Dehumidification by alternative cooling systems
-Sorption-supported dehumidification with different liquid salt solutions-

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1. Introduction

The traditional way to dehumidify the outdoor air in a heating, ventilating and air conditioning (HVAC) system is by cooling the air temperature down below the dew point. For this process a refrigeration system is necessary to realise these low temperatures. Nowadays the disadvantages of refrigeration systems are widely known. An alternative method to dehumidify the air is by separating the process of dehumidification and cooling. There are different ways to get low supply air temperatures for cooling the indoor spaces. It is possible for example to use well water, an evaporative cooling system or, of course, a refrigeration system with relatively high evaporation temperature. This cooling components are well known and already in practice so that this paper focuses on the dehumidification process.

The paper gives a general view of the adsorptive and absorptive dehumidification components. Then a new dehumidifier which uses a liquid desiccant will be described. A small prototype was tested in an experimental plant in the laboratory of the Institute of Applied Thermodynamics and Air Conditioning in Essen. The design of the dehumidifier and the first results of the measurements will be presented.

2. Methods of dehumidification

In the HVAC technology the following dehumidification systems are commonly used: ❶ Condensation on cold surfaces of chillers or water droplets. ❷ Desiccating through the contact with hygroscopic materials.

To ❶: This kind of dehumidification is the frequent applied technology. To get condensate, temperatures below the dew point of the dehumidifying air are necessary. These low temperatures can be realised by an evaporating refrigerant (direct evaporator) or by cold water (water cooled chiller). The cold water is made by a refrigeration plant and its usual supply temperature is approximately 6°C. The refrigeration systems can be basically subdivided into the two following groups: Compression-refrigeration and Absorption-refrigeration-system.

The disadvantages of this systems are:

- Poor controllability due to constant water temperature in the cold water chiller.
- High energy demand for the refrigeration process.
    - ⇨ For the air conditioning it is not always necessary to have supply water temperatures of 6°C.
    - ⇨ Energy demand for the compressor.
- Reheating of the dehumidified air is often necessary.
- Only limited usability of low temperature heat by the refrigeration systems.

By increasing the supply water temperature it is possible to reduce the energy demand for preparing the cooling water with refrigeration systems. By increasing the water temperature of about 1 K the improvement of the coefficient of performance (COP) is approximately 3 %.

To ❷: Desiccating by contact with hygroscopic materials is distinguished by the kind of the used materials: Solid hygroscopic and liquid hygroscopic-materials.

There is a great variety of solid materials which can be used for air dehumidification. Active carbon, active aluminium, silicagel, zeolithes as well as hygroscopic salts are mostly used for technical drying. Silicagel and hygroscopic salts are preferred for the air dehumidifier. Continuous working rotary wheels or discontinuous working packed beds are equipped with such solid desiccants. In this paper the solid desiccants and the design of belonging plants is not described because the main emphasis lies on the use of liquid desiccants.

One of the first liquid desiccants which was used for the dehumidification of air was triethylenglycol. Due to the high vapour pressure the application of this desiccant in open cycle systems is unfit because there are high losses of desiccants which have a negative influence to the environment. However open desiccant cycles working with solutions of lithium chloride, respectively, calcium chloride are partly successful in practice or investigated in promising research projects.

3. Liquid desiccants

The dehumidification of air is possible by using different solid or liquid hygroscopic materials. In this work we only used liquid desiccants like Calciumchloride-, Lithiumchloride- and Klimat 3930S-solutions. The Klimat 3930S-solution is made by the company Solvay Deutschland and consists of 39 Ma-% $CaCl_2$, 18 Ma-% $Ca(NO_3)_2 \cdot 4H_2O$, 5 Ma-% emulsifier S and 38 Ma-% water.

3.1 Requirements on liquid desiccants

In general the desiccants should be non toxic and environmental-compatible, because they are used in open cycle systems at ambient pressure. Furthermore, volatile contents are not allowed in the hygroscopic material, except water, and the desiccant should be non-flammable and non- explosive.

