit the risks for the gas to be cooled by the liquid evaporation, be it only locally, which would otherwise result in a decrease of the maximum possible humidification rate.

[0010] The gas can thus accept more evaporated liquid per unit of dry gas before reaching the condensation limit, which increases the maximum possible humidification rate.

[0011] In addition, by having both the gas inlet and the liquid pouring device oriented in a same direction, the invention makes it possible to optimize as much as possible the homogeneity of liquid distribution into the gas, and consequently, the homogeneity of heat exchange and liquid evaporation taking place in the heat exchanger.

[0012] Furthermore, the top-to-bottom orientation of the gas and liquid flows within the gas passage enables the poured liquid to flow by gravity on the surfaces of the heat exchange structure delimiting said portions of the gas flow passage, starting from the top end of said heat exchange structure.

[0013] This helps to ensure that the humidification process remains homogeneous across the whole transversal cross-section of the gas flow passage.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The invention will be better understood and other details, advantages and characteristics of it will become clear after reading the following description given as a non-limitative example with reference to the appended drawings in which:

- Figure 1 is a schematic cross-sectional view of an apparatus according to a first embodiment of the invention;
- Figure 2 is a view similar to figure 1, showing a second embodiment of the invention;
- Figure 3 is a view similar to figure 1, showing a third embodiment of the invention;
- Figure 4 is a view similar to figure 1, showing a fourth embodiment of the invention;
- Figure 5 is a view similar to figure 1, showing a fifth embodiment of the invention.

[0015] In all these figures, identical references may denote identical or similar elements.

DESCRIPTION OF A PREFERED EMBODIMENT

[0016] An apparatus 10 for humidifying a gas according to a first embodiment of the invention is illustrated on figure 1.

[0017] The apparatus 10 generally comprises a vessel 12 having a shape exhibiting symmetry of revolution about a longitudinal axis 14 and having two opposite open ends with respect to the longitudinal axis, namely a top end 16 and a bottom end 18. The vessel 12 defines a gas flow passage 20 extending preferentially straight along a top-to-bottom direction D parallel to the longitudinal axis 14, from a gas inlet 22 defined through said top end 16 to a gas outlet 24 defined through said bottom end 18. It will therefore be understood that the gas inlet 22 extends transversally to the top-to-bottom direction D at a top end of the gas flow passage 20 so as to open downwards. The words "top" and "bottom" are to be interpreted with respect to a nominal orientation of the apparatus 10 in use, as will become clearer in the following.

[0018] The gas inlet 22 preferentially extends over the whole transversal cross-section of the top end 16 of the vessel 12 with respect to the top-to-bottom direction D. Similarly, the gas outlet 24 preferentially extends transversally to the top-to-bottom direction D at the bottom end of the gas flow passage.

[0019] The apparatus 10 further comprises a heat exchanger 30 and a heat source 32.

[0020] The heat exchanger 30 comprises a heat exchange structure 34 arranged within the gas flow passage 20 between the gas inlet 22 and gas outlet 24. The heat exchange structure 34 delimits portions 36 of the gas flow passage 20. Typically, the heat exchange structure 34 comprises a plurality of fins 38 extending parallel to the top-to-bottom direction D.

[0021] In the first embodiment, the heat exchanger 30 comprises a heat transfer fluid circuit 40 configured for transferring heat to the heat exchange structure 34. For example, the heat transfer fluid circuit 40 comprises a duct or a plurality of interconnected ducts extending through the fins 38 transversally to the top-to-bottom direction D. Alternatively, the heat transfer fluid circuit 40 may comprise one or more microchannel elements, for example microchannel plates, arranged in contact to the heat exchange structure 34.

[0022] In such cases, the heat source 32 is a source of heat transfer fluid connected to an inlet 42 of the heat transfer fluid circuit 40.

[0023] Moreover, in the disclosed example, a return channel 44 advantageously connects an outlet 46 of the heat transfer fluid circuit 40 to a return port of the heat source 32 so as to define a closed circuit for the heat transfer fluid.

[0024] The apparatus 10 further comprises a liquid pouring device 50 arranged within the gas flow passage 20 between the gas inlet 22 and the heat exchange structure 34 for pouring a liquid 51 downwards onto an upper end 52 of the heat exchange structure. In addition, the heat exchange structure 34 is configured for such poured liquid to flow by gravity onto surfaces 53 of the heat exchange structure 34 which delimit said portions 36 of the gas flow passage 20. In other words, the heat exchange structure 34 enables such poured liquid to wet the heat exchange structure 34 where the latter delimits said portions 36 of the gas flow passage. This of course assumes that the vessel 12 is held in a correct orientation, with its top end 16 in an upper position and its bottom end 18 in a lower position and with its longitudinal axis 14 extending vertically.

