

Method for dehumidifying humid gas mixtures using ionic liquids

The invention relates to a process for dehumidifying a moist gas mixture. The invention further relates to an apparatus for dehumidifying a moist gas mixture and to the use of said apparatus in the process according to the invention.

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Background of the invention

Dehumidification of moist gas mixtures is necessary in a multitude of technical fields.

For instance ventilation and air conditioning of buildings or vehicles generally necessitates not only cooling but also dehumidification of the air since the air to be cooled is often so humid that during
10 cooling to the desired temperature the temperature falls below the dew point temperature. Hence in conventional air conditioning systems dehumidification of the air accounts for a large part of the electricity consumption.

The electricity consumption of air conditioning systems for buildings is reduced by dehumidifying the air by adsorption or absorption of water with a drying medium and subsequently regenerating
15 the water-laden drying medium by heating to a temperature at which the water is desorbed again. Compared to adsorption on a solid absorbent, the advantage of absorption in a liquid absorption medium is that drying of air can be performed with reduced equipment complexity and with less drying medium and that regeneration of the water-laden drying medium using solar heat is easier to carry out.

20 A further technical field where dehumidifying of moist gas mixtures is employed is the field of absorption chillers (principle described in WO 2014/079675 A1). Here, the damp gas mixture is formed during evaporation of water under low pressure. The water vapour thus formed needs to be removed from the moist gas mixture so that said mixture may then be returned to the water evaporation to pass through a new cycle. Here too, absorption in a liquid absorption medium is
25 favoured over absorption in a solid absorption medium.

Finally, dehumidification of moist gas mixtures is also important in the field of natural gas extraction, as described in DE 10 2010 004 779 A1 for example.

Examples of materials incorporated in air or natural gas dehumidifying plants and in chillers include titanium, copper and noble metals. Components based on aluminium too are installed in air
30 dehumidifying plants. Compared to alternative materials such as titanium, copper or stainless steel, aluminium has the advantage that it has a higher thermal conductivity. It is additionally easier to process, lighter and cheaper. Hence in automobile manufacture in particular air conditioning systems made of aluminium are preferred over other materials.

The aqueous solutions of lithium bromide, lithium chloride or calcium chloride hitherto employed as
35 liquid absorption media in commercial air conditioning systems have the disadvantage that they are corrosive towards the materials of construction typically employed in air conditioning systems and that they thus necessitate the use of expensive specific materials of construction. This problem is

encountered particularly for aluminium. These solutions can additionally cause problems due to salt crystallizing out of the absorption medium.

Y. Luo et al., Appl. Thermal Eng. 31 (2011) 2772-2777 proposes using the ionic liquid 1-ethyl-3-methylimidazolium tetrafluoroborate in place of an aqueous solutions of lithium bromide for drying
5 of air. However, this ionic liquid has the disadvantage of only poor absorption capability.

Y. Luo et al., Solar Energy 86 (2012) 2718-2724 proposes using the ionic liquid 1,3-dimethylimidazolium acetate as an alternative to 1-ethyl-3-methylimidazolium tetrafluoroborate for drying of air. However, 1,3-dimethylimidazolium acetate is not stable and decomposes to a not inconsiderable extent during desorption.

10 This problem is also encountered for the ionic liquid proposed in US 2011/0247494 A1, paragraph [0145]. This document proposes using trimethylammonium acetate or 1-ethyl-3-methylimidazolium acetate as liquid drying agent in place of aqueous lithium chloride solution. Example 3 compares water uptake from moist air for a series of further ionic liquids.

CN 102335545 A describes aqueous solutions of ionic liquids that do not suffer from the
15 abovementioned problems as absorption media for air dehumidification. The absorption media are reported to be noncorrosive toward steel. Ionic liquids described are, inter alia, 1,3-dimethylimidazolium dimethylphosphate, 1-ethyl-3-methylimidazolium dimethylphosphate and 1-butyl-3-methylimidazolium dimethylphosphate. However, CN 102335545 A is chiefly concerned with steel-based air dehumidifiers. Yet this material is disadvantageous compared to aluminium for
20 the abovementioned reasons. Additionally the heat transfer achieved with the ionic liquids cited in CN 102335545 A, which is important for efficient air dehumidification, was relatively low.

The present invention accordingly has for its object to provide absorption media that exhibit lower corrosivity than prior art absorption media when used in aluminium-based air conditioning systems, air dehumidifiers, absorption chillers. These absorption media should also ensure improved heat
25 transfer.

Absorption media have now been found which, surprisingly, exhibit a low corrosiveness towards aluminium and ensure particularly good heat transfer.

Detailed description of the invention

30 The present invention accordingly relates in a first aspect to a process for dehumidifying a moist gas mixture **G**, in particular moist air, in an apparatus **V**₁, comprising the steps of:

(a) contacting the moist gas mixture **G** with a liquid absorption medium **A**_{VE} comprising at least one salt selected from the group consisting of $Q^+(RO)_2PO_2^-$, $(Q^+)_2ROPO_3^{2-}$, $Q^+M^+ROPO_3^{2-}$, wherein the liquid absorption medium **A**_{VE} at least partially absorbs water from the moist
35 gas mixture **G**,

to obtain a liquid absorption medium A_{VE1} having an elevated water content compared to the liquid absorption medium A_{VE} and a gas mixture G_1 having a relatively low water content compared to the moist gas mixture G ,

- 5 (b) at least partially removing water from the liquid absorption medium A_{VE1} to obtain a liquid absorption medium A_{VE2} having a relatively low water content compared to the liquid absorption medium A_{VE1} ,

wherein the apparatus V_1 at least partially comprises a surface made of an aluminium material of construction O_{Al} and in the apparatus V_1 at least one of the liquid absorption media selected from the group consisting of A_{VE} , A_{VE1} , A_{VE2} contacts the surface made of an aluminium material of
10 construction O_{Al} via at least one contact surface,

characterized in that

Q^+ is a 1,3-dialkylimidazolium where the alkyl groups are independently of one another unbranched or branched C_1 - C_6 alkyl groups,

R is an unbranched or branched C_2 - C_6 alkyl group,

- 15 and M^+ is an alkali metal ion, preferably selected from the group consisting of Li^+ , K^+ , Na^+ , more preferably selected from the group consisting of K^+ , Na^+ , preferably K^+ .