To guarantee a continuous dehumidification process the desiccant must possess a long-term stability. Another advantage of air dehumidification with hygroscopic materials is the possibility to use low temperature heat for the regeneration process. The material costs should not be high and the steady quality of the material is to be guaranteed.

To evaluate the hygroscopic materials, the substance data for the considered temperature range is taken from literature but also by experiments in the laboratory. With this data it was possible to create equations to calculate the following material characteristics: vapour pressure, dew-point temperature, density, specific heat capacity, dynamic viscosity and the surface tension.

4. Testing plant to dehumidify air

The centre of the testing plant is a new dehumidifier which uses liquid desiccants to dry the air. The saline solution ($CaCl_2$- respectively Klimat 3930S-solution) is running in direct contact with the air and both in counterflow. Figure 1 shows the testing plant with the dehumidifier and the several components to create steady conditions.

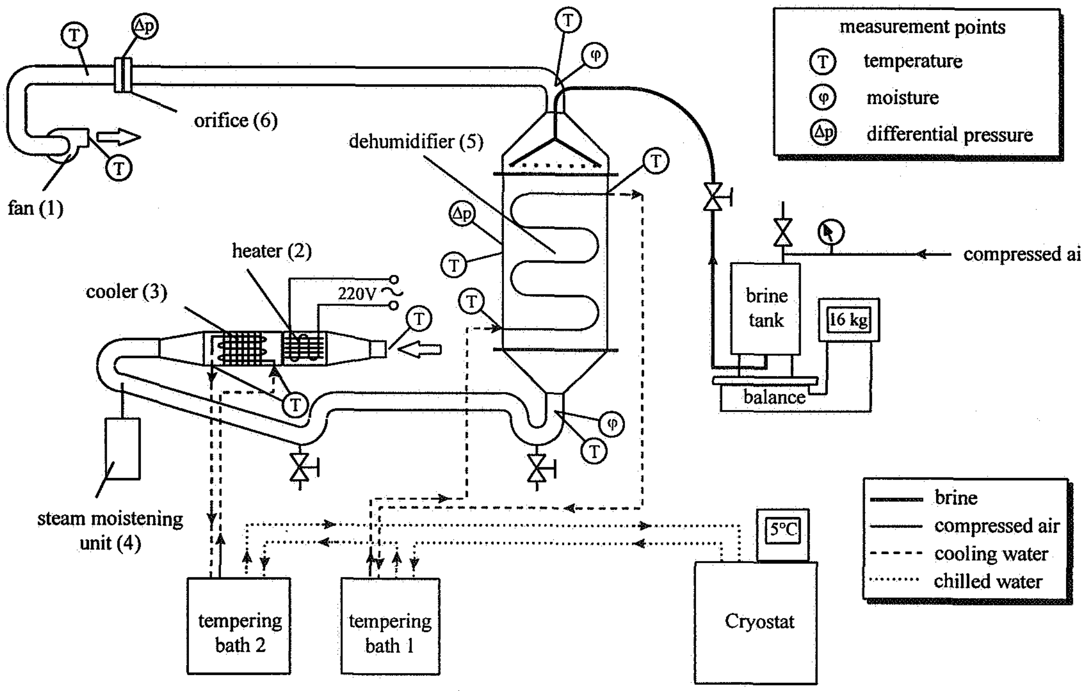

Figure 1: Testing plant with the new liquid dehumidifier.

To carry off the absorption heat it is possible to cool the dehumidifier with chilled water. The water is running through little channels of a double-web-plate in cross-counterflow with the saline solution. The direction of the air, the saline solution and the chilled water are shown in figure 2. The surface for the heat and mass transfer is 4 m^2 and five double-web-plates are built in the test dehumidifier.