[0025] The liquid pouring device 50 for example comprises a spray nozzle configured for evenly spraying the liquid downwards onto the upper end 52 of the heat exchange structure. Although spraying water evenly tends to increase performance, the system described in this document is flexible and also works when the liquid pouring flowrate is unevenly distributed in the plane perpendicular to the main air stream, as long as the upper end 52 of the heat exchanger structure remains completely wet. Such spray nozzle may offer a great compactness to avoid as much as possible obstructing the gas flow passage 20.

[0026] In preferred embodiments, the liquid pouring device 50 is configured for delivering liquid droplets of a diameter of at least 50 μm. Such droplets can for example be simply obtained by means of a spray nozzle supplied with water under a pressure of 4 to 6 bars. In other embodiments, the liquid pouring device 50 is configured for delivering one or multiple continuous flows of the liquid. By delivering large droplets or continuous flows of liquid, the liquid pouring device 50 helps limiting liquid pre-evaporation in the gas upstream from the heat exchanger 30. Devices configured for delivering larger droplets or continuous flows of liquid are also generally cheaper than devices able to deliver smaller droplets.

[0027] It is to be noted that the cross-section of vessel 12 may alternatively be of square shape, rectangular shape, or any other shape, provided the liquid pouring device 50 spray pattern be adapted to such shape.

[0028] The apparatus 10 further comprises a liquid inlet 54 connected to the liquid pouring device 50 for supplying the latter with said liquid. To this end, the liquid inlet 54 is connected to a source of liquid 55. In a preferred embodiment, the liquid is water.

[0029] In the illustrated example, the apparatus 10 also comprises a liquid collector 60 arranged within the gas flow passage 20 between the heat exchange structure 34 and the gas outlet 24.

[0030] The liquid collector 60 for example is a drain pan extending transversally to the top-to-bottom direction D.

[0031] The vessel 12 comprises an enlarged part 62 below the heat exchange structure 34 for delimiting a lower portion 64 of the gas flow passage 20 about the liquid collector 60, thus ensuring a sufficiently large free section about the liquid collector 60 to avoid obstructing the circulation of the gas down to the gas outlet 24.

[0032] Accordingly, a method for humidifying a gas by means of the apparatus 10 comprises steps of:

- A) heating the heat exchange structure 34 with heat provided by the heat source 32; to this end, in the first embodiment, heat transfer fluid provided by the heat source 32 is circulated through the heat transfer fluid circuit 40 for heating the fins 38;
- B) injecting gas G1 through the gas inlet 22 into the gas flow passage 20 so as to establish a circulation of said gas in the top-to-bottom direction D;
- C) supplying liquid from said source of liquid 55 to the liquid pouring device 50 such that the liquid pour-

ing device 50 pours said liquid downwards onto the upper end 52 of the heat exchange structure 34, typically at a volume flow rate much smaller than the volume flow rate of the gas; and letting at least part of said liquid flow by gravity on the heat exchange structure 34 thereby wetting the same where it delimits said portions 36 of the gas flow passage 20;

- D) transferring heat from the heat exchange structure 34 to said gas and liquid whereby at least part of said liquid will simultaneously evaporate into said gas;
- E) outputting the gas thus humidified G2 through the gas outlet 24.

[0033] In the illustrated example, the method further comprises a step F of collecting possibly unevaporated liquid UL into the liquid collector 60 and evacuating said liquid through an output port of said liquid collector 60.

[0034] It should thus be understood that gas humidification and heat exchange occur both on the wet surface of the heat exchange structure 34, thus leading to a higher possible humidity rate at the gas outlet 24, for a given rate of thermal energy supplied to the heat exchanger 30.

[0035] This comes from a thermodynamic property according to which when a liquid substance evaporates in a gas stream, this gas stream cools down. In addition, the maximum possible vapor content of the gas decreases as the gas cools down. Consequently, the gas humidification is limited by its own cooling effect. Although it is possible to compensate this cooling effect by means of a heat exchanger for heating the gas flow, if such process happens subsequently, that is if heating happens after the humidification, it will only compensate the sensible cooling effect for the outputted humidified gas without any positive impact on the humidification itself. By contrast, the invention makes it possible for this cooling compensation to occur at the same time as the humidification process, which allows the gas temperature to remain at a higher level. For instance, by maintaining a constant gas temperature, it is possible to prevent the maximum possible vapor content of the gas from decreasing despite the energy consumption corresponding to the latent heat of the evaporation process.

[0036] Moreover, by pouring the liquid on the full horizontal upper end 52 of the heat exchange structure 34 and letting the liquid flow by gravity, the heat exchange structure 34 is wetted on its full cross section at once. This allows the evaporation process to occur at the same pace in any given horizontal plane within the heat exchange structure 34.