The gas mixture G is not subject particularly restricted. "Moist" is to be understood as meaning in the context of the invention "comprising water, in particular water vapour". "Dehumidifying" is to be understood as meaning at least partially removing water.

- 20 "At least partially" is to be understood as meaning in the context of the invention "partially or completely".

"Moist gas mixture G " is accordingly to be understood as meaning in the context of the invention that the gas mixture G comprises water, preferably water vapour ("water vapour" is to be understood as meaning water in the gaseous physical state), and that its composition is otherwise
25 not particularly restricted. The water content of this moist gas mixture is not particularly restricted and is in particular from 0.01 vol% to 99.99 vol% ("vol%" indicates the volume of water vapour based on the overall volume of moist gas mixture G). The composition of the moist gas G may otherwise vary depending on the application of the process according to the invention. The moist gas mixture G is in particular selected from moist natural gas, moist air (this may be moist indoor
30 air or the moist air resulting from evaporation of water in absorption chillers), preferably moist air. For moist natural gas the water content is in particular from 0.01 vol% to 15.00 vol%, for moist air said content is in particular from 0.01 vol% to 5.00 vol% in the case of moist indoor air or in particular from 95.00 vol% to 99.99 vol% which is the preferred range when moist air resulting from evaporation of water in absorption chillers is concerned.

- 35 The process according to the invention is carried out in an apparatus V_1 . The apparatus V_1 is restricted only to the extent that it shall be suitable for carrying out the process according to the invention. It is in particular possible to employ an apparatus V_1 having the following components:

- (i) at least one water absorption unit W_{abs1} set up for contacting the moist gas mixture with the liquid absorption medium A_{VE} ,
- (ii) at least one water desorption unit W_{des1} which comprises a heat exchanger W_{x1} and is set up for at least partially removing water from a liquid absorption medium A_{VE} ,
- 5 (iii) and a circuit U_1 which connects the water absorption unit W_{abs1} with the water desorption unit W_{des1} and by means of which the liquid absorption medium A_{VE} may be circulated.

The water absorption unit W_{abs1} is the component in which step a) of the process according to the invention in particular is carried out. Employable as water absorption unit W_{abs1} are in particular the water absorbers known to those skilled in the art. Said absorbers are based on the principle of
10 increasing the surface area of the liquid absorption medium A_{VE} and simultaneously achieving the longest possible residence time of the liquid absorption medium A_{VE} in the water absorber during absorption of water. It is in particular possible here to employ water absorbers selected from the group of: packed beds, spray columns, falling-films, bubble columns, tray columns, wet scrubbers (for example Venturi scrubbers), stirred tanks and combinations of these absorbers. It is particularly
15 preferable to employ as water absorbers falling-films, in particular shell and tube falling-films. The water absorption unit W_{abs1} may in particular also comprise an additional heat exchanger W_{z1} set up such that the liquid absorption medium A_{VE} is coolable.

The water desorption unit W_{des1} which comprises a heat exchanger W_{x1} is the unit in which step b) of the process according to the invention in particular is carried out. The water desorption unit
20 W_{des1} is based on the principle of supplying heat to the water-laden liquid absorption medium A_{VE} , increasing the surface area of the water-laden liquid absorption medium A_{VE} and simultaneously achieving the longest possible residence time of the water-laden liquid absorption medium A_{VE} in the water desorption unit.

Employable as water desorption unit W_{des1} comprising a heat exchanger W_{x1} are in particular the
25 combinations of heat exchanger and water desorber known to those skilled in the art, in particular horizontal tube evaporators having an upstream heat exchanger, in particular shell and tube heat exchangers, plate and frame heat exchangers. In addition the water desorption unit W_{des1} comprising a heat exchanger W_{x1} may also be a water desorber having an integrated heat exchanger. Such water desorbers having an integrated heat exchanger are in particular climbing
30 film evaporators, long tube vertical evaporators, short tube vertical evaporators, forced circulation evaporators, agitated thin film evaporators. It is particularly preferable to employ as water desorption unit W_{des1} falling-films, in particular shell and tube falling-films.

Circuit U_1 in particular passes A_{VE1} from step a) of the process according to the invention from the water absorption unit W_{abs1} to the water desorption unit W_{des1} and more preferably - in particular
35 when the process according to the invention is carried out in continuous fashion - additionally passes A_{VE2} from step b) of the process according to the invention from the water absorption unit W_{des1} to the water desorption unit W_{abs1} .

The circuit U_1 is in particular a conduit, in particular selected from the group consisting of tube, hose.

In a further preferred embodiment the circuit U_1 also comprises a pump.

A first step of the process according to the invention comprises contacting the moist gas mixture G with a liquid absorption medium A_{VE} comprising at least one salt selected from the group consisting of $Q^+(RO)_2PO_2^-$, $(Q^+)_2ROPO_3^{2-}$, $Q^+M^+ROPO_3^{2-}$. The contacting may be effected in any way known to those skilled in the art, in particular in a water absorption unit W_{abs1} . The contacting causes the absorption medium A_{VE} to at least partially absorb moisture, i.e. water, from the moist gas stream G to afford a liquid absorption medium A_{VE1} having an elevated water content compared to the liquid absorption medium A_{VE} and a gas mixture G_1 having a relatively low water content compared to the moist gas mixture G .

It is preferable to cool the absorption medium A_{VE} during contacting of the moist gas mixture G in order that as much moisture as possible is absorbed from the moist gas mixture G . This may be achieved, for example, via an additional heat exchanger W_{z1} in the water absorption unit W_{abs1} . The temperature of the absorption medium A_{VE} during contacting of the moist gas mixture G is thus preferably in the range of from 15°C to 90°C , more preferably from 20°C to 80°C , most preferably from 20°C to 40°C .

The absorption medium A_{VE} comprises at least one salt selected from the group consisting of $Q^+(RO)_2PO_2^-$, $(Q^+)_2ROPO_3^{2-}$, $Q^+M^+ROPO_3^{2-}$, wherein Q^+ is a 1,3-dialkylimidazolium where the alkyl groups are independently of one another unbranched or branched C_1 - C_6 alkyl groups, R is an unbranched or branched C_2 - C_6 alkyl group and M^+ is an alkali metal ion preferably selected from the group consisting of Li^+ , K^+ , Na^+ , more preferably selected from the group consisting of K^+ , Na^+ , preferably K^+ .