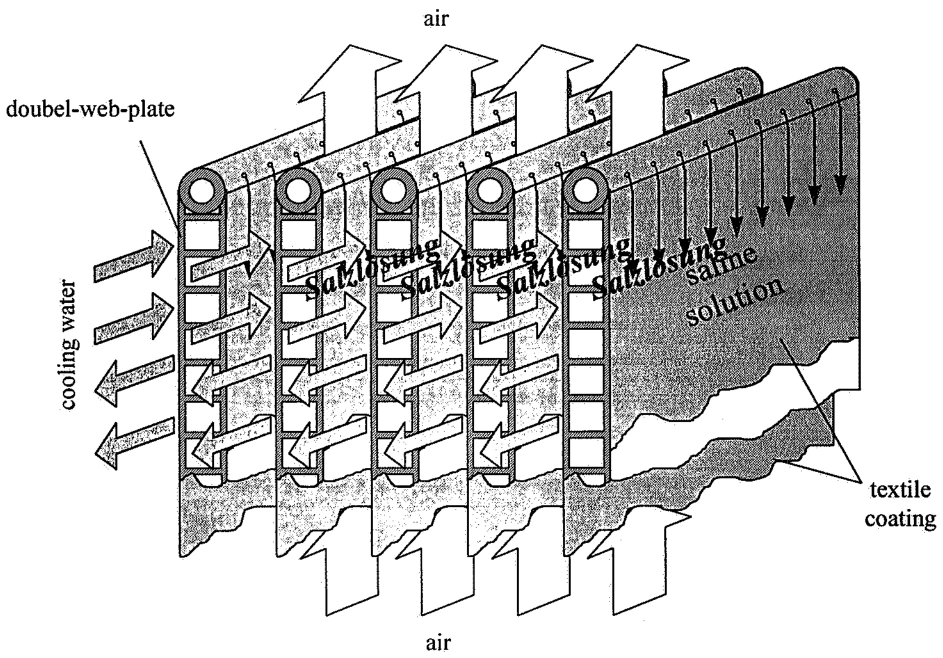

Figure 2: Schematic display of the transfer surfaces

4.1 Measurements

For the investigation of the dehumidifier several measurements were carried through. They can be classified in three groups: The measurements without desiccants, the measurements with the $CaCl_2$-solution and the measurements with the Klimat 3930S-solution. The following measurement program shows the boundary conditions which were changed to describe the behaviour of the dehumidifier:

✸ Without desiccants: Constant air inlet temperature ($t_{G,in}$ = 32,5°C), cooling water inlet temperature ($t_{KW,in}$ = 20°C) and a constant cooling water mass flow ($\dot{M}_{KW}$ = 0,044kg/s). Variable air velocity in the dehumidifier (w_G = 1 m/s to 2,5 m/s).

✸ With desiccants: Constant air inlet temperature ($t_{G,in}$ = 32,5°C) and constant water content of the air ($x_{G,in}$ = 14,5 $g_{water}/kg_{dry\ air}$).
Variable cooling water inlet temperature ($t_{KW,in}$ = 20°C; 25°C), variable air velocity in the dehumidifier (w_G = 1 m/s to 1,8 m/s), variable cooling water mass flow ($\dot{M}_{KW}$ = 0,044kg/s; 0,022 kg/s; 0 kg/s) and a variable mass flow ratio ($\dot{M}_G/\dot{M}_L = \Pi$ = 10 to 110).

4.2 Heat and mass transfer in the dehumidifier

By the measurements it was possible to find equations which describe the heat and mass transfer. To design a dehumidifier it is helpful to use dimensionless numbers. The following dimensionless numbers were used in this research work.