[0037] The apparatus and method of the invention provide the additional advantages of low power consumption because the gas has only one heat exchanger to flow through and because of the straight geometry of the gas flow passage, which helps limiting the associated pressure drop. Low power consumption also results from the fact that the liquid is simply poured or sprayed into large droplets or continuous flows onto the heat exchanger. Such apparatus may also be of relative compacity. In addition, conventional heat exchangers can be used, which helps limiting costs. Besides, the apparatus can be operated at a low temperature and atmospheric pressure and thus proves to be secure. It can also be operated at pressures below or greater than atmospheric pressure.

[0038] Figures 2 to 5 show various alternative embodiments of the apparatus 10 which all share the mode of operation and main technical advantages explained above with respect to the first embodiment.

[0039] Figure 2 illustrates a second embodiment of the apparatus 10, which is similar to the first embodiment but includes means for optimizing the flow rate of the liquid to be evaporated.

[0040] The exact amount or rate of liquid that the apparatus 10 can evaporate depends on a number of parameters, including dynamic ones. It is therefore difficult to analytically predict the optimum flowrate leading to the highest possible humidification. A too low flowrate would limit the humidification, while a too high flowrate would bring the risk of flooding the heat exchanger, leading to high pressure drop for the gas.

[0041] The apparatus 10 according to the second embodiment solves this problem by making it possible to constantly adjust the flowrate of poured liquid based on the pressure drop of the gas flow due to the heat exchange structure 34.

[0042] To this end, the apparatus 10 comprises a liquid flow controller 70 configured to adjust the flow rate of liquid supplied to the liquid pouring device 50 based on the drop of gas pressure within the gas flow passage 20 between a first location 72 upstream of the heat exchange structure 34 and a second location 74 downstream of the heat exchange structure 34.

[0043] This innovative feature is based on an indirect effect of surface tension forces that affect the liquid flow in a greater way than gravity or even gaseous flow in a given channel. Indeed, tension forces tend to aggregate the liquid on surfaces of the heat exchange structure 34, which reduces the available cross section for the gas within the portions 36 of the gas flow passage delimited by the heat exchange structure 34, thus increasing said gas pressure drop. Said gaseous pressure drop is therefore a relevant physical indication of the wetting level of the heat exchange structure 34.

[0044] The liquid flow controller 70 is for example configured for stopping or reducing liquid supply to the liquid pouring device 50 when said gas pressure drop becomes higher than a threshold, and for starting or increasing liquid supply to the liquid pouring device 50 when said gas pressure drop becomes lower than said threshold minus a hysteresis value. In alternative embodiments, the liquid flow controller 70 can be configured to implement more complex flow control algorithms.

[0045] The liquid flow controller 70 generally comprises a gas pressure drop sensor 76, an actuator for modulating the liquid flow supplied to the liquid pouring device 50, for instance by switching a pump or a valve on and off, and a control unit 80.

[0046] The gas pressure drop sensor 76 may be a differential pressure drop sensor pneumatically connected to the gas flow passage 20 on both sides of the heat exchange structure 34. The control unit 80 is configured for running a flow control algorithm to output orders to the actuator that controls the liquid flow rate based on the output of said sensor read by the control unit 80.

[0047] Figure 2 shows two possible types of actuators. The first type is a switching valve or control valve 82 connected to the source of liquid 55 in which case the latter must provide the liquid under pressure. The second type is a pump 84 connected to a liquid tank 86 which then constitutes said source of liquid 55. In this case, the latter must be filled periodically either manually or automatically. Means for automatically filling such liquid tank 86 will be described below.

[0048] As will be readily understood from the preceding, when using the apparatus 10 according to the second embodiment, step C of the above method includes a substep C1 of having the flow controller 70 adjust the flow rate of liquid supplied to the liquid pouring device 50 based on the gas pressure drop within the gas flow passage 20 between a first location 72 upstream of the heat exchange structure 34 and a second location 74 downstream of the heat exchange structure 34.

[0049] Figure 3 illustrates a third embodiment of the apparatus 10, which is similar to the second embodiment but includes a recirculation circuit 90 connecting an output of the liquid collector 60 to the liquid pouring device 50. This enables to supply the liquid pouring device 50 with a possibly unevaporated part of the liquid, collected by the liquid collector 60.

[0050] In the example shown in figure 3, the recirculation circuit 90 comprises:

- an output duct 92 connecting an output port of the liquid collector 60 to a first input port of a liquid tank 86;
- the liquid tank 86;
- an upstream recirculation duct 94 connecting a first output port of the liquid tank 86 to an input port of a pump 84 constituting the actuator of said liquid flow controller 70;
- a downstream recirculation duct 98 connecting an output port of the pump 84 to an input port of the liquid pouring device 50.