In a preferred embodiment R is selected from the group consisting of ethyl group, n-propyl group, isopropyl group, n-butyl group, sec-butyl group, tert-butyl group, n-pentyl group, 2-pentyl group, 3-pentyl group, 2-methylbutyl group, 3-methylbutyl group, 3-methylbut-2-yl group, 2-methylbut-2-yl group, 2-dimethylpropyl group, n-hexyl group. R is preferably selected from the group consisting of ethyl group, n-propyl group, isopropyl group, n-butyl group, sec-butyl group, tert-butyl group, n-pentyl group, n-hexyl group; R is more preferably selected from the group consisting of ethyl group, n-butyl group. In a very particularly preferred embodiment of the present invention R = ethyl group. This is because it has now been found that, surprisingly, imidazolium salts where R = ethyl group have a particularly small contact angle and thus ensure particularly good surface wetting. This results in a relatively large contact area, thus also in fewer nonwetted spaces and thus in improved heat transfer inside the apparatus V_1 and thus also in a particularly efficient process.

Q^+ is in particular selected from the group consisting of 1,3-dimethylimidazolium, 1,3-diethylimidazolium, 1-ethyl-3-methylimidazolium, 1-n-butyl-3-methylimidazolium. Q^+ is preferably selected from the group consisting of 1,3-diethylimidazolium, 1-ethyl-3-methylimidazolium, 1-n-butyl-3-methylimidazolium. Q^+ is more preferably selected from the group consisting of 1-ethyl-3-methylimidazolium, 1-n-butyl-3-methylimidazolium. Q^+ is even more preferably 1-ethyl-3-methylimidazolium.

The liquid absorption medium A_{VE} may be employed in the form of the pure salts of the structure $Q^+(RO)_2PO_2^-$, $(Q^+)_2ROPO_3^{2-}$ and $Q^+M^+ROPO_3^{2-}$. Alternatively and more preferably the liquid absorption medium A_{VE} is an aqueous solution in which the total weight of all salts of structure $Q^+(RO)_2PO_2^-$, $(Q^+)_2ROPO_3^{2-}$ and $Q^+M^+ROPO_3^{2-}$ is at least 70 wt% based on the total weight of the aqueous solution. It is yet more preferable when the total weight of all salts of the structure $Q^+(RO)_2PO_2^-$, $(Q^+)_2ROPO_3^{2-}$ und $Q^+M^+ROPO_3^{2-}$ is at least 80 wt% based on the total weight of the aqueous solution, yet more preferably 85 wt%, yet more preferably 90 wt%.

The gas mixture G_1 obtained in the first step of the process according to the invention and having a relatively low water content compared to the moist gas mixture G then represents the dehumidified gas stream which, depending on the application, can be returned to living or working spaces in the form of dehumidified air or in the case of natural gas can be supplied to power generation.

The absorption medium A_{VE1} obtained in the first step of the process according to the invention has an elevated water content compared to the liquid absorption medium A_{VE} . It will be appreciated that A_{VE1} , in terms of the salts comprised in it and selected from the group consisting of $Q^+(RO)_2PO_2^-$, $(Q^+)_2ROPO_3^{2-}$, $Q^+M^+ROPO_3^{2-}$, is identical to A_{VE} and is preferably distinguished therefrom only by the water content.

A second step of the process according to the invention comprises at least partially removing water from the liquid absorption medium A_{VE1} to obtain a liquid absorption medium A_{VE2} having a relatively low water content compared to the liquid absorption medium A_{VE1} . This additionally comprises supplying heat to the liquid absorption medium A_{VE1} . The supply of heat and the at least partial removal may be effected in any way known to those skilled in the art, in particular in a water desorption unit W_{des1} comprising a heat exchanger W_{x1} . The at least partial removal of water from the liquid absorption medium A_{VE1} affords a liquid absorption medium A_{VE2} having a relatively low water content compared to the liquid absorption medium A_{VE1} .

It will be appreciated that A_{VE2} , in terms of the salts comprised in it and selected from the group consisting of $Q^+(RO)_2PO_2^-$, $(Q^+)_2ROPO_3^{2-}$, $Q^+M^+ROPO_3^{2-}$, is identical to A_{VE1} and is preferably distinguished therefrom only by the water content.

An essential feature of the process according to the invention is that the apparatus V_1 at least partially comprises a surface made of an aluminium material of construction O_{Al} (in the context of the invention O_{Al} is an abbreviation for "surface made of an aluminium material of construction").

An aluminium material of construction in the context of the present invention is to be understood as meaning both unalloyed aluminium and aluminium alloys where in particular the mass fraction of aluminium is greater than the mass fraction of every other element. The aluminium material of construction is preferably unalloyed aluminium.

Unalloyed aluminium is in particular highest purity aluminium having a purity of > 99.0 wt%, more preferably > 99.9 wt%.

Aluminium alloys comprise in addition to the aluminium in particular at least one alloying metal selected from the group consisting of magnesium, manganese, silicon, zinc, lead, copper, titanium,

iron, more preferably selected from the group consisting of magnesium, manganese, silicon, zinc, lead, copper, titanium. The aluminium material of construction may in particular be in the form of a wrought alloy or of a cast alloy.

A further essential feature of the process according to the invention is that in the apparatus V_1 at least one of the liquid absorption media selected from the group consisting of A_{VE} , A_{VE1} , A_{VE2} contacts the surface made of an aluminium material of construction O_{Al} via at least one contact surface. This is to be understood as meaning that at this contact surface the liquid absorption medium A_{VE} is in direct contact with the surface made of an aluminium material of construction O_{Al} . In the context of the present invention "in direct contact" is to be understood as meaning "wetting". It will be appreciated that the liquid absorption medium selected from the group consisting of A_{VE} , A_{VE1} , A_{VE2} and the aluminium comprised in the contact surface are thus in direct contact. The aluminium comprised in the contact surface is not particularly restricted and is in particular selected from the group consisting of elemental aluminium or aluminium compounds such as in particular passivated aluminium (where passivated aluminium is to be understood as meaning in particular aluminium oxide).