Reynolds-number: $$Re = \frac{w \cdot L^*}{\nu} \quad \text{or} \quad Re = \frac{w \cdot \rho \cdot L^*}{\eta}$$

Nusselt-number: $\mathrm{Nu} = \frac{\alpha \cdot L^*}{\lambda}$

Péclet-number: $\mathrm{Pe} = \frac{w \cdot L^*}{a}$ or $\mathrm{Pe} = \mathrm{Re} \cdot \mathrm{Pr}$

Prandtl-number: $\mathrm{Pr} = \frac{\nu}{a}$ or $\mathrm{Pr} = \frac{\eta \cdot c_p}{\lambda}$

Sherwood-number: $\mathrm{Sh} = \frac{\beta \cdot L^*}{D}$

Schmidt-number: $\mathrm{Sc} = \frac{\nu}{D}$

Where L* is the characteristic length. As in this work exclusively the diameters of passed channels are concerned so that the hydraulic diameter is used:

$$d_h = \frac{4 \cdot A}{U}$$

It was possible to determine the following dimensionless equation to describe the heat transfer in the dehumidifier by the results of the extensive measurements:

$$Nu_G = 2{,}05 \cdot \left(Re_G \cdot Pr_G \cdot \frac{d_h}{L} \right)^{0{,}5}$$

The liquid desiccant and the air in the dehumidifier are in a direct contact so that the velocity of the desiccant has an influence to the air. Therefore, the Reynolds-numbers of the saline solution were calculated with the following equation.

$$Re_L = \frac{\dot{M}_S \cdot \left[1 + \left(\frac{C_{ein} - C_{aus}}{2} \right) \right]}{8 \cdot b \cdot \eta_L}$$

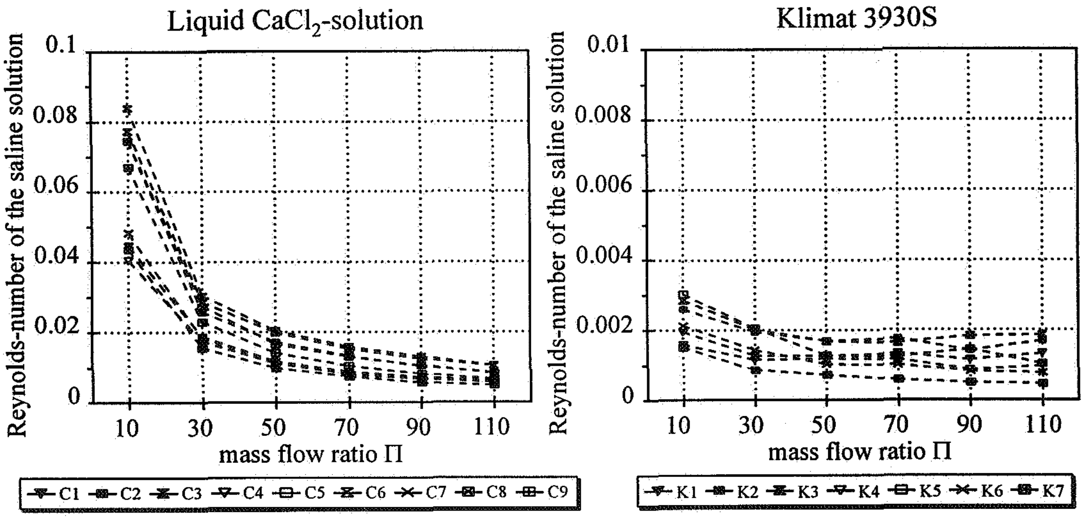

Figure 3: Reynolds-numbers of all series of measurements with liquid desiccants in dependence of the mass flow ratio.

Figure 3 shows the Reynolds-numbers of liquid $CaCl_2$- and Klimat 3930S-solution in dependence of the mass flow ratio Π. The dimensionless equation to describe the mass transfer in the dehumidifier includes therefore the Reynolds-number of the liquid desiccant.

$$Sh_G = 2{,}05 \cdot \left(Re_G \cdot Sc_G \cdot \frac{d_h}{L} \right)^{0{,}5} \cdot \left(1 + K \cdot Re_L^{0{,}33} \right)$$

The equation to describe the mass transfer includes a correction term. In this term K is a specific material constant.