[0051] The apparatus 10 shown in figure 3 further comprises means for automatically filling the liquid tank 86 with liquid from the source of liquid 55 when required. Such means for example include a liquid level detector 100 provided inside the liquid tank 86 and a switching or control valve 102 provided on a connecting duct 104 which connects an output port of the source of liquid 55 to a second input port of the liquid tank 86. The liquid tank 86 preferentially includes an overflow port connected to an evacuation drain 106.

[0052] In such case, the liquid tank 86 acts as a buffer between the source of liquid 55 and liquid collector 60 on the one hand and the liquid pouring device 50 on the other hand, while the means for automatically filling the liquid tank 86 ensure that there is always at least a minimum amount of liquid to be evaporated in the apparatus.

[0053] As will be readily understood from the preceding, when using the apparatus 10 according to the third embodiment, step F of the above method includes a substep F1 of returning an unevaporated part of the liquid collected by the liquid collector 60 to the liquid pouring device 50.

[0054] Figure 4 illustrates an apparatus 10 according to a fourth embodiment of the invention, which is similar to the first embodiment but in which the heat transfer fluid circuit 40 and the source of hot heat transfer fluid are replaced by an electrical heater 110 configured for heating the heat exchange structure 34, and therefore connected to a source of electrical energy 112. The electrical heater 110 thus constitutes the aforementioned heat source 32. The electrical heater 110 and the heat exchange structure 34 may of course be combined into a single element.

[0055] As will be readily understood from the preceding, when using the apparatus 10 according to the fourth embodiment, step A of the above method includes heating the heat exchange structure 34 by the electrical heater 110.

[0056] Figure 5 illustrates an apparatus 10 according to a fifth embodiment of the invention, which is similar to the first embodiment but which includes a heat pump 120 including said heat exchanger 30 as a condenser and including an evaporator 122 arranged outside of the vessel 12. The evaporator can be heated by ambient air or any other external heat source and therefore constitutes the aforementioned source of hot heat transfer fluid or heat source 32. Such heat pump 120 further includes a compressor 124 connecting an output of a heat transfer fluid circuit 125 of the evaporator 122 to an input of the heat transfer fluid circuit 40 of the heat exchanger 30 or condenser, and an expansion valve 126 connecting an output of the heat transfer fluid circuit 40 of the heat exchanger 30 or condenser to an input of the heat transfer fluid circuit 125 of the evaporator 122.

[0057] Such embodiment is characterized by a low electrical consumption, in particular if compared to the embodiment of figure 4.

Claims

1. An apparatus (10) for humidifying a gas, comprising:

   a vessel (12) defining a gas flow passage (20) extending along a top-to-bottom direction (D) so as to connect a gas inlet (22) to a gas outlet (24) of said vessel, wherein the gas inlet (22) extends transversally to the top-to-bottom direction (D)

at a top end of the gas flow passage so as to open towards a bottom end of the gas flow passage, whereby a circulation of the gas (G1, G2) can be established in the top to bottom direction from the gas inlet (22) to the gas outlet (24) within the gas flow passage (20);
a heat exchanger (30) comprising a heat exchange structure (34) arranged within the gas flow passage (20) between said gas inlet (22) and gas outlet (24) and delimiting portions (36) of said gas flow passage (20);
a heat source (32) configured for heating said heat exchange structure (34);
a liquid pouring device (50) arranged within the gas flow passage (20) between the gas inlet (22) and the heat exchange structure (34) for pouring a liquid downwards onto an upper end (52) of the heat exchange structure (34) such that said liquid at least partially wets the heat exchange structure where the latter delimits said portions (36) of the gas flow passage;
a liquid inlet (54) connected to the liquid pouring device (50) for supplying the liquid pouring device with said liquid;
whereby the apparatus enables evaporation of at least part of said liquid into said gas within the portions (36) of said gas flow passage delimited by the heat exchange structure (34).

2. The apparatus according to claim 1, wherein said liquid pouring device (50) is configured for delivering liquid droplets of at least 50 micro-meter in diameter or for delivering one or multiple continuous flows of the liquid.

3. The apparatus according to claim 1 or 2, wherein the heat exchanger (30) comprises a heat transfer fluid circuit (40) configured for transferring heat to the heat exchange structure (34) and wherein the heat source (32) is a source of heat transfer fluid connected to said heat transfer fluid circuit (40).

4. The apparatus according to claim 3, comprising a heat pump (120) including said heat exchanger (30) as condenser and including an evaporator (122) arranged outside from the vessel (12) and constituting said source of hot heat transfer fluid.