In the embodiment according to the invention in which an apparatus V_1 is employed and comprises the following components:

- (i) at least one water absorption unit W_{abs1} set up for contacting the moist gas mixture with the liquid absorption medium A_{VE} ,
- (ii) at least one water desorption unit W_{des1} which comprises a heat exchanger W_{x1} and is set up for at least partially removing water from a liquid absorption medium A_{VE} ,
- (iii) and a circuit U_1 which connects the water absorption unit W_{abs1} with the water desorption unit W_{des1} and by means of which the liquid absorption medium A_{VE} may be circulated,

the contact surface at which the liquid absorption medium selected from the group consisting of A_{VE} , A_{VE1} , A_{VE2} contacts the surface made of an aluminium material of construction O_{Al} , is disposed in particular in at least one of the components selected from the group water absorption unit W_{abs1} , water desorption unit W_{des1} , circuit U_1 , preferably in at least one of the components selected from the group water absorption unit W_{abs1} , water desorption unit W_{des1} .

This is because it has now been found that, surprisingly, the salts according to the invention bring about a particularly low level of aluminium corrosion and are thus particularly suitable as liquid absorption media in the apparatus V_1 having a surface made of an aluminium material of construction O_{Al} , in which one of the absorption media selected from the group consisting of A_{VE} , A_{VE1} , A_{VE2} is in direct contact with the surface made of an aluminium material of construction O_{Al} .

In a further preferred embodiment the process according to the invention is carried out in continuous fashion. This is to be understood as meaning in particular that following step b) the steps a) and b) are performed at least one more time and that the liquid absorption medium A_{VE} employed the steps a) additionally performed in each case is at least partially the liquid absorption medium A_{VE2} obtained from the step b) performed immediately beforehand, i.e. in particular the water content of the liquid absorption medium A_{VE} employed in the step a) additionally performed in

each case and of the liquid absorption medium A_{VE2} from the immediately preceding step b) is identical.

It is more preferable when this embodiment comprises heating liquid absorption medium A_{VE1} with heat from liquid absorption medium A_{VE2} . This may be carried out in an additional heat exchanger W_{Y1} , in particular selected from the group consisting of shell and tube heat exchangers and plate and frame heat exchangers. This makes it possible to carry out the process according to the invention in a particularly energy efficient fashion.

The invention also relates in a further aspect to an apparatus V_2 for dehumidifying a moist gas mixture, in particular moist air, comprising the components

- 10 (i) a liquid absorption medium A_{VO} comprising at least one salt selected from the group consisting of $Q^+(RO)_2PO_2^-$, $(Q^+)_2ROPO_3^{2-}$, $Q^+M^+ROPO_3^{2-}$,
 - (ii) at least one water absorption unit W_{abs2} set up for contacting the moist gas mixture with the liquid absorption medium A_{VO} ,
 - (iii) at least one water desorption unit W_{des2} which comprises a heat exchanger W_{x2} and is set up for at least partially removing water from a liquid absorption medium A_{VO} ,
 - 15 (iv) and a circuit U_2 which connects the water absorption unit W_{abs2} with the water desorption unit W_{des2} and by means of which the liquid absorption medium A_{VO} may be circulated,
- wherein at least one of the components water absorption unit W_{abs2} , water desorption unit W_{des2} , circuit U_2 at least partially comprises a surface made of an aluminium material of construction O_{Al} , and
- 20 wherein disposed in the apparatus V_2 is at least one contact surface at which the liquid absorption medium A_{VO} contacts the surface made of an aluminium material of construction O_{Al} ,
- characterized in that
- 25 Q^+ is a 1,3-dialkylimidazolium where the alkyl groups are independently of one another unbranched or branched C_1 - C_6 alkyl groups,
- R is an unbranched or branched C_2 - C_6 alkyl group,
- and M^+ is an alkali metal ion, preferably selected from the group consisting of Li^+ , K^+ , Na^+ , more preferably selected from the group consisting of K^+ , Na^+ , preferably K^+ .

30 The apparatus according to the invention V_2 is suitable for dehumidifying a moist gas mixture, in particular moist air. Said apparatus comprises the following components:

As a first component the apparatus V_2 according to the invention comprises a liquid absorption medium A_{VO} which comprises at least one salt selected from the group consisting of $Q^+(RO)_2PO_2^-$, $(Q^+)_2ROPO_3^{2-}$, $Q^+M^+ROPO_3^{2-}$, where Q^+ is a 1,3-dialkylimidazolium where the alkyl groups are

35 independently of one another unbranched or branched C_1 - C_6 alkyl groups, R is an unbranched or

branched C₂-C₆ alkyl group and M⁺ is an alkali metal ion preferably selected from the group consisting of Li⁺, K⁺, Na⁺, more preferably selected from the group consisting of K⁺, Na⁺, preferably K⁺.

- In a preferred embodiment R is selected from the group consisting of ethyl group, n-propyl group, isopropyl group, n-butyl group, sec-butyl group, tert-butyl group, n-pentyl group, 2-pentyl group, 3-pentyl group, 2-methylbutyl group, 3-methylbutyl group, 3-methylbut-2-yl group, 2-methylbut-2-yl group, 2-dimethylpropyl group, n-hexyl group. R is preferably selected from the group consisting of ethyl group, n-propyl group, isopropyl group, n-butyl group, sec-butyl group, tert-butyl group, n-pentyl group, n-hexyl group; R is more preferably selected from the group consisting of ethyl group, n-butyl group. In a very particularly preferred embodiment of the present invention R = ethyl group. This is because it has now been found that, surprisingly, imidazolium salts where R = ethyl group have a particularly small contact angle and thus ensure particularly good surface wetting. This results in a relatively large contact area, thus also in fewer nonwetted spaces and thus in improved heat transfer inside the apparatus V₂ and thus also in a particularly efficient process.
- Q⁺ is in particular selected from the group consisting of 1,3-dimethylimidazolium, 1,3-diethylimidazolium, 1-ethyl-3-methylimidazolium, 1-n-butyl-3-methylimidazolium. Q⁺ is preferably selected from the group consisting of 1,3-diethylimidazolium, 1-ethyl-3-methylimidazolium, 1-n-butyl-3-methylimidazolium. Q⁺ is more preferably selected from the group consisting of 1-ethyl-3-methylimidazolium, 1-n-butyl-3-methylimidazolium. Q⁺ is even more preferably 1-ethyl-3-methylimidazolium.