By an empirical way it was possible to find the specific material constants for the investigated liquid desiccants.

Liquid $CaCl_2$-solution	$K = 0{,}21$
Liquid Klimat 3930s-solution	$K = 0{,}60$

The range of dehumidification Δx in dependence of the mass flow ratio of both desiccants is shown in figure 4.

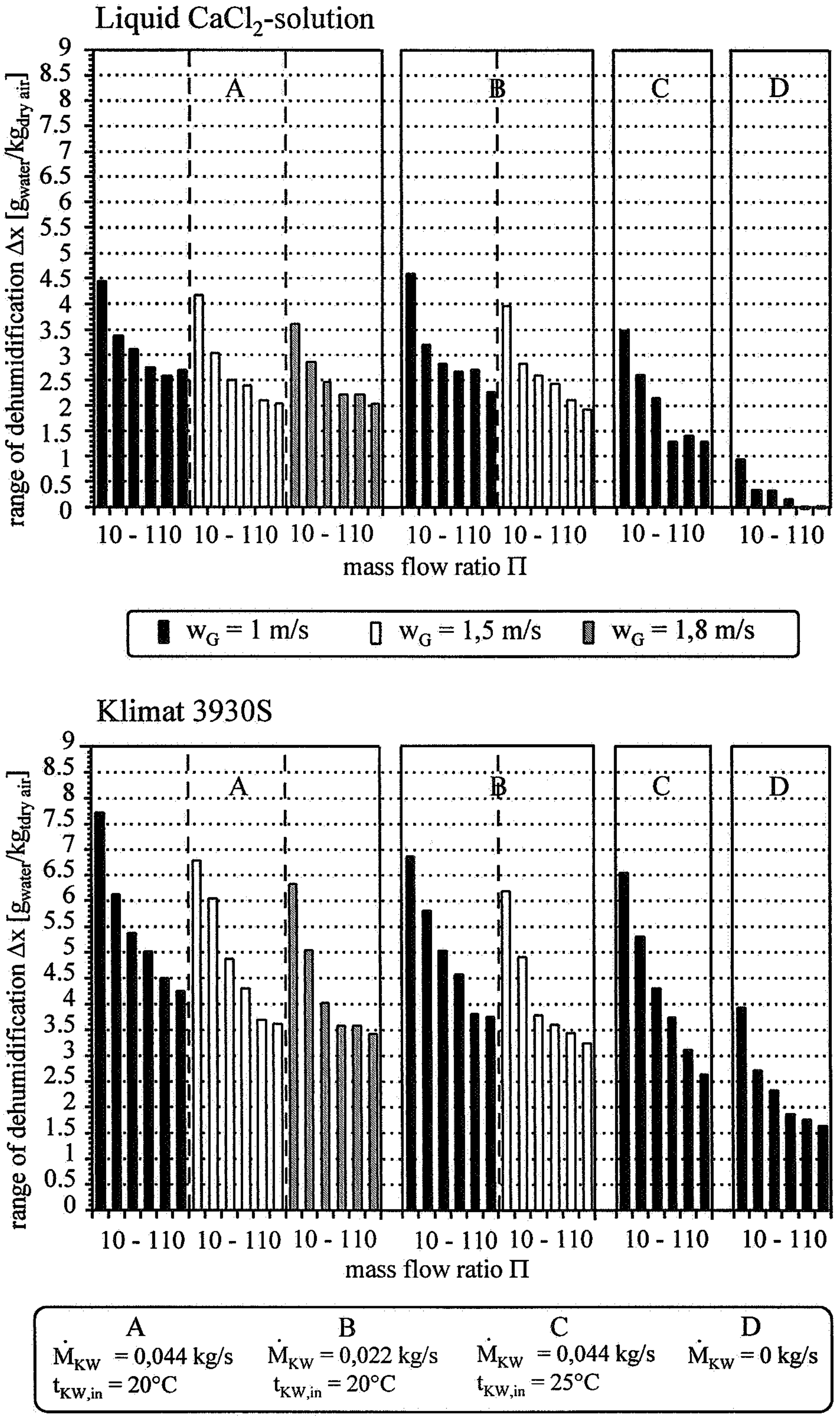

Figure 4: Achieved range of dehumidification Δx in dependence of the mass flow ratio of both desiccants.