5. The apparatus according to claim 1 or 2, wherein said heat source (32) is an electrical heater (110) or a solar collector configured for heating the heat exchange structure (34).

6. The apparatus according to any one of claims 1 to 5, comprising a liquid flow controller (70) configured for adjusting a flow rate of liquid supplied to the liquid pouring device (50) based on a gas pressure drop within the gas flow passage (20) between a first location (72) upstream of the heat exchange structure (34) and a second location (74) downstream of the heat exchange structure (34).

7. The apparatus according to claim 6, wherein the liquid flow controller (70) is configured for stopping or reducing liquid supply to the liquid pouring device (50) when said gas pressure drop becomes higher than a threshold, and for starting or increasing liquid supply to the liquid pouring device (50) when said gas pressure drop becomes lower than said threshold minus a hysteresis value.

8. The apparatus according to any one of claims 1 to 7, comprising a liquid collector (60) arranged within the gas flow passage (20) between the heat exchange structure (34) and the gas outlet (24), and a recirculation circuit (90) connecting an output of the liquid collector (60) to the liquid pouring device (50) in addition to said liquid inlet (54) for supplying the liquid pouring device (50) with an unevaporated part of the liquid collected by the liquid collector (60).

9. The apparatus according to claim 8, wherein the liquid collector (60) is a drain pan extending transversally to the top-to-bottom direction (D), and wherein the vessel (12) comprises an enlarged part (62) below the heat exchange structure (34) to define a lower portion (64) of the gas flow passage (20) about said drain pan.

10. A method for humidifying a gas by means of an apparatus (10) according to any one of claims 1 to 9, comprising steps of:

- A) heating the heat exchange structure (34) with heat provided by said heat source (32);
- B) injecting gas (G1) through the gas inlet (22) into the gas flow passage (20) so as to establish a circulation of said gas in the top-to-bottom direction (D);
- C) supplying liquid from a source of liquid (55) to the liquid pouring device (50) via the liquid inlet (54) such that the liquid pouring device (50) pours said liquid downwards onto the upper end (52) of the heat exchange structure (34), whereby at least part of said liquid at least partially wets the heat exchange structure (34) where the latter delimits said portions (36) of the gas flow passage;
- D) transferring heat from the heat exchange structure (34) to said gas and liquid and simultaneously evaporating at least part of said liquid into said gas;
- E) outputting the gas thus humidified (G2) through the gas outlet (24).

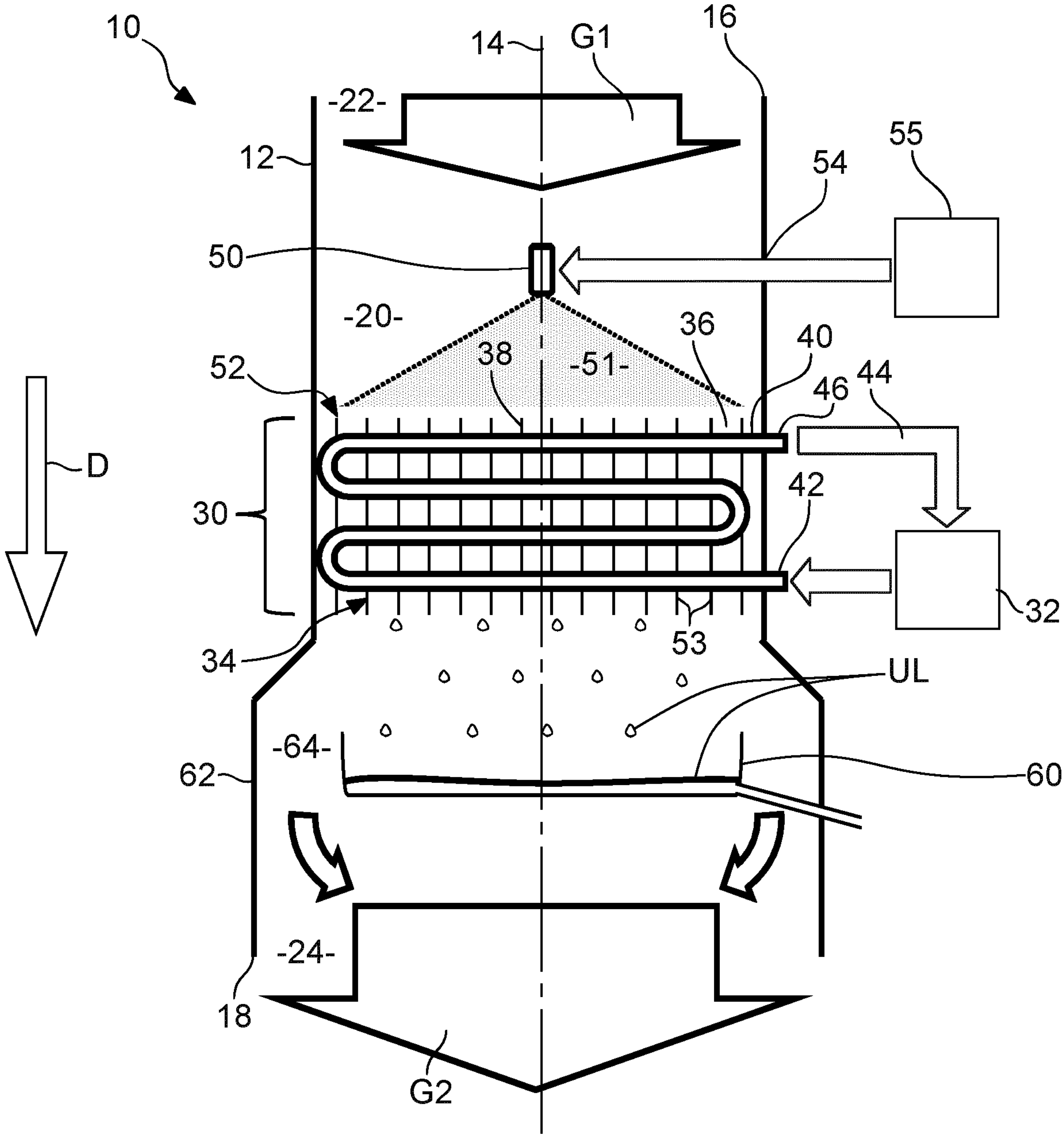
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FIG. 1