The liquid absorption medium A_{VO} may be employed in the form of the pure salts of the structure Q⁺(RO)₂PO₂⁻, (Q⁺)₂ROPO₃²⁻ and Q⁺M⁺ROPO₃²⁻. Alternatively and more preferably the liquid absorption medium A_{VO} is an aqueous solution in which the total weight of all salts of structure Q⁺(RO)₂PO₂⁻, (Q⁺)₂ROPO₃²⁻ and Q⁺M⁺ROPO₃²⁻ is at least 70 wt% based on the total weight of the aqueous solution. It is yet more preferable when the total weight of all salts of the structure Q⁺(RO)₂PO₂⁻, (Q⁺)₂ROPO₃²⁻ und Q⁺M⁺ROPO₃²⁻ is at least 80 wt% based on the total weight of the aqueous solution, yet more preferably 85 wt%, yet more preferably 90 wt%.

As a second component the apparatus V₂ according to the invention comprises a water absorption unit W_{abs2} set up for contacting the moist gas mixture with the liquid absorption medium A_{VO}. The water absorption unit W_{abs2} may in particular comprise an additional heat exchanger W₂₂ set up such that the liquid absorption medium A_{VO} is coolable. Employable as such a water absorption unit W_{abs2} are in particular the water absorbers known to those skilled in the art. Said absorbers are based on the principle of increasing the surface area of the liquid absorption medium A_{VO} and simultaneously achieving the longest possible residence time of the liquid absorption medium A_{VO} in the water absorber during absorption of water. It is in particular possible here to employ water absorbers selected from the group of: packed beds, spray columns, falling-films, bubble columns, tray columns, wet scrubbers (for example Venturi scrubbers), stirred tanks and combinations of these absorbers. It is particularly preferable to employ as water absorbers falling-films, in particular shell and tube falling-films.

As a third component the apparatus V_2 according to the invention comprises a water desorption unit W_{des2} which comprises a heat exchanger W_{x2} and is set up for at least partially removing water from the liquid absorption medium A_{V0} . Employable therefor are in particular the combinations of heat exchanger and water desorber known to those skilled in the art. The water desorption unit

5 W_{des2} is based on the principle of supplying heat to the liquid absorption medium A_{V0} , increasing the surface area of the liquid absorption medium A_{V0} and simultaneously achieving the longest possible residence time of the liquid absorption medium A_{V0} in the water desorption unit.

Employable as water desorption unit W_{des2} comprising a heat exchanger W_{x1} are in particular the combinations of heat exchanger and water desorber known to those skilled in the art, in particular

10 horizontal tube evaporators having an upstream heat exchanger, in particular shell and tube heat exchangers, plate and frame heat exchangers. In addition the water desorption unit W_{des2} comprising a heat exchanger W_{x2} may also be a water desorber having an integrated heat exchanger. Such water desorbers having an integrated heat exchanger are in particular climbing film evaporators, long tube vertical evaporators, short tube vertical evaporators, forced circulation

15 evaporators, agitated thin film evaporators. It is particularly preferable to employ as water desorption unit W_{des2} falling-films, in particular shell and tube falling-films.

As a fourth component the apparatus V_2 according to the invention comprises a circuit U_2 which connects the water absorption unit W_{abs2} with the water desorption unit W_{des2} and by means of which the liquid absorption medium A_{V0} may be circulated. The circuit U_2 is preferably a conduit,

20 more preferably selected from the group consisting of tube, hose. In a further preferred embodiment the circuit U_2 also comprises a pump.

An essential feature of the apparatus V_2 according to the invention is that said apparatus at least partially comprises a surface made of an aluminium material of construction O_{Al} (in the context of the invention O_{Al} is an abbreviation for "surface made of an aluminium material of construction").

25 An aluminium material of construction in the context of the present invention is to be understood as meaning both unalloyed aluminium and aluminium alloys where in particular the mass fraction of aluminium is greater than the mass fraction of every other element. The aluminium material of construction is preferably unalloyed aluminium.

Unalloyed aluminium is in particular highest purity aluminium having a purity of > 99.0 wt%, more

30 preferably > 99.9 wt%.

Aluminium alloys comprise in addition to the aluminium in particular at least one alloying metal selected from the group consisting of magnesium, manganese, silicon, zinc, lead, copper, titanium, iron, more preferably selected from the group consisting of magnesium, manganese, silicon, zinc, lead, copper, titanium. The aluminium material of construction may in particular be in the form of a

35 wrought alloy or of a cast alloy.

A further essential feature of the apparatus V_2 according to the invention is that disposed in said apparatus is a contact surface at which the liquid absorption medium A_{V0} contacts the surface made of an aluminium material of construction O_{Al} . This is to be understood as meaning that at this contact surface the liquid absorption medium A_{V0} is in direct contact with the surface made of an

aluminium material of construction O_{Al} . In the context of the present invention "in direct contact" is to be understood as meaning "wetting". It will be appreciated that the liquid absorption medium A_{Vo} and the aluminium comprised in the contact surface are thus in direct contact. The aluminium comprised in the contact surface is not particularly restricted and is in particular selected from the group consisting of elemental aluminium or aluminium compounds such as in particular passivated aluminium (where passivated aluminium is to be understood as meaning in particular aluminium oxide).

In a preferred embodiment the apparatus V_2 comprises a further heat exchanger W_{y2} (additional to the heat exchanger W_{x2} comprised in the water desorption unit W_{des2}). The heat exchanger W_{y2} is set up such that liquid absorption medium A_{Vo} sent from the water absorption unit W_{abs2} to the water desorption unit W_{des2} is suppliable with heat from liquid absorption medium A_{Vo} , said medium being conducted away from the water desorption unit W_{des2} . This can be ensured by employing as heat exchanger W_{y2} in particular a heat exchanger selected from shell and tube heat exchangers, plate and frame heat exchangers.