It is obvious that the range of dehumidification by using the liquid $CaCl_2$-solution is lower than by using Klimat 3930S. The results of series D are very interesting, because this measurements were done without chilled water for the removal of the absorption heat. The range of dehumidification by using Klimat 3930S is here up to $\Delta x = 4\ g_{water}/kg_{dry\ air}$ and by using $CaCl_2$-solution only $\Delta x = 1\ g_{water}/kg_{dry\ air}$.

5. Conclusions

The results of the theoretical and experimental research work can summarised to the following points:

1. Modelling of equations to describe the desiccant material characteristic for a temperature range from 10°C to 70°C and the considered range of concentration of saline solution ($CaCl_2$-, LiCl-, Klimat 3930S-solution).
2. Modelling of an equation to describe the heat transfer in the new dehumidifier.
3. Modelling of an equation to describe the mass transfer in the new dehumidifier.
4. Comparison of the dehumidification behaviour of different liquid desiccants.

With this results it is possible to design a dehumidifier, which operates in according to the investigated test dehumidifier.

6. Acknowledgement

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7. Symbols and Indices

Symbols:

a	thermal diffusivity
A	transfer area
b	width
C	water content (solution)
d	diameter
D	diffusion coefficient
K	specific material constant
L	length
L*	characteristic length
$\dot{M}$	mass flow
t	temperature
U	circumference
w	velocity
x	water content (air)

Indices:

G	gas (air)
h	hydraulic
in	intake
KW	chilled water
L	saline solution
S	salt

Greek Symbols:

α	heat transfer coefficient
β	mass transfer coefficient
Δ	delta
η	dynamic viscosity
φ	density
λ	thermal conductivity
ν	cinematic viscosity

8. References

[1] Gilliland, E. R.; Sherwood, T. K.
„Diffusion of Vapors into Air Streams“
Industrial and Engineering Chemistry, Vol.: 26, Page: 516-523, 1934

[2] Kipping, D. E., Bischoff, M.
„Entwicklung von umweltfreundlichen, langzeitstabilen, materialverträglichen Betriebsmedien für offene Raumklimaanlagen über Sorption als Ersatz für FCKW“
Abschlußbericht zum BMFT-Forschungsvorhaben Nr. 032 9151 A, Solvay Deutschland GmbH, Hannover, 1993

[3] Kourouma, S.Y., Röben, J.
„Air Dehumidification by Absorptive and Evaporative Cooling“
Proceedings of the 16th AIVC Conference, Palm Springs, USA, Implementing the Results of Ventilation Research, S. 341 - 350, 1995

[4] Lävemann, E., Keßling, W., Röhle, B., Kink, C.
„Klimatisierung über Sorption“
Endbericht zur Phase I des Forschungsvorhaben Nr. 032 9151 B des BMFT, 1993

[5] Steimle, F., Röben, J., Reingen, M.
„Sorptive Entfeuchtung und Temperaturabsenkung bei der Klimatisierung“
Zusammenstellung von Literatur im Auftrag des BMBF Nr. 032 9151J, 1995

[6] Steimle, F., Reckzügel, M., Röben, J.
„Air Dehumidification by Absorption - A Model for Numerical Calculation“
Proceedings of the 17th AIVC Conference, Göteborg, Schweden, Optimum Ventilation and Air Flow Control in Buildings, S. 549 - 559, 1996

[7] VDI-Verein Deutscher Ingenieure
„VDI-Wärmeatlas“
7. Auflage, VDI-Verlag, 1994