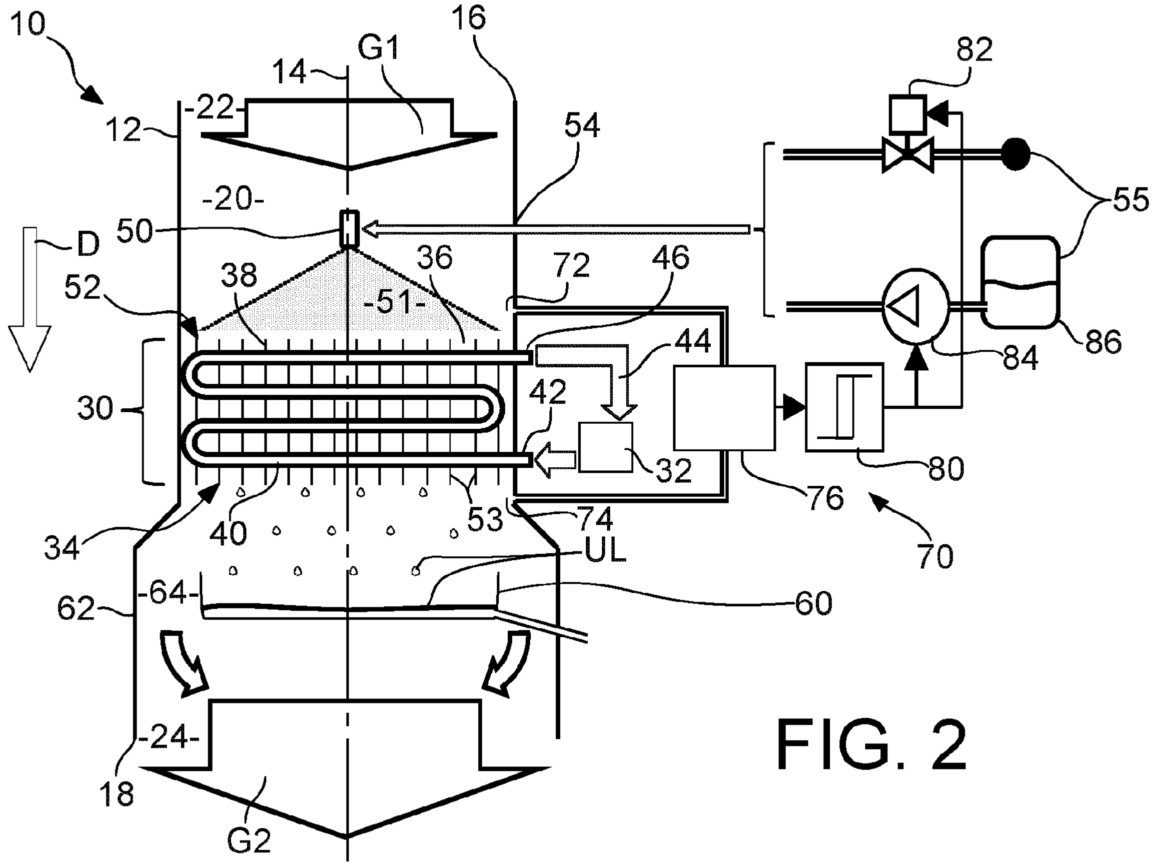
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FIG. 2