In a further preferred embodiment of the invention the apparatus V_2 is part of an absorption chiller. This absorption chiller then comprises as further components a condenser, an evaporator and a coolant, wherein the coolant is water.

The condenser is in particular connected to the water desorption unit W_{des2} via a conduit and is set up for condensing water at least partially removed from the liquid absorption medium A_{Vo} in the water desorption unit W_{des2} . The condenser preferably also comprises a cooling water circuit.

The evaporator is in particular connected to the condenser via a conduit (which may comprise a throttling means) and connected to the water absorption unit W_{abs2} via a further conduit and is set up for evaporating condensed water from the condenser. The evaporator preferably also comprises a pressure of < 1 bar, more preferably < 0.1 bar, to permit evaporation of the condensed water at the lowest possible temperatures. The evaporator may further preferably additionally comprise an apparatus from which heat may be drawn and so that the condensed water may be evaporated (for example a coolant conduit in which coolant is passed into the space in which water is evaporated).

The Figures 1 and 2 elucidated hereinbelow show preferred embodiments of the process according to the invention and the apparatus according to the invention.

Figure 1 (abbreviated to "Fig. 1") shows an embodiment of the apparatus V_2/V_1 according to the invention.

The apparatus V_2 shown in Figure 1 comprises a water absorption unit W_{abs2} <103> (with optional additional heat exchanger W_{z2} <104>) to which a conduit <101> leads and from which a conduit <102> leads away, a water desorption unit W_{des2} which comprises a heat exchanger W_{x2} <108> and a water desorber <109> and to which conduit <111> leads and from which conduits <110>, <112> and <113> lead away, and a circuit U_2 formed from conduits <106>, <111> and <113> or <106>, <111>, <112> and <105> (in each case optionally with conduit <114>). The apparatus in Figure 1 may also optionally comprise a further heat exchanger W_{y2} <107> to which conduits <106> and <112> lead and from which conduits <105> and <111> lead away. In addition the

- apparatus also comprises a liquid absorption medium A_{V0} . Said medium is disposed in one or more of the abovementioned components water absorption unit W_{abs2} , water desorption unit W_{des2} , circuit U_2 . Water absorption unit W_{abs2} <103> may optionally also comprise an additional heat exchanger W_{z2} <104>. Apparatus V_2 , in particular at least one of the components selected from the
- 5 group consisting of water absorption unit W_{abs2} , water desorption unit W_{des2} , circuit U_2 , at least partially comprises a surface made of an aluminium material of construction O_{A1} and there is at least one contact surface at which the liquid absorption medium A_{V0} contacts the surface made of an aluminium material of construction O_{A1} . Optionally circuit U_2 may also additionally comprise a pump for conveying the liquid absorption medium.
- 10 Apparatus V_1 corresponds to apparatus V_2 without absorption medium A_{V0} , wherein in the figure description for Figure 1 and Figure 2 the terms U_2 , W_{abs2} , W_{des2} , W_{x2} , W_{y2} , W_{z2} are to be replaced by U_1 , W_{abs1} , W_{des1} , W_{x1} , W_{y1} , and W_{z1} respectively.

The process according to the invention will now be illustratively described with reference to apparatus V_1 using Figure 1:

- 15 A stream moist gas mixture G (said stream may moist air, moist natural gas or moist gas mixture originating from the evaporator of an absorption chiller - see also Figure 2 with regard to this option) is supplied via conduit <101> to a water absorption unit W_{abs1} <103> and contacted there with the liquid absorption medium A_{VE} supplied to the water absorption unit W_{abs1} <103> via the conduit <105> or via the conduit <113>. The water absorption unit W_{abs1} <103> may be any of the
- 20 water absorbers cited hereinabove for W_{abs1} , in particular a falling-film. Contacting, in the water absorption unit W_{abs1} <103>, gas mixture G supplied via conduit <101> with the liquid absorption medium A_{VE} supplied via the conduit <105> or via the conduit <113> affords a liquid absorption medium A_{VE1} having an elevated water content compared to the liquid absorption medium A_{VE} and a stream of a gas mixture G_1 discharged via the conduit <102>, G_1 having a relatively low water
- 25 content compared to the moist gas mixture G . Depending on the application G_1 is in particular dehumidified air or dehumidified natural gas. The water absorption unit W_{abs1} <103> may optionally also comprise an additional heat exchanger W_{z1} <104>. Preferably via the conduits <106>, <111> and the heat exchanger W_{y1} <107> (or, when heat exchanger W_{y1} <107> is not employed, via conduits <106>, <111> and <114>) the liquid absorption medium A_{VE1} is then passed to the water
- 30 desorption unit W_{des1} composed of the heat exchanger W_{x1} <108> and the water desorber <109>. The water-laden liquid absorption medium A_{VE1} may additionally be supplied with heat in the optional heat exchanger W_{y1} <107>. The at least partial removal of water from liquid absorption medium A_{VE1} is then carried out in the water desorber <109> to afford a liquid absorption medium A_{VE2} having a relatively low water content compared to the liquid absorption A_{VE1} . The water
- 35 removed is then discharged from the water desorber <109> as liquid or vapour, preferably as vapour, via conduit <110>. The liquid absorption medium A_{VE2} is then discharged from the water desorber <109> and returned to the water absorption unit W_{abs1} <103>. This may either be carried out directly, i.e. via the conduit <113> which is shown in dashed form in Figure 1. Alternatively and preferably the liquid absorption medium A_{VE2} may also be supplied via the conduit <112> to the
- 40 optional heat exchanger W_{y1} <107> in which the liquid absorption medium A_{VE1} supplied via

conduit <106> to the optional heat exchanger W_{y1} <107> is supplied with heat from the liquid absorption medium A_{VE2} supplied via conduit <112> to the optional heat exchanger W_{y1} <107>. Once the concentrated liquid absorption medium A_{VE2} has been supplied to the water absorption unit W_{abs1} via conduit <105> or <113> said medium is reused as A_{VE} for at least partially
5 dehumidifying the gas stream in a new cycle. It is essential to the invention that in this process the apparatus according to Figure 1, preferably at least one of the components selected from the group consisting of water absorption unit W_{abs1} <103> (In Figure 1 said unit comprises the heat exchanger <104>), water desorption unit W_{des1} (in Figure 1 said unit comprises the heat exchanger <108>), circuit U_1 (composed in Figure 1 of the conduits <106>, <111>, <113>, or <106>, <111>, <112>, <105>, and in each case optionally also conduit <114>) at least partially comprises a
10 surface made of an aluminium material of construction O_{Al} and that disposed in the apparatus is at least one contact surface at which at least one of the liquid absorption media A_{VE} , A_{VE1} , A_{VE2} contacts the surface made of an aluminium material of construction O_{Al} .

Figure 2 (abbreviated as "Fig. 2") shows in schematic fashion an absorption chiller into which an
15 apparatus V_2 is integrated. The constituents <101> to <114> are shown as for the apparatus V_2 described in Figure 1. Additionally, the absorption chiller in Figure 2 also comprises a condenser <211> which is connected to the water desorption unit W_{des2} <109> via the conduit <110> and is set up for condensing water at least partially removed from the liquid absorption medium A_{V0} in the water desorption unit W_{des2} . Condenser <211> preferably also comprises a heat exchanger <212>
20 with which cooling water may be supplied.

The absorption chiller shown in Figure 2 also comprises an evaporator <214> connected to the condenser <211> via a conduit <216> (which may optionally comprise a throttling means <213>) and connected via the conduit <101> with the water absorption unit W_{abs2} . The evaporator <214> is set up to evaporate condensed water from the condenser. Additionally, the evaporator <214> can
25 further preferably also comprise a heat exchanger <215> which supplies a medium, heat being drawn off from the medium to thus evaporate the condensed water (for example a coolant conduit with, in particular, water as coolant, this coolant being passed into the evaporator <214>).

In an embodiment of the process according to the invention (described hereinbelow with reference to apparatus V_1 using Figure 2) moist gas mixture G originating from evaporator <214> is passed
30 via the conduit <101> to the water absorption unit W_{abs1} <103>. The water removed in water desorption unit W_{des1} is supplied via the conduit <110> to the condenser <211> in which said water is recondensed. A cooling water circuit as heat exchanger <212> installed in the condenser is optionally likewise used therefor. The condensed water is then supplied via a conduit <216> to the evaporator <214> in which the evaporation of water is effected in particular at low pressures thus
35 bringing about a cooling effect. This may optionally also be effected using a throttling means <213>. This achieves a cooling action in the evaporator <214> and, for example, coolant may be cooled via the heat exchanger <215>. The water vapour generated is then returned to the water absorption unit W_{abs1} <103> via conduit <101>.

The examples which follow are intended to elucidate the present invention without limiting said
40 invention in any way.

Examples

The following test series were carried out:

1. Test series: E1, V1-V4

5

1.1 Chemicals employed

EMIM DEP (= ethylmethylimidazolium diethylphosphate) was obtained from Sigma Aldrich.

EMIM HSO₄ (= ethylmethylimidazolium hydrogensulphate) was obtained from Sigma Aldrich.

10 LiCl was obtained from Sigma Aldrich.

MMIM⁺ H⁺ ROPO₃²⁻ where R = ethyl group (dimethylimidazolium hydrogen monoethylphosphate) was obtained as follows:

Added to a cryostat at -5°C were methylamine (4.8 mol), formaldehyde (2.4 mol) and monoethyl phosphate (2.4 mol). The mixture was stirred for 1 h before glyoxal (2.4 mol) was added. The

15 volatile constituents were subsequently removed under reduced pressure using a rotary evaporator to obtain the pure substance.

1.2 Test procedure

20 At 70°C and under air, aluminium plates (highest purity aluminium, purity > 99.0%) having dimensions of 3 cm x 7 cm and a thickness of 3 mm were immersed in 350 ml of the respective solution. The liquid was stirred during the test to ensure uniform flow of the liquid around the metal plates. Determination of the removal rates (removal rate = "loss due to corroded aluminium", reported in Table 1 in the unit g / m² * year) was carried out gravimetrically after chemical and

25 mechanical removal of the corrosion products from the immersed aluminium plates. The results are shown in Table 1 which follows.

1.3 Results

30 Table 1

test	solution employed	removal rate
V1	EMIM HSO ₄ (80 wt% in H ₂ O)	7548
V2	LiCl (30 wt% in H ₂ O)	575
V3	H ₂ O	130
V4	MMIM ⁺ H ⁺ ROPO ₃ ²⁻ where R = ethyl (80 wt% in H ₂ O)	353
E1	EMIM DEP (80 wt% in H ₂ O)	33

As is apparent from the results in Table 1 corrosion is markedly lower when using the liquid absorption medium cited in **E1** than for the liquid absorption media employed in **V1-V4**. The use of liquid absorption media according to the invention thus surprisingly makes it possible to reduce the

corrosion of aluminium compared to the liquid absorption media otherwise employed in the prior art.

2. Test series: E2, E3, V5

5

This effect is corroborated by the test series which follows.

2.1 Chemicals employed

- 10 EMIM DEP (= ethylmethylimidazolium diethylphosphate) was obtained from Sigma Aldrich. MMIM⁺ K⁺ ROPO₃²⁻ where R = ethyl (=dimethylimidazolium potassium monoethylphosphate) was obtained as follows: Added to a cryostat at -5°C were methylamine (4.8 mol), formaldehyde (2.4 mol) and monoethyl phosphate (2.4 mol). The mixture was stirred for 1 h before glyoxal (2.4 mol) was added. The volatile constituents were subsequently removed under reduced pressure using a rotary evaporator and the pH of the pure substance thus obtained was adjusted from 7.0 to 7.5 with 50 wt% aqueous potassium hydroxide solution.
- 15

- MMIM MeSO₃ (= dimethylimidazolium methylsulphonate) was obtained as follows: Added to a cryostat at -5°C were methylamine (4.8 mol), formaldehyde (2.4 mol) and methanesulphonic acid (2.4 mol). The mixture was stirred for 1 h before glyoxal (2.4 mol) was added. The volatile constituents were subsequently removed under reduced pressure using a rotary evaporator to obtain the pure substance.
- 20

2.2 Test procedure

25

At 70°C and under air, aluminium plates (highest purity aluminium; purity > 99.0%) having dimensions of 3 cm x 7 cm and a thickness of 3 mm were immersed in 350 ml of the respective solution. The liquid was stirred during the test to ensure uniform flow of the liquid around the metal plates.