FIG. 3

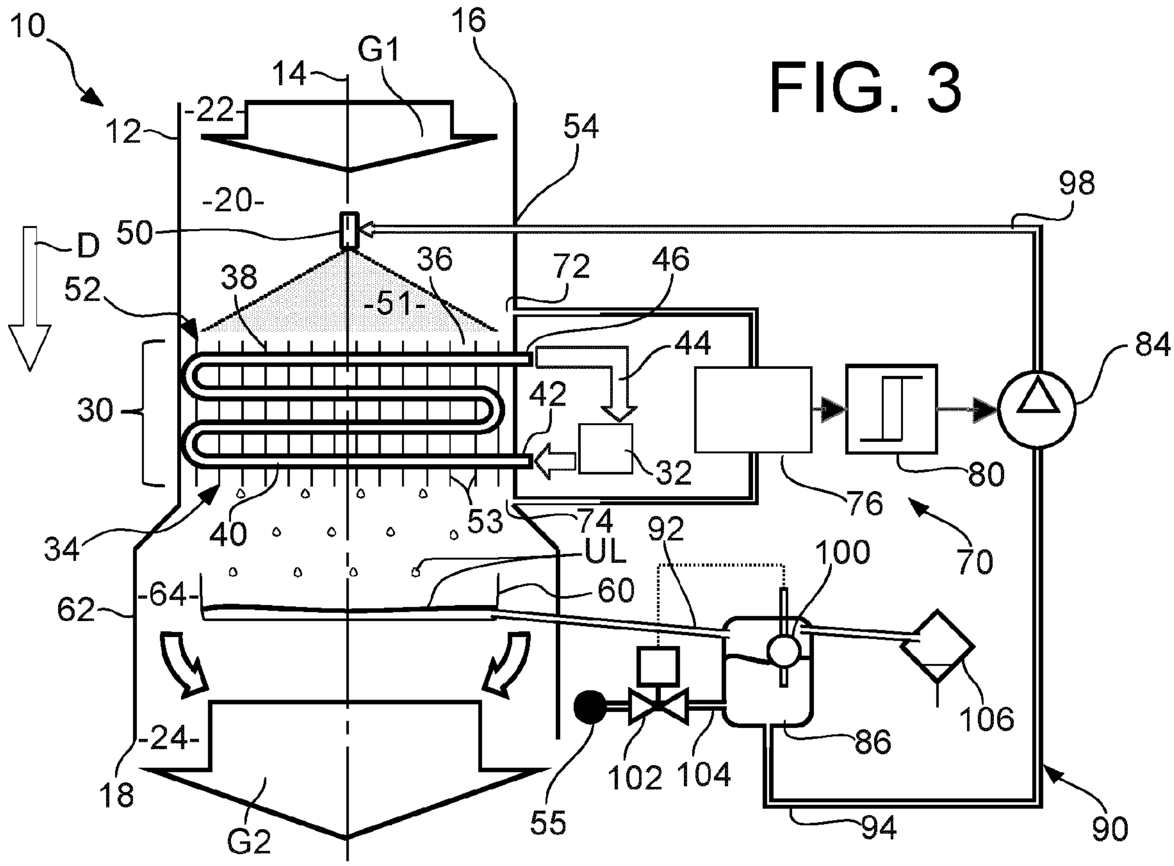
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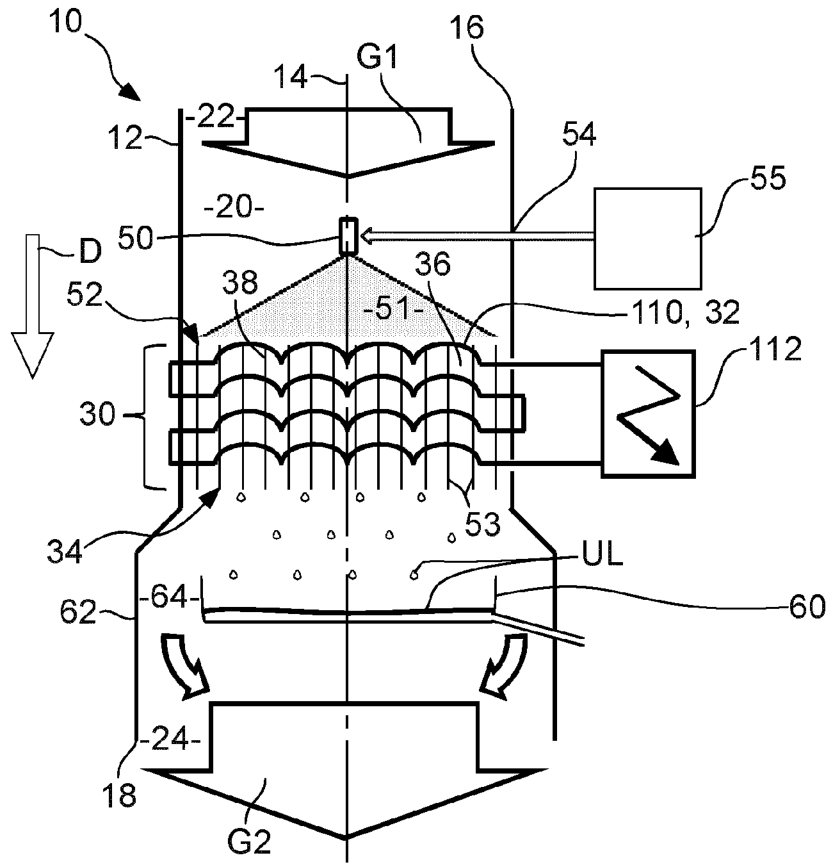
FIG. 4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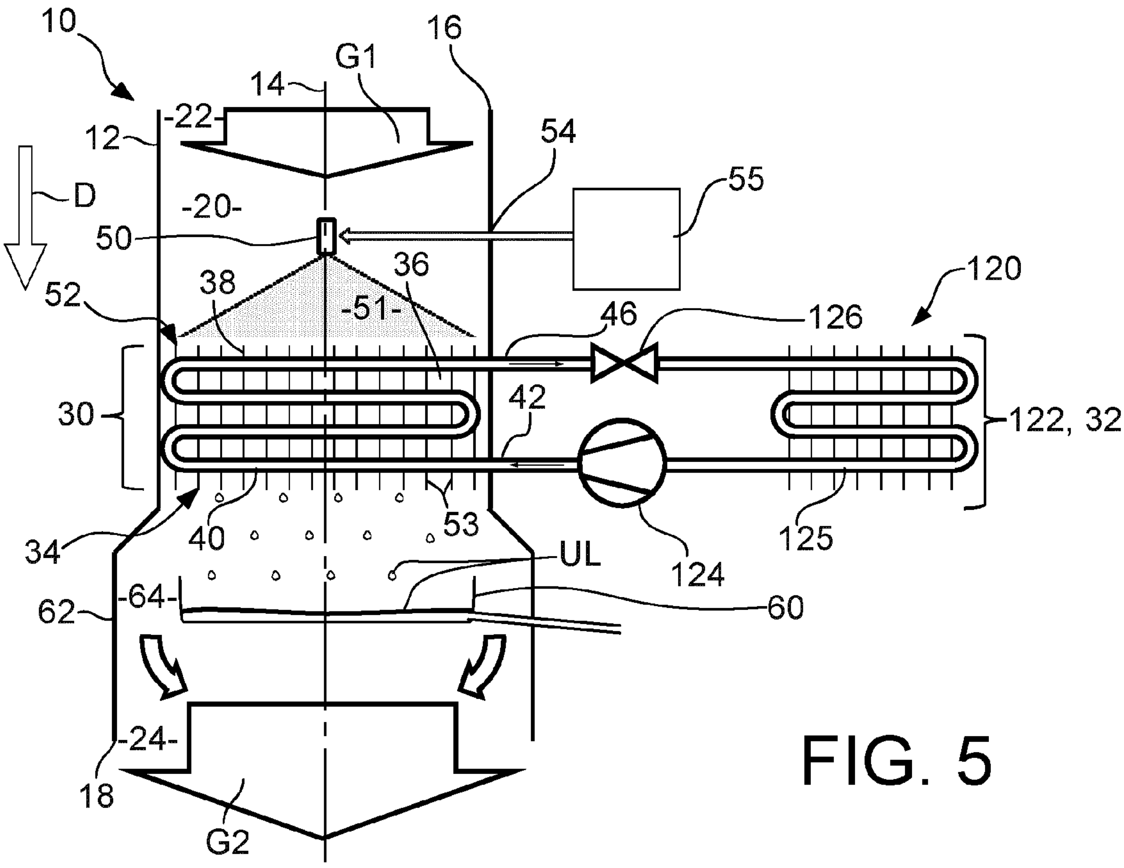
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FIG. 5

Europäisches Patentamt
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EUROPEAN SEARCH REPORT

Application Number
EP 22 30 6853

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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A	GB 1 582 891 A (HUMIDIFIER GROUP LTD) 14 January 1981 (1981-01-14) * abstract *	5	

TECHNICAL FIELDS SEARCHED (IPC)

F24F
F28F
F25B
F28D

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	4 May 2023	Lienhard, Dominique

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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