- 30 Tests **E2, E3, V5** employed wet chemical evaluation by measurement of Al in the medium with ICP-OES (inductively coupled plasma optical emission spectrometry). The determined aluminium content in the solution was extrapolated to the mass of the aluminium plates employed. The results are shown in Table 2 which follows.

35

2.3 Results

Table 2

test	solution employed	mg of dissolved aluminium per g of aluminium
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V5	MMIM MeSO ₃ (80 wt% in water)	1,040
E2	MMIM ⁺ K ⁺ ROPO ₃ ²⁻ where R = ethyl (80 wt% in water)	0,001
E3	EMIM DEP (80 wt% in water)	0,011

As is apparent from the results in Table 2, use of the liquid absorption media according to the invention makes it possible to reduce the corrosion of aluminium compared to the liquid absorption media otherwise employed in the prior art.

5

3. Test series E4, E5, V6, V7

3.1 Chemicals employed

10

EMIM DEP (= ethylmethyimidazolium diethylphosphate) was obtained from Sigma Aldrich.
EMIM DMP (= ethylmethyimidazolium dimethylphosphate) was obtained from Sigma Aldrich.

3.2 Test procedure

15

3 drops of the respective solution were dropped onto an aluminium plate (highest purity aluminium, purity > 99.0%) having dimensions of 3 cm x 7 cm and a maximum thickness of 3 mm. The contact angle determination was carried out according to SOP 1827. The results are shown in Table 3 which follows.

20

3.3 Results

Table 3

test	solution employed	Contact angle (°)
E4	EMIM DEP (90 wt% in water)	45.7
E5	EMIM DEP (80 wt% in water)	53
V6	EMIM DMP (90 wt% in water)	86
V7	EMIM DMP (80 wt% in water)	90.4

The results show that the absorption media according to the invention (**E4, E5**) exhibit a small contact angle compared to those of the prior art (**V6, V7**) and thus ensure good heat conduction in the process according to the invention/for the apparatus according to the invention. This is shown in the comparisons of **E4** with **E6** and **E5** with **E7**. The use of imidazolium salts with diethylphosphate as counterion as opposed to dimethylphosphate as counterion surprisingly achieves a smaller contact angle to the aluminium-containing surface. This results in improved surface wetting and thus to greater and more efficient heat exchange in the case of diethyl

25

30

phosphate.

Claims

1. Process for dehumidifying a moist gas mixture **G** in an apparatus **V₁**, comprising the steps of:
 - (a) contacting the moist gas mixture **G** with a liquid absorption medium **A_{VE}** comprising at least one salt selected from 1-ethyl-3-methylimidazolium diethylphosphate,
wherein the liquid absorption medium **A_{VE}** at least partially absorbs water from the moist gas mixture **G**,
to obtain a liquid absorption medium **A_{VE1}** having an elevated water content compared to the liquid absorption medium **A_{VE}** and a gas mixture **G₁** having a relatively low water content compared to the moist gas mixture **G**,
 - (b) at least partially removing water from the liquid absorption medium **A_{VE1}** to obtain a liquid absorption medium **A_{VE2}** having a relatively low water content compared to the liquid absorption medium **A_{VE1}**,wherein the apparatus **V₁** at least partially comprises a surface made of an aluminium material of construction **O_{Al}** and in the apparatus **V₁** at least one of the liquid absorption media selected from the group consisting of **A_{VE}**, **A_{VE1}**, **A_{VE2}** contacts the surface made of an aluminium material of construction **O_{Al}** via at least one contact surface.
2. Process according to Claim 1, wherein the liquid absorption medium **A_{VE}** is an aqueous solution in which the total weight of all salts of 1-ethyl-3-methylimidazolium diethylphosphate is at least 70 wt% based on the total weight of the aqueous solution.
3. Process according to Claim 1 or 2, wherein said process is carried out in continuous fashion.
4. Apparatus **V₂** for dehumidifying a moist gas mixture, comprising the components
 - (i) a liquid absorption medium **A_{VO}** comprising at least one salt selected from 1-ethyl-3-methylimidazolium diethylphosphate,
 - (ii) at least one water absorption unit **W_{abs2}** <103> set up for contacting the moist gas mixture with the liquid absorption medium **A_{VO}**,
 - (iii) at least one water desorption unit **W_{des2}** <109> which comprises a heat exchanger **W_{x2}** <108> and is set up for at least partially removing water from a liquid absorption medium **A_{VO}**,
 - (iv) and a circuit **U₂** which connects the water absorption unit **W_{abs2}** <103> with the water desorption unit **W_{des2}** <109> and by means of which the liquid absorption medium **A_{VO}** may be circulated,

wherein at least one of the components water absorption unit W_{abs2} <103>, water desorption unit W_{des2} <109>, circuit U_2 at least partially comprises a surface made of an aluminium material of construction O_{Al} , and

5 wherein disposed in the apparatus V_2 is at least one contact surface at which the liquid absorption medium A_{V0} contacts the surface made of an aluminium material of construction O_{Al} .

- 10 5. Apparatus V_2 according to Claim 4, wherein A_{V0} is an aqueous solution in which the total weight of all salts of 1-ethyl-3-methylimidazolium diethylphosphate is at least 70 wt% based on the total weight of the aqueous solution.
6. Apparatus V_2 according to Claim 4 or 5, wherein at least one of the components water absorption unit W_{abs2} <103>, water desorption unit W_{des2} <109> is a falling film.
- 15 7. Apparatus V_2 according to any of Claims 4 to 6, comprising a further heat exchanger W_{y2} <107> set up such that liquid absorption medium A_{V0} sent from the water absorption unit W_{abs2} <103> to the water desorption unit W_{des2} <109> is suppliable with heat from liquid absorption medium A_{V0} , said medium being conducted away from the water desorption unit W_{des2} <109>.
- 20 8. Absorption heat pump, comprising an apparatus V_2 according to any of Claims 4 to 7 and, as further components, a condenser, an evaporator and a coolant, wherein the coolant is water.
9. Use of the apparatus V_2 according to any of the Claims 4 to 7 for carrying out a process according to any of Claims 1 to 